

# EFRC Training Workshop

## Basic Training of Reciprocating Compressor Systems

“Typical applications for Reciprocating Compressors”

Bas Bruins – Shell Pernis Refinery

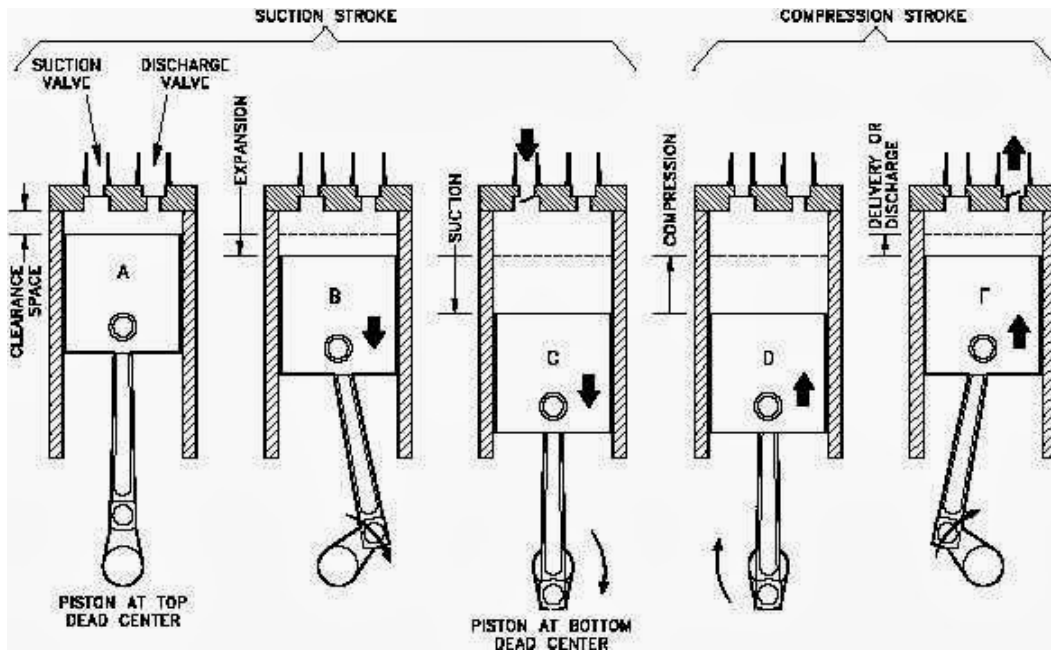
The Netherlands



# Methods of Compression

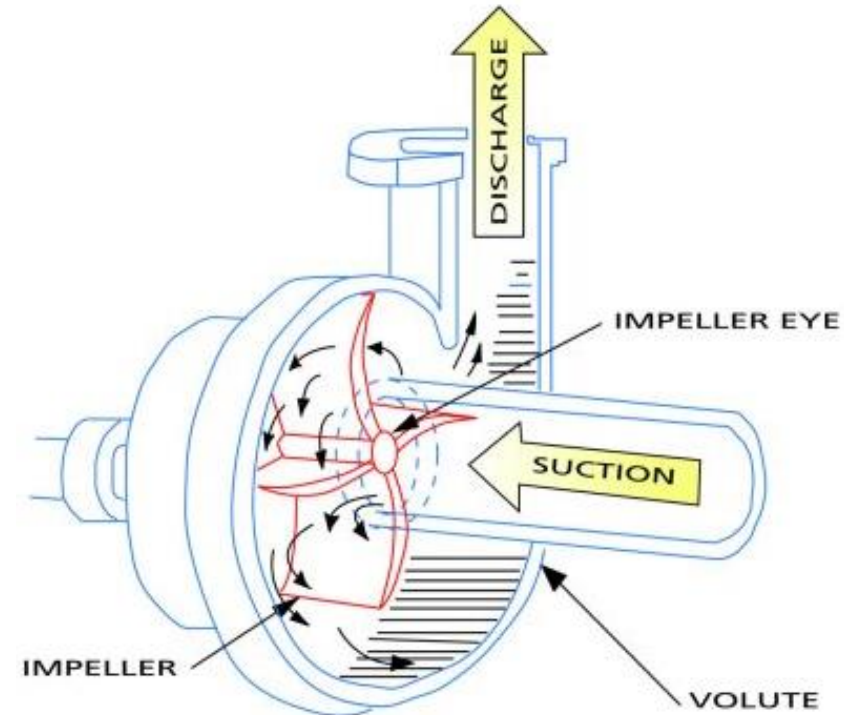
## Positive Displacement

- Pressure increase by reducing volume in a compression chamber

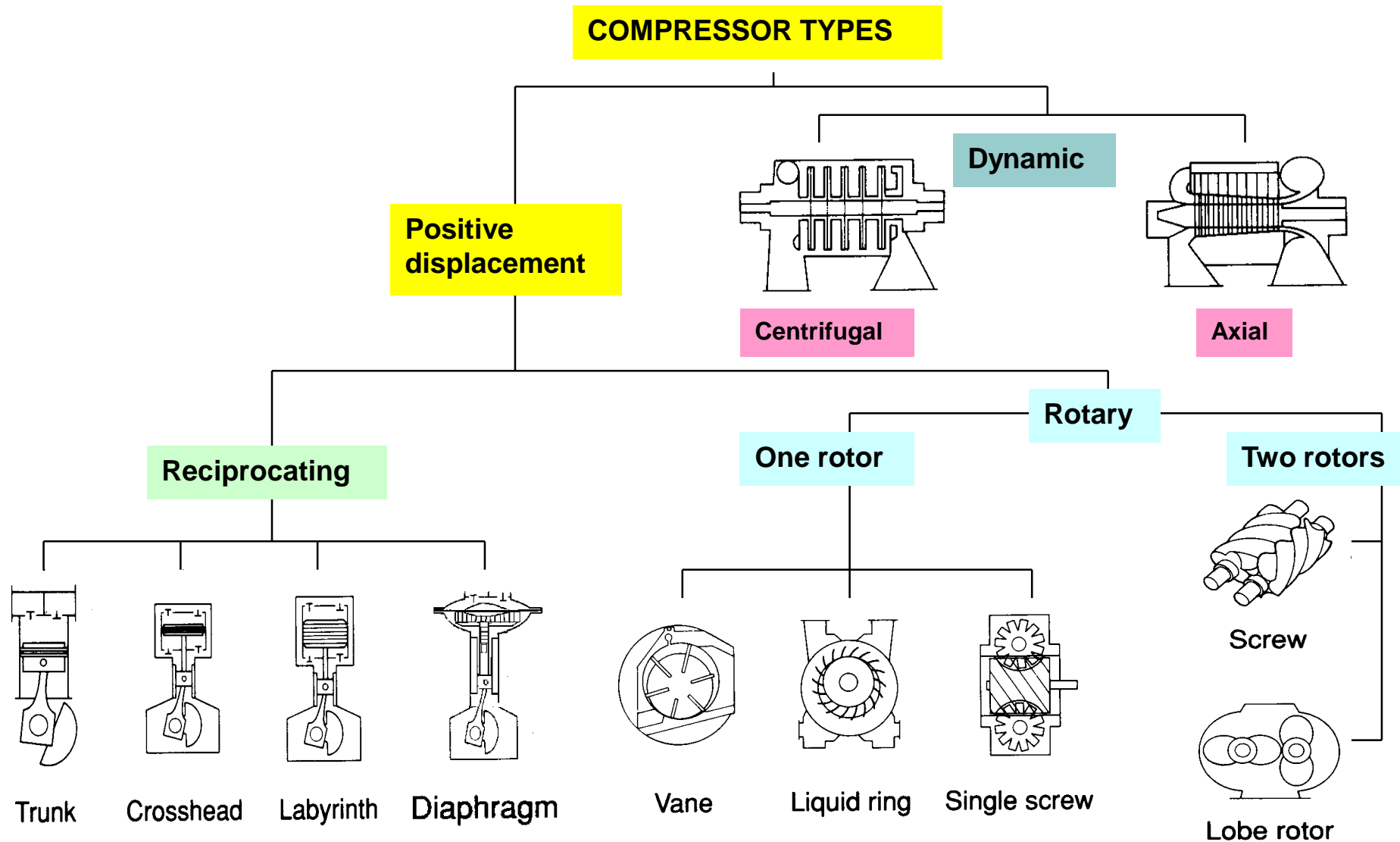


## Dynamic machine

- Pressure Increase by transfer of kinetic energy to gas and then converted to pressure



