EFRC Training Workshop
Basic training

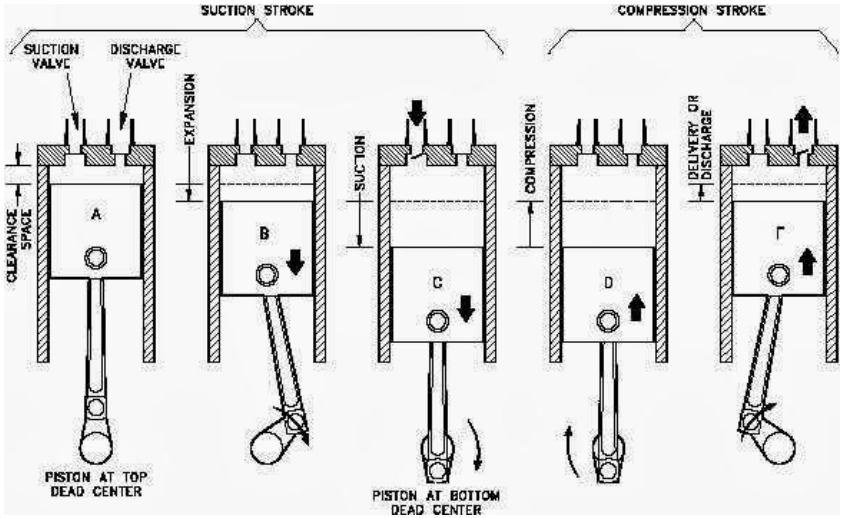
"Typical applications for Reciprocating Compressors"