# Typical applications for Reciprocating Compressors





# When to apply recip

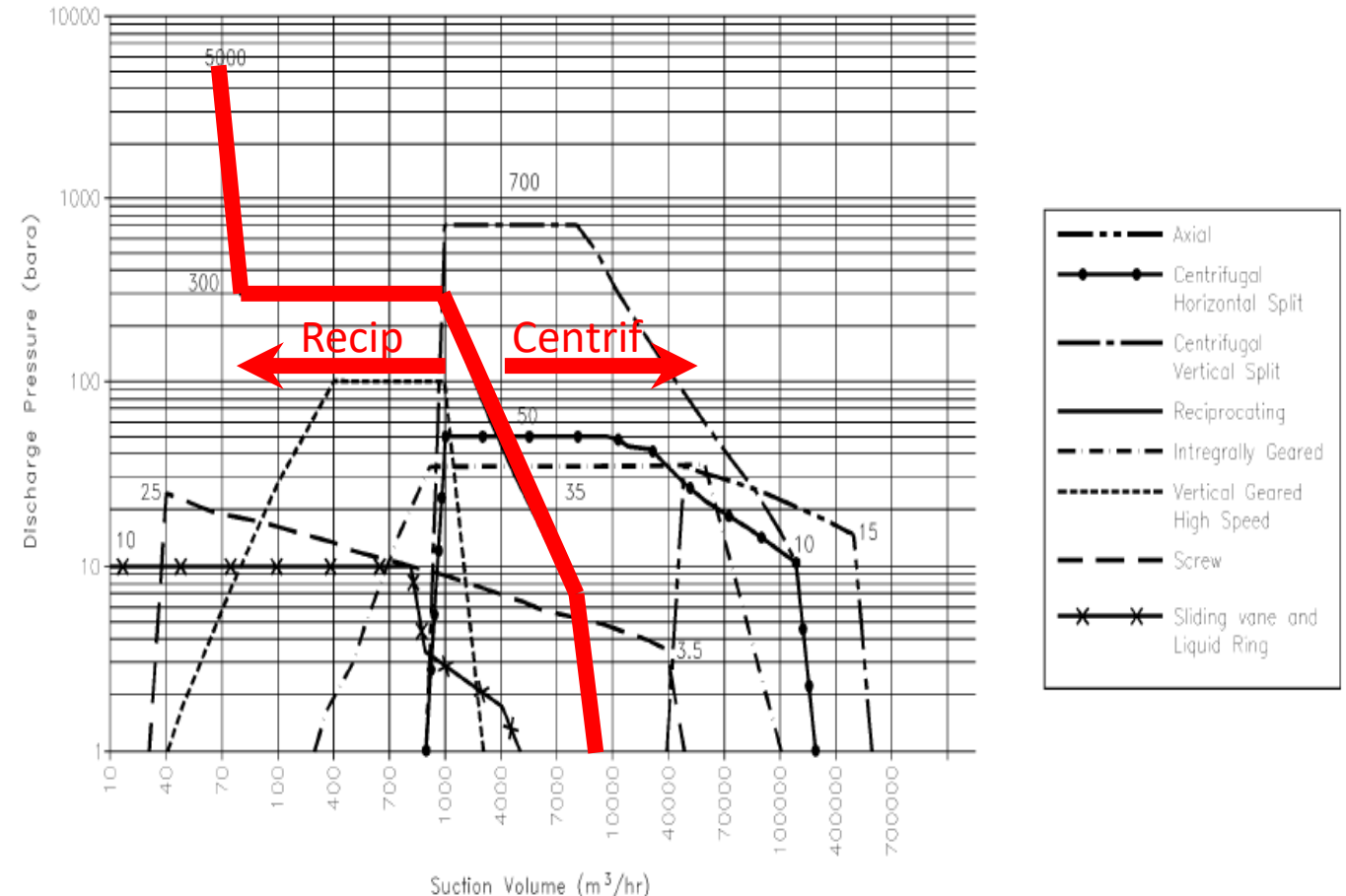
## Reciprocating Compressors

- High compression ratio's
- Relatively low flow
- Varying moleweights

## Centrifugal Compressors

- Wet service
- Low compression ratios
- Relatively high flow

APPENDIX 2 PRESSURE/ VOLUME MAP FOR VARIOUS COMPRESSOR TYPES



## Typical applications for Reciprocating Compressors



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COMPRESSORS

# Key Characteristics

	Reciprocating	Centrifugal
Flow/capacity	Limited by geometry (volume)	Limited by Surge point (function of geometry and gas conditions)
Pressures	up to 3500 barg (HYPER)	up to 770 barg (experimental)
Flow Range	Throughput from 0-100%	Limited by surge
Reliability	Many moving parts, high forces in changing directions, gas contamination	One moving part, availability to 95%
Maintenance intervals	1 to 3 years on wear parts - depending on service and technology*	up to 10 years
Gas MW	Unlimited	Difficult to achieve high compression ratio's on low MW
Installation costs	Low (\$750k - \$1 Million)	High (\$2 - \$3 Million)
Power	up to 30 MW	Up to 100MW
Lead time	10-40 weeks	30-70 weeks

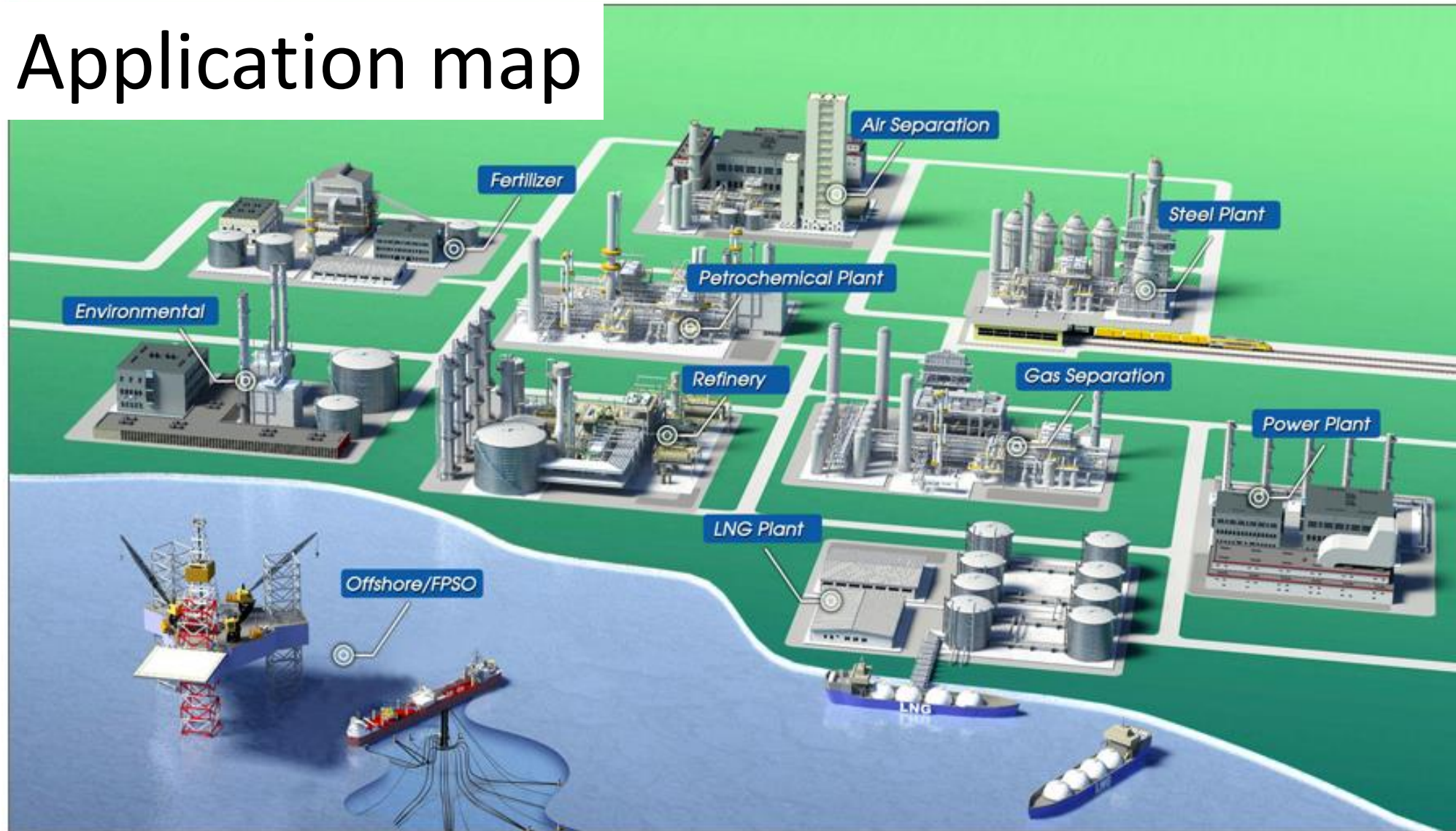
# Types

- API 618 process reciprocating compressors (Generally 277-600 rpm)
  - Heavy duty applications
  - Mainly downstream (oil refining)
- ISO 13631 High Speed reciprocating compressors (700-1800rpm)
  - Oil & gas, offshore, motor or engine driven
  - Upstream and midstream (gas recovery)



## Typical applications for Reciprocating Compressors

# Application map



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COMPRESSORS

## Typical applications for Reciprocating Compressors

# Applications where recips are used

Energy Transition



CO<sub>2</sub> capture  
H<sub>2</sub> Transport



Air



PET  
bottle blowing



Chemical



Polyethylene  
production,  
Fertilizers,...



Refining



Refinery  
products



Natural Gas



Gas  
gathering



Technical Gas



Steel production,  
Nitrogen,...



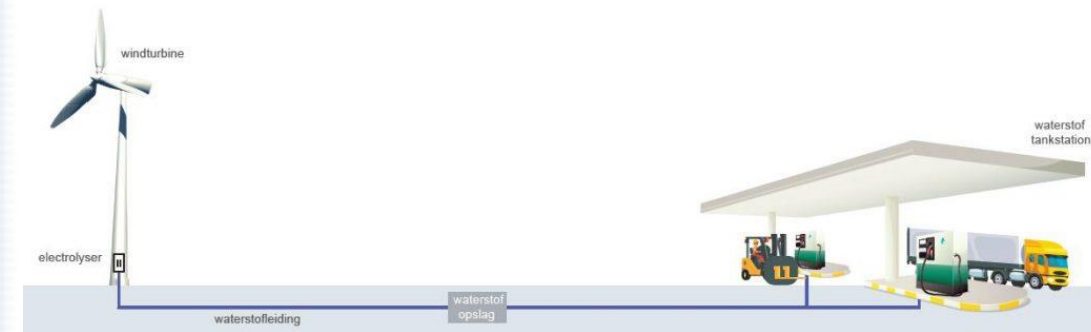
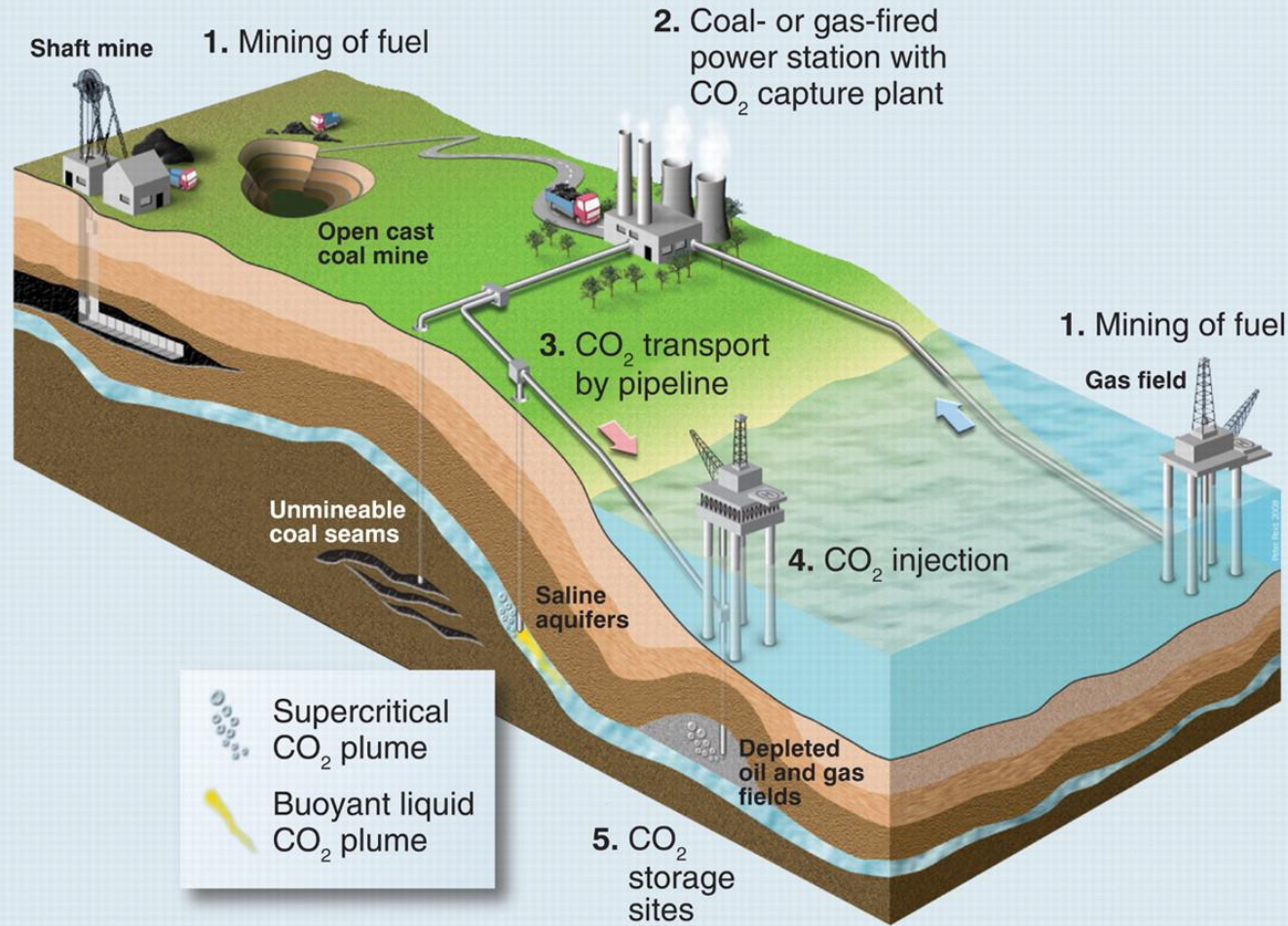
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# Typical applications for Reciprocating Compressors



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## Typical applications for Reciprocating Compressors



- In future scenarios, transport and storage of Hydrogen may play a significant role in the energy distribution system (in addition to electric and traditional natural gas)
- Challenges for future hydrogen transport and storage
  - Low Molecular Weight
  - Hydrogen storage; varying conditions
  - Large capacity for transport

→ Centrifugal compressor is usually not an option

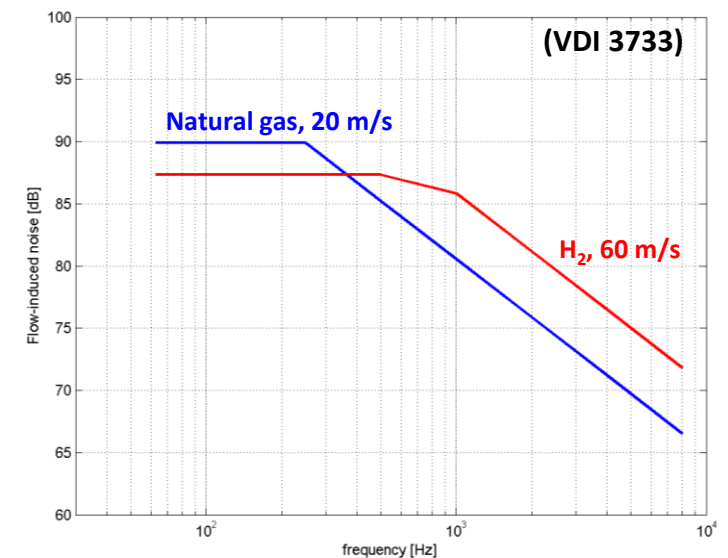
→ Challenge for reciprocating compressor
- What kind of challenges to be expected?

## Typical applications for Reciprocating Compressors

- Specific challenges for reciprocating compression systems
- Generic challenges, in case of same energy flux as natural gas:

- Flow-induced turbulence
- Flow-induced pulsations at side branches
- Valve noise
- Thermowell assessment
- Erosion (in case of extraction from Underground Storage)
- Mixing with natural gas at low capacity
- Impact on fatigue properties (hydrogen embrittlement)
- Increased leakage
- Combustion processes

→ Similar amplitudes, shift to higher frequencies

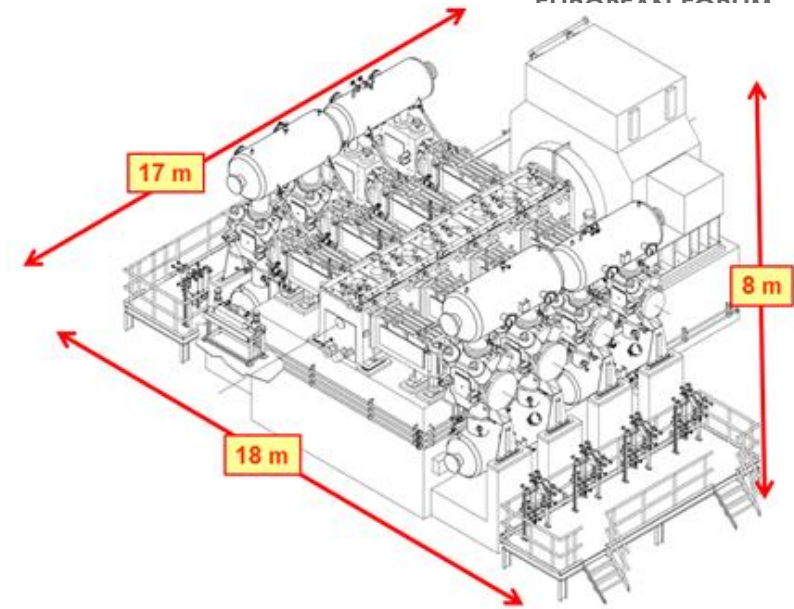




## Typical applications for Reciprocating Compressors



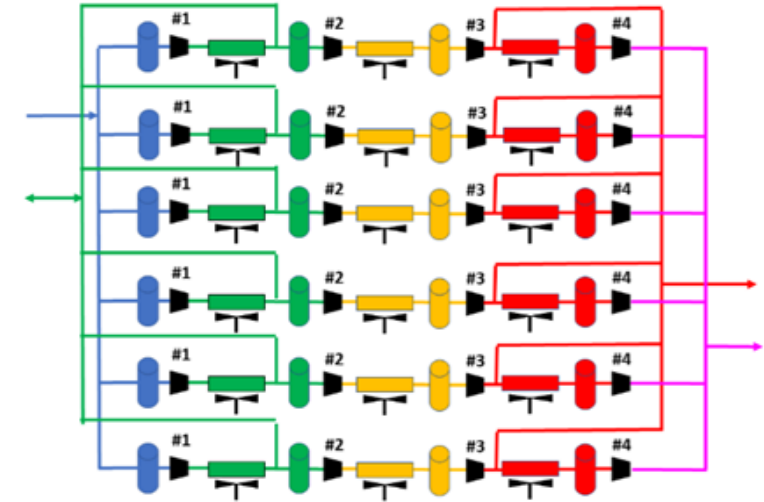
- EFRC paper 2018 “Engineering approach for world’s largest hydrogen compression system” (TNO, HTC, FLUOR)
- 6 compressor trains, parallel operation
- 8-throw, 4-stage design, 17 MW each
- Construction challenges (torsional, power train)
- Capacity control challenges (part loads, spillbacks)



# Typical applications for Reciprocating Compressors



- Pulsation and vibration control
  - Large number of pulsation sources
  - Low effect of acoustic damping; large simulation models required
  - Complex and strong interaction between compressors
  - ‘Infinite’ number of running cases
  - Evaluation criteria in guidelines not suited
- Proposed approach in paper, based on step-wise analysis and selection of most relevant cases



$$P = \sum_{i=1}^{N-1} \binom{N}{i} L^i$$

$N$  compressors  
 $L$  load steps

$N$	1	2	3	4	5	6	7
$P$	4	8	60	368	2100	11528	61740



# Typical applications for Reciprocating Compressors

Energy Transition



CO<sub>2</sub> capture  
H<sub>2</sub> Transport



Air



PET  
bottle blowing



Chemical



Polyethylene  
production,  
Fertilizers,...



Refining



Refinery  
products



Natural Gas



Gas  
gathering



Technical Gas



Steel production,  
Nitrogen,...



# PET Bottle blowing

- Polyethylene terephthalate (PET) is used in the production of plastic bottles.
- Plastic pre-forms are made by injection molding, followed by a reheat stretch blow molder, working at 40-50 bar, which creates the final shape.
- Typical machines manufacture 10.000 bottles per hour (some much more) and require the respective amount of **clean, compressed air**, depending on PET-bottle size (0.2 – 3.00 l)



# Typical applications for Reciprocating Compressors

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# POLYETHYLENE PRODUCTION

- Polyethylene production can be either high density polyethylene (HDPE) produced using low pressure, typically 30 bar, or low density polyethylene (LDPE) produced using high pressure, up to **3500** bar
- Both processes use compressors but the LDPE process must use reciprocating compressors to generate this very high pressures necessary for polymerisation of ethylene gas to LDPE (HYPER compressors).





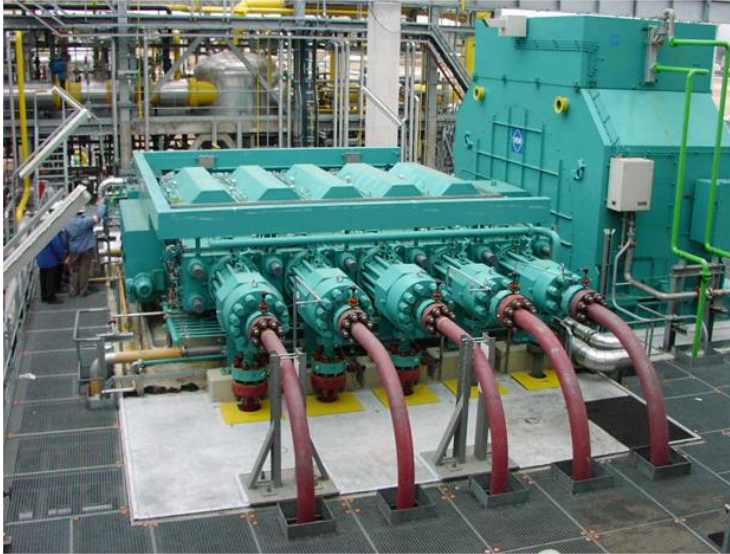
# LDPE (Low Density Polyethylene)

- Ethylene gas is compressed in usually 4-5 stages in the booster plus primary compressor up to 300 - 350 bar.
- Then it is passed to the 'Secondary compressor' which increases the pressure in further 2 stages up to 2800 - 3500 bar.
- Secondary compressors generally use single acting plunger rods which are sealed with so called 'hyper rod packing rings'.
- BOOSTER and PRIMARY compressors can be individual compressors but also combined to a unit. In that case they are driven by one common crankshaft. Also, they are very often equipped with stepless capacity control system.
- These are the highest pressures used in any industrial process on earth. The rod packing rings are critical to the process. The valves used in secondary compressors are steel poppet types similar to car engine valves.

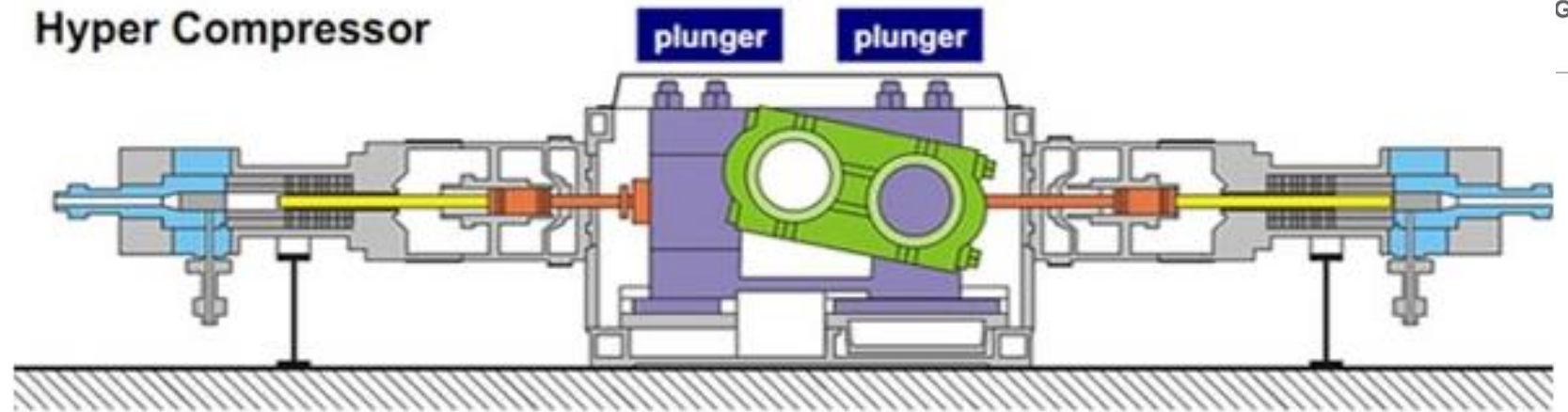


## Typical applications for Reciprocating Compressors

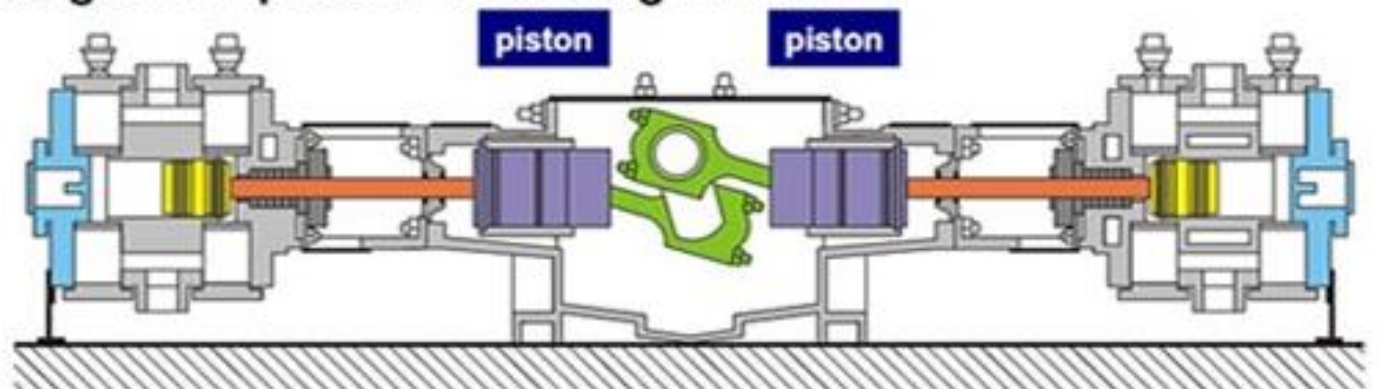
# Hyper Compressors



Hyper Compressor



Process gas compressor according API 618



# HDPE (High Density Polyethylene)

- The main ethylene compressors (30 bar) in most modern plants are invariably centrifugal compressors, the recycle stage invariably reciprocating compressors.
- The 30 bar ethylene is passed over a fluidised bed reactor with a catalyst, typically silicon dioxide. Unconverted gas is recycled back into the reactor which is where the reciprocating compressor is used.
- These compressors are notorious for forming polyethylene inside the cylinders, which can lead to disastrous consequences.



HDPE pipe installation in storm drain project in Mexico

# FERTILIZERS

## UREA, AMMONIA AND AMMONIA NITRATE PRODUCTION

- Ammonia is synthesized from hydrogen and nitrogen. Hydrogen is produced by catalytically reforming of hydrocarbon (usually natural gas) and steam using a nickel catalyst. Air is used to supply nitrogen (air separation plant).
- For the  $\text{NH}_3$ -synthesis process a gas mixture of 74%  $\text{H}_2$  and 25%  $\text{N}_2$  (called synthesis gas) is compressed to 150 - 250 bar and introduced to the ammonia converter where the catalytic reaction takes place. In older plants reciprocating compressors are used for that.





# FERTILIZERS

- Generally these compressors are very large units with many stages and are often multi-purpose, i.e. they compress various gases (synthesis gas, air, natural gas) in different cylinders. These processes require high pressures which in older plants are produced by piston type compressors.
- More modern plants tend to use multistage centrifugal compressors to bring the pressures up to 50 bar and then reciprocating compressors after that.
- Ammonia is used for the production of:
  - Urea (refer below)
  - Nickel refining (called the CARBONYL process)
  - Ammonium nitrate used for production of fertilizers and explosives arises by neutralisation of ammonia with nitric acids.
  - Ammonia is also used as a refrigerant.

# Typical applications for Reciprocating Compressors

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H<sub>2</sub> Transport



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Steel production,  
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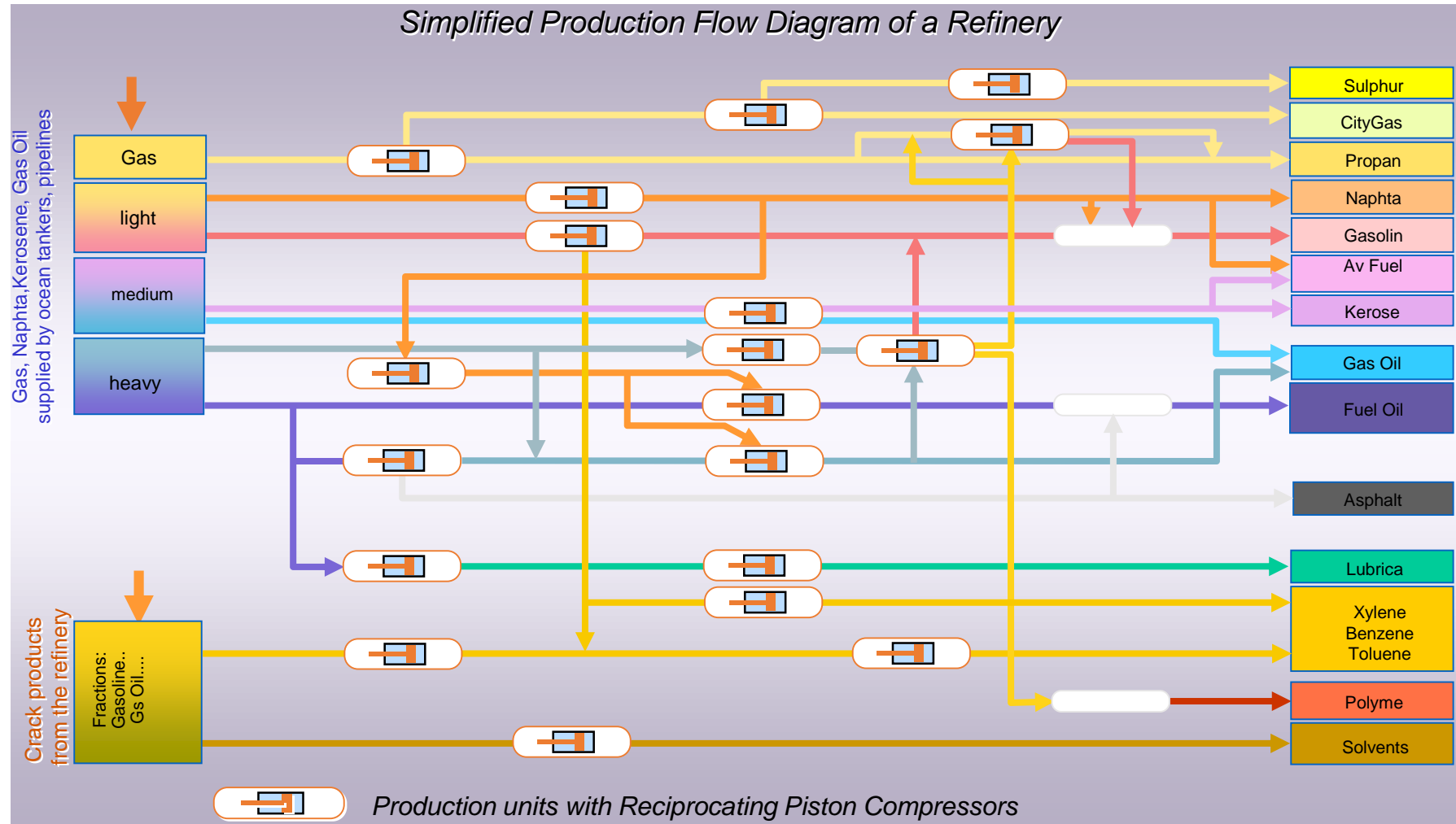
### APPLICATIONS OF RECIPROCATING COMPRESSORS IN REFINING INDUSTRY

- Distillation
- Hydrodesulphurisation HDS
- Hydrotreater
- Hydrofiner
- HydroCracking
- Catalytic Cracking
- Reforming
- Coking
- Visbreaking



## Typical applications for Reciprocating Compressors

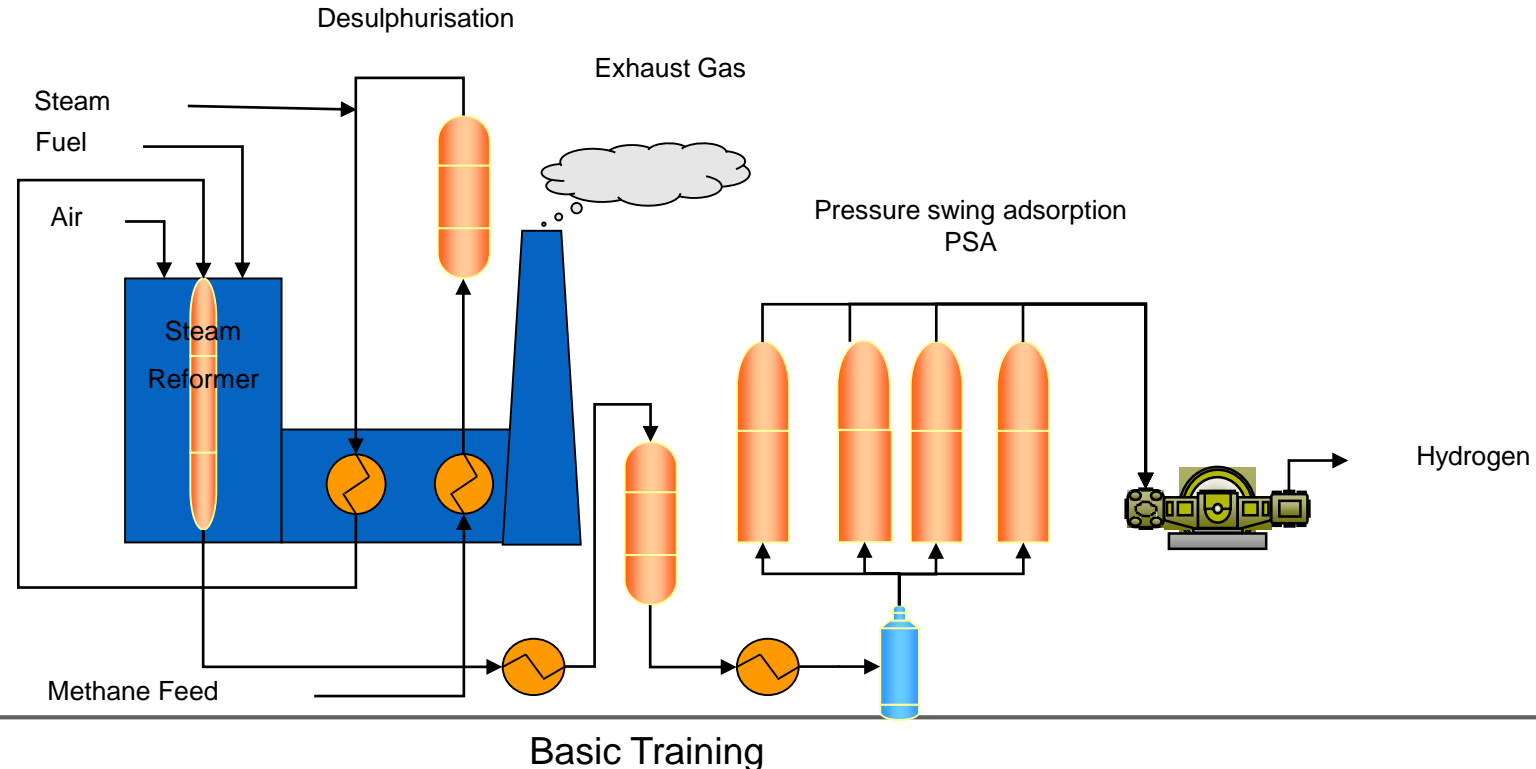
# NUMBER OF RECIPs USED IN REFINERY (EXAMPLE)



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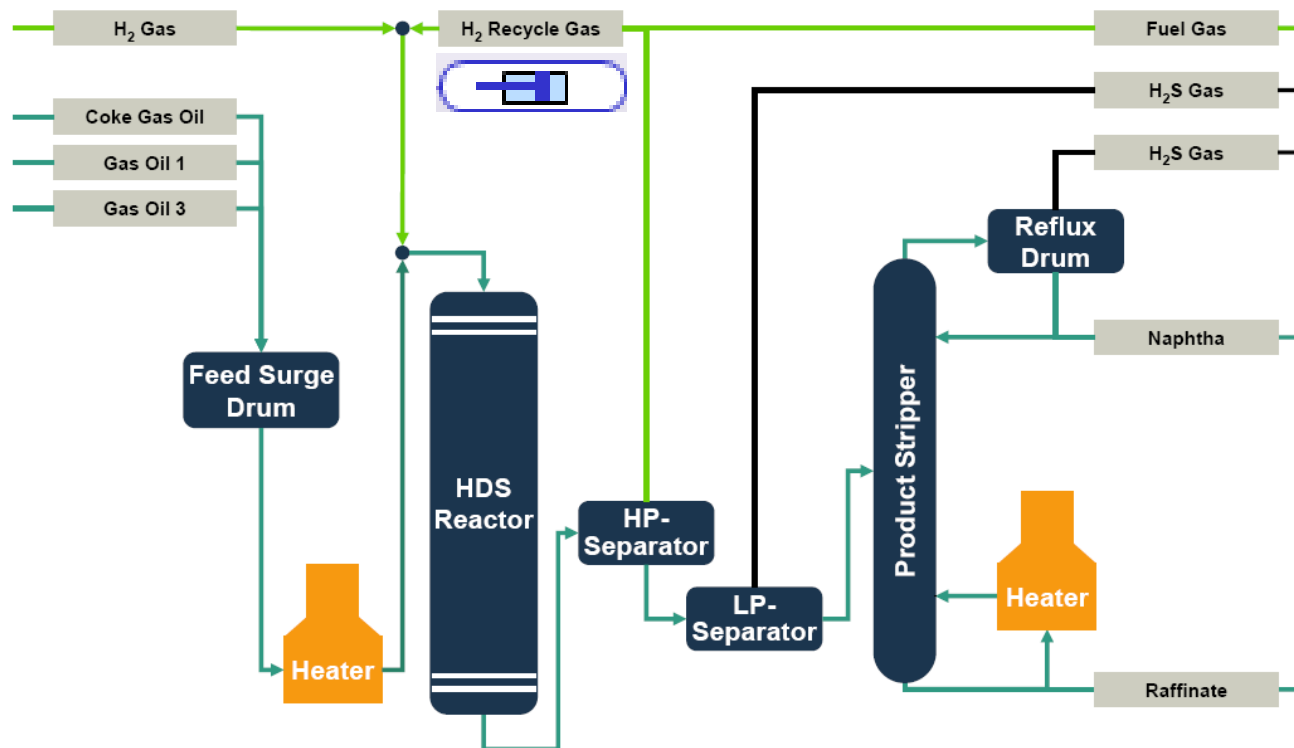
# HYDROGEN MANUFACTURING UNIT (HMU)

- Hydrogen generation in a high temperature, high pressure, thermal cracking process to produce a very clean stream of hydrogen gas.
- The standard process route comprises feed de-sulfurization, steam reforming, shift conversion and hydrogen purification by means of Pressure Swing Adsorption (PSA). Even up to 300bar.



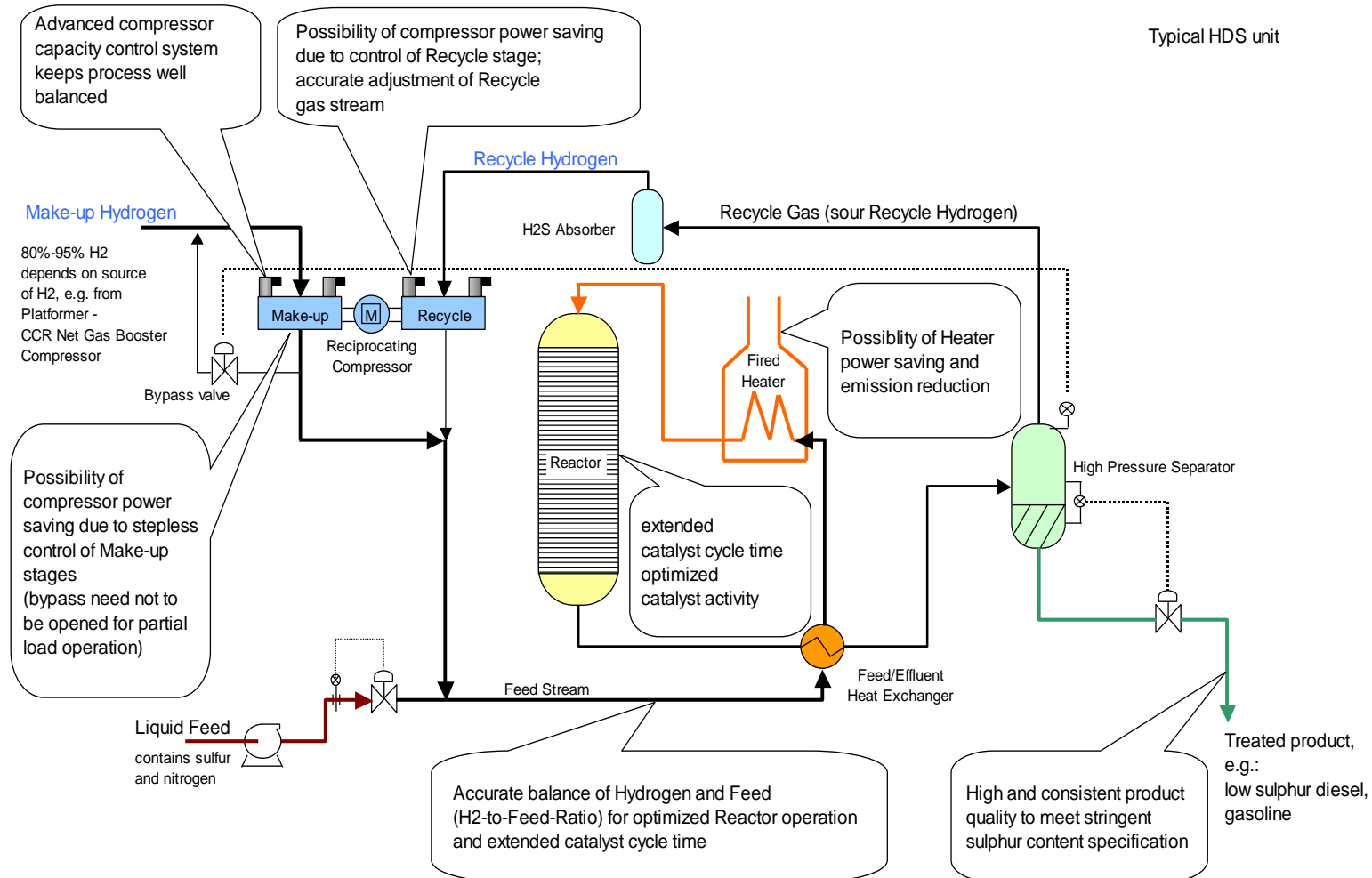
# HYDRODESULFURIZATION (HDS)

- The hydrocarbon feedstock is mixed with recycled hydrogen. The desulphurisation comprises two process steps. In the first step organic sulphur compounds are converted to  $\text{H}_2\text{S}$  at about  $360^\circ\text{C}$  on a cobalt-molybdenum or nickel-molybdenum hydrogenation catalyst. In the second step,  $\text{H}_2\text{S}$  is adsorbed on zinc oxide, DiEthanolAmin (DEA), etc.
- These processes usually operate at 20 to 60 bar, depending on the content of  $\text{H}_2\text{S}$ .



## Typical applications for Reciprocating Compressors

# HYDRODESULFURIZATION (HDS)



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# HYDRO - CRACKER

- The Hydro-cracking process is a high temperature, high pressure process which catalytically cracks and reacts hydrogen with heavy high boiling point hydrocarbons converting them to lighter, lower boiling point hydrocarbons. They operate at elevated pressure up to 150 bar and temperatures around 315°C. The hydrogen is usually taken from the HYDROGEN MANUFACTURING UNIT (HMU) and raised in pressure in a multistage reciprocating compressor up to 150 bar for injection into the Hydro cracker.
- The compressors are mostly 3-stage on the 'MAKE-UP' or 'FRESH GAS' side.
- In the 'RECYCLE' stage tail gas from the process is recompressed from about
- 130 bar to 150 bar. The recycle
- gas may contain Hydrocarbons (HC's)
- and Hydrogen sulfide (H<sub>2</sub>S).



# CATALYTIC CRACKING (CAT- CRACKING)

- The heavy distillate oil with a boiling range usually in the area of 300°C (572°F) to 343°C (650°F) is catalytically cracked into shorter molecule chains using high reactor temperatures of about 538°C (1000°F) and low pressures of 7 bar without adding hydrogen.
- The catalytic reaction converts a portion of heavy distillate oil from the APS and distillate oils from the VPS into gasoline and light distillate oil.
- Only old designs have a recip in here. New designs include a centrifugal compressors for Wet Gas



Fluid Catalytic  
Cracking Plant  
Germany

# HYDROTREATER (HTU)

- The second lightest stream obtained from the column is kerosene or jet fuel with a boiling range usually in the area of 154°C (310°F) to 227°C (440°F). This product is pumped from the tower to a Hydrotreater operating at elevated temperature and pressure for removal of sulphur.
- The compressor consists of two systems, the fresh gas side (or make-up) and the recycle side. The recycle unit recompresses the unused hydrogen (usually contaminated with H<sub>2</sub>S) and feeds it back to the Hydrotreater.



Recycle Side:  
3rd-stage cylinders of  
a Mitsui C454 compressor  
equipped with HydroCOM,  
discharge pressure 203 bara

# Flare gas Recovery

- Purpose to recover the normal continuous flow of refinery flare gas for treatment and use in the refinery fuel gas system.
- Only when the flow requirement is low, otherwise screw type compressors are used more often.
- Challenge for dirt gas – contains many different fouling agents (H<sub>2</sub>S, chlorides, free water, liquids, etc)
- Flare gas may have varying MW, which reciprocating compressors are ideal to handle.
- Leads to € savings, but most important reduction of flaring (=legislation, reputation)



# Typical applications for Reciprocating Compressors

Energy Transition



CO<sub>2</sub> capture  
H<sub>2</sub> Transport



Air



PET  
bottle blowing



Chemical



Polyethylene  
production,  
Fertilizers,...



Refining



Refinery  
products



Natural Gas



Gas  
gathering



Technical Gas



Steel production,  
Nitrogen,...



# PRODUCTION, TRANSMISSION, STORAGE OF GAS

- The natural gas is used for:
  - Gas-Reinjection
  - Gas Lift
  - Gas Transmission and “Liquid Treatment Plants” (L.T.P.)
  - Liquefaction
  - Gas Storage
- Reciprocating compressors are often used for these duties. They are designed to compress clean and dry natural gas containing mostly methane. However natural gas very often contains a considerable amount of potential liquids like propane and butane but also water. The durability of the wear components of compressors is directly related to the amount of **contamination** like liquids, solids and sulfur (mostly in form of H<sub>2</sub>S) in the gas.

# GAS TRANSMISSION AND STORAGE

### GAS RE-INJECTION

- Natural gas is compressed and re-injected down the well at high pressure to reinforce crude oil production (discharge pressure up to 380 bar).



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COMPRESSORS

# GAS TRANSMISSION AND STORAGE

## LIQUEFACTION

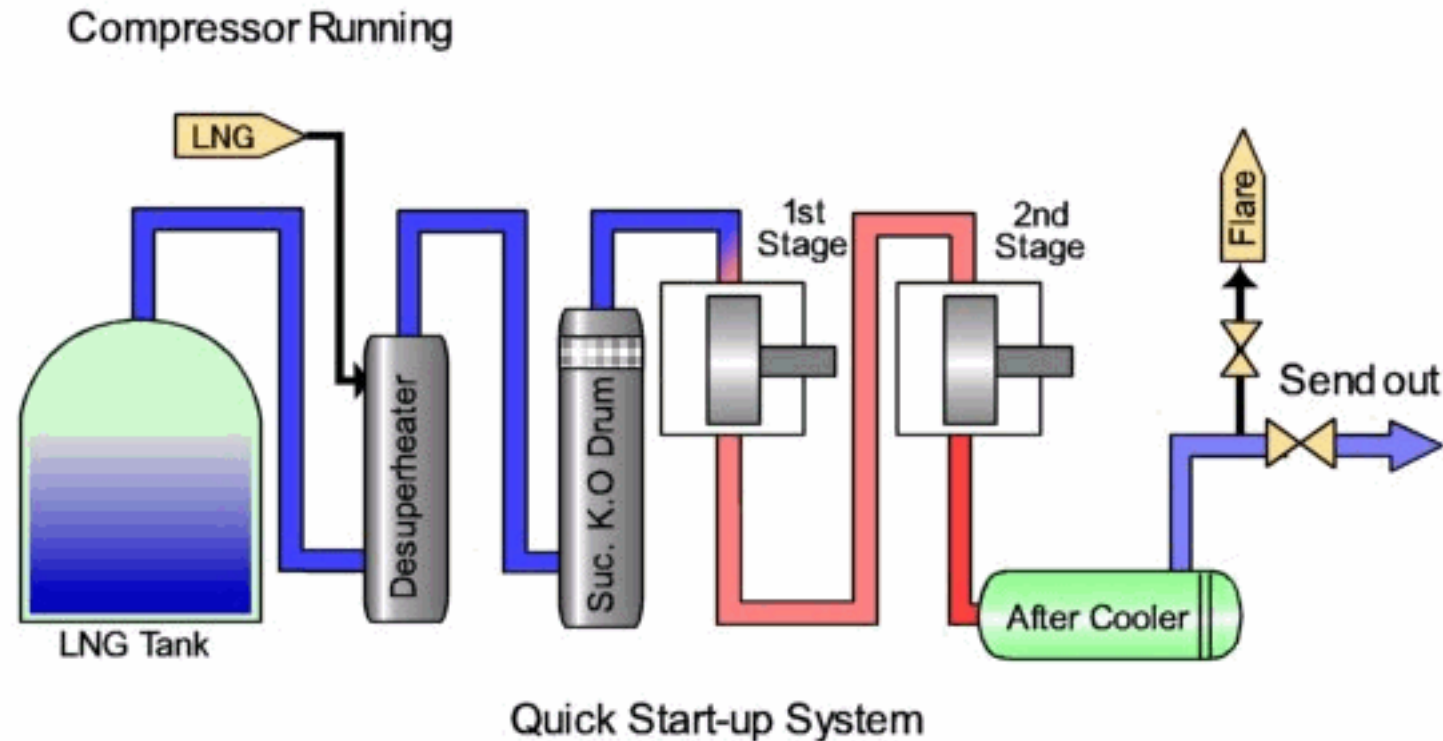
- If transportation by pipeline is not feasible then the gas is liquefied to 'LNG' (Liquified Natural Gas) at temperatures below  $-160^{\circ}\text{C}$ . The low temperatures are obtained by two refrigeration cycles in cascade. For liquefaction plants normally gas turbine driven centrifugal compressors are used.
- Reciprocating compressors are used as '**BOIL OFF**'- units for re-liquefaction of vapourised LNG due to temperature increase e.g. solar radiation.
- Also BUTANE and PROPANE are liquefied.





# Boil-off compressor

- Often labyrinth compressors – no oil leakage to the process
- Need to handle bone-dry gasses



# Cryogenic Services

- - LNG BOG compressor  
(Suction temperature -160 °C (-260 °F))
- - Ethylene BOG compressor  
(Suction temperature -100 °C (-150 °F))
- - Nitrogen BOG compressor  
(Suction temperature -150 °C (-250 °F))

# GAS TRANSMISSION AND STORAGE

- Gas gathering (from the well head to the main treatment plant) is frequently done by reciprocating compressors.
- The L.T.P. (liquid treatment plant) removes higher hydrocarbons such as butane and propane. After the L.T.P. the natural gas is relatively dry and clean, mostly methane. The natural gas, now containing more than 90% methane, is transmitted to the user.
- Many of the 'MAIN PIPELINE COMPRESSORS' are 'TURBOS', which require clean gases.
- Most of the L.T.P.'s use propane or ethylene as the refrigerant gases, where Recips (reciprocating compressors) often are used.

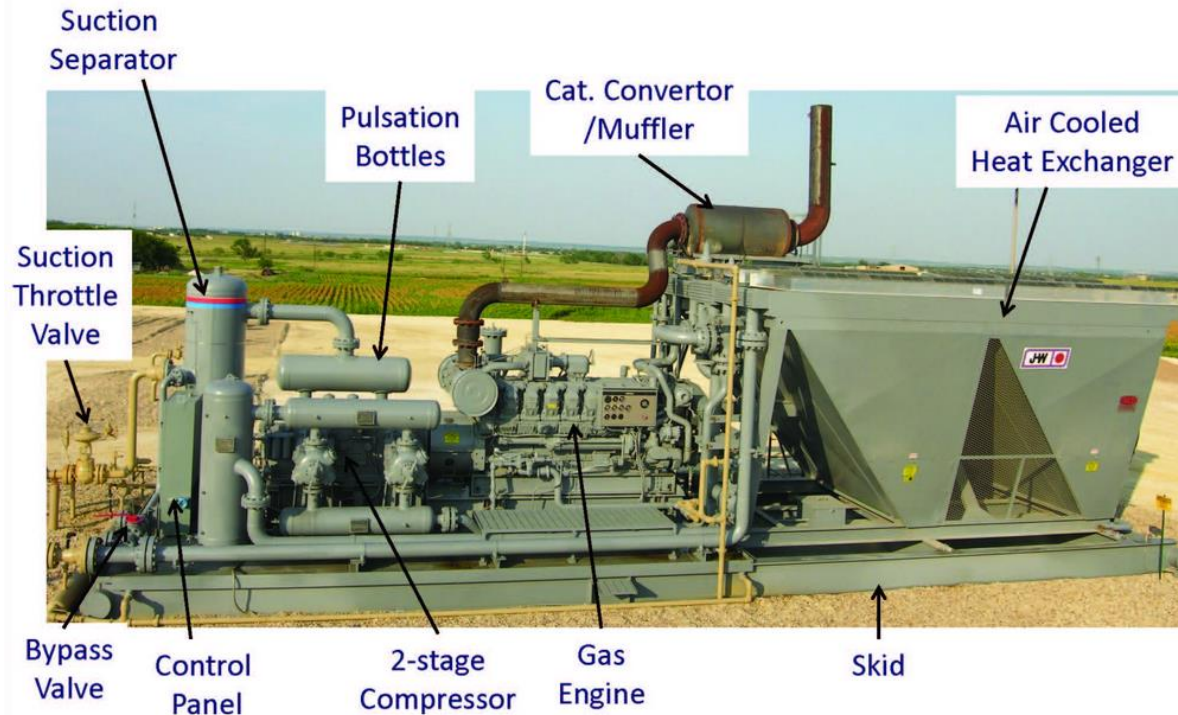


Skid mounted integral compressor

## Typical applications for Reciprocating Compressors

# Shale Gas

- Natural gas compressors are literally the heart of natural gas production. Shale gas wells tend to produce at very high pressures and flow rates initially, but they decline rapidly to a lower level that is sustained for many years. As the pressure declines, gas compressors must be deployed to boost the gas pressure high enough to push it through pipelines to market. Just as the heart is vital to collecting and pumping blood throughout the body, a gas compressor collects natural gas from underground wells and “pumps” it to market.





# Typical applications for Reciprocating Compressors

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H<sub>2</sub> Transport



Air



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bottle blowing



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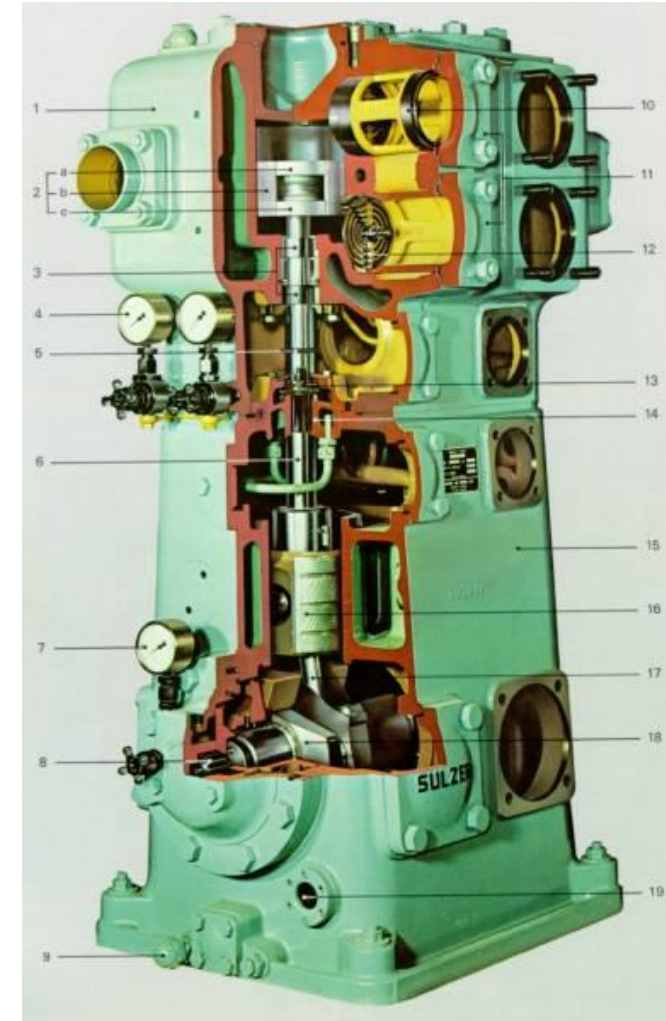
Steel production,  
Nitrogen,...



# OXYGEN COMPRESSOR FOR STEEL PRODUCTION

### Air separation:

- Air is liquefied in the air separation plant by using the different evaporation temperatures of its components.
- Normally turbo compressors are used in these plants.
- All equipment in contact with oxygen must be completely free of any organic material. Even painting marks on valve springs are forbidden.
- Labyrinth compressors



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# Challenges when deploying Reciprocating Compressors

- **Fouling service** – never trust a process engineer when they say it is a clean and dry gas.
- **SU conditions** – many times SU is with Nitrogen to activate Catalyst, but hardly ever mentioned on the data sheets
- **Controllability** – recycle lines, stepless valve control
- **Liquids entering system** – read EFRC “Guideline to prevent liquids in Recips”
- **Gas composition** – possible corrosion, remember - a “trace” is not an SI unit,
- **Selection of valves, packing and rider/piston rings**
- **Location** - remote location, onshore/offshore, climate, indoor/outdoor, maintenance capabilities
- **Driver** – emotor, diesel, integral diesel/compressor, steam turbine, sparing
- **Pulsations and Vibrations** - methodology and limits according API618
- .....etc

## Typical applications for Reciprocating Compressors



END