Mr. Jeroen van Koperen – Shell

Methods of Compression

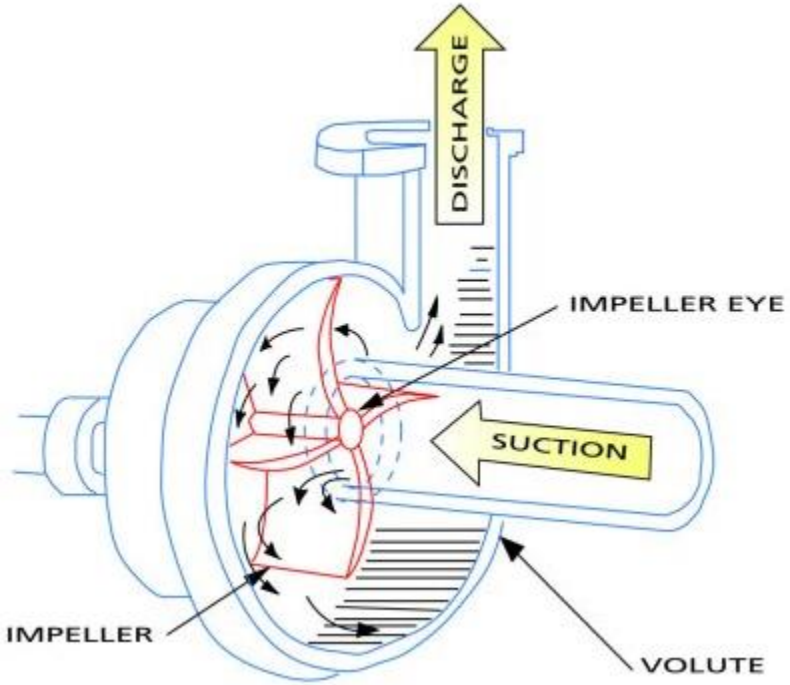
Positive Displacement

- Pressure increase – reducing volume in a compression chamber

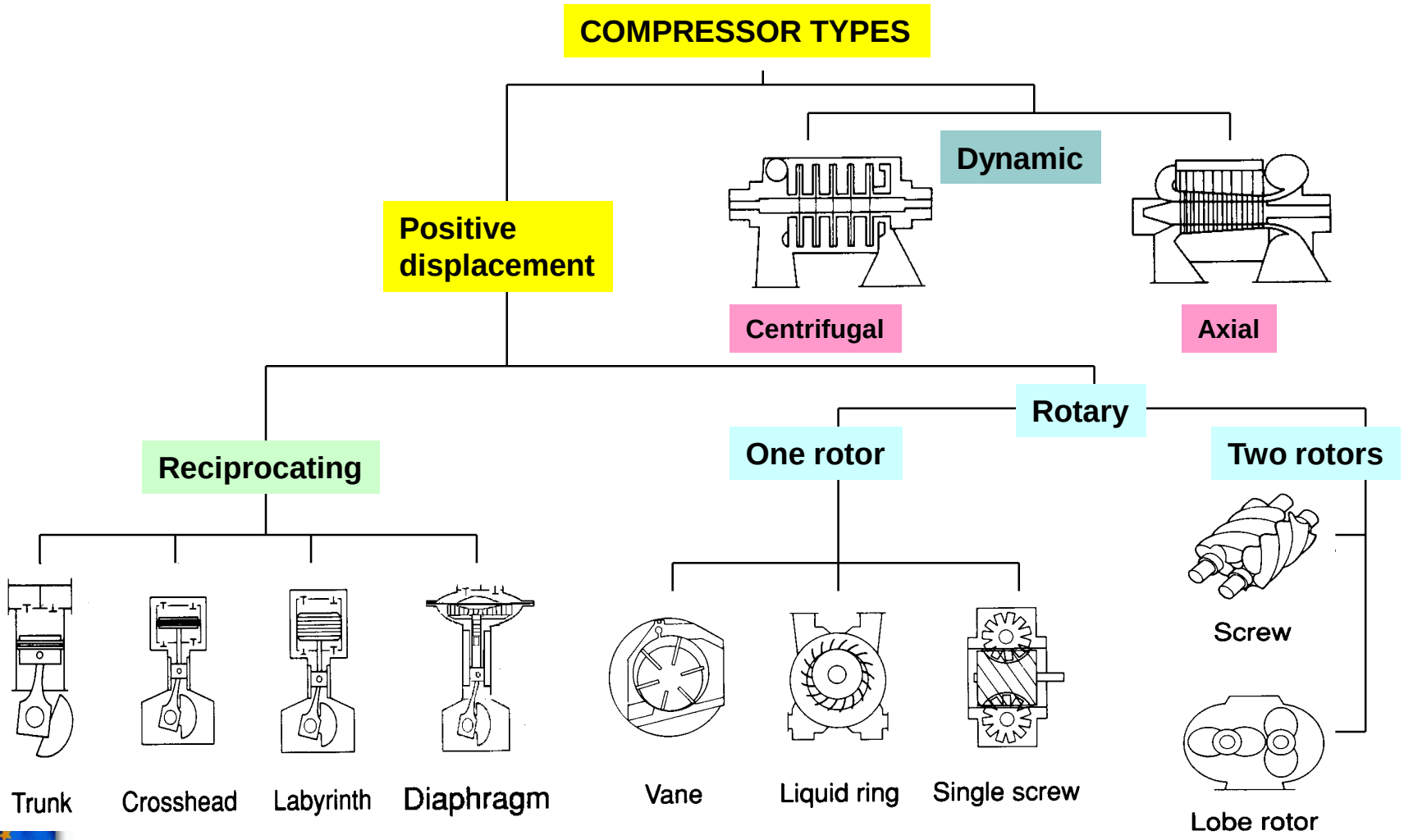


• Dynamic machine

Pressure Increase – transfer kinetic energy to gas and than converted to pressure



Compressors



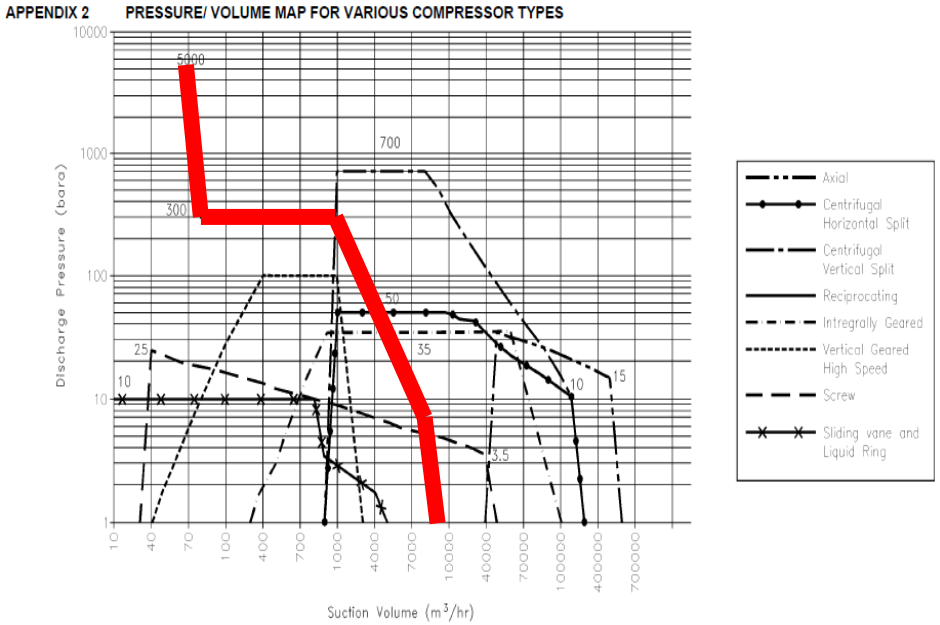
When to apply recips

Reciprocating compressors

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

Centrifugal Compressrs

- Wet service
- Low compression ratios
- Relatively high flow



Reference: Shell DEP for compressor selection

Key Characteristics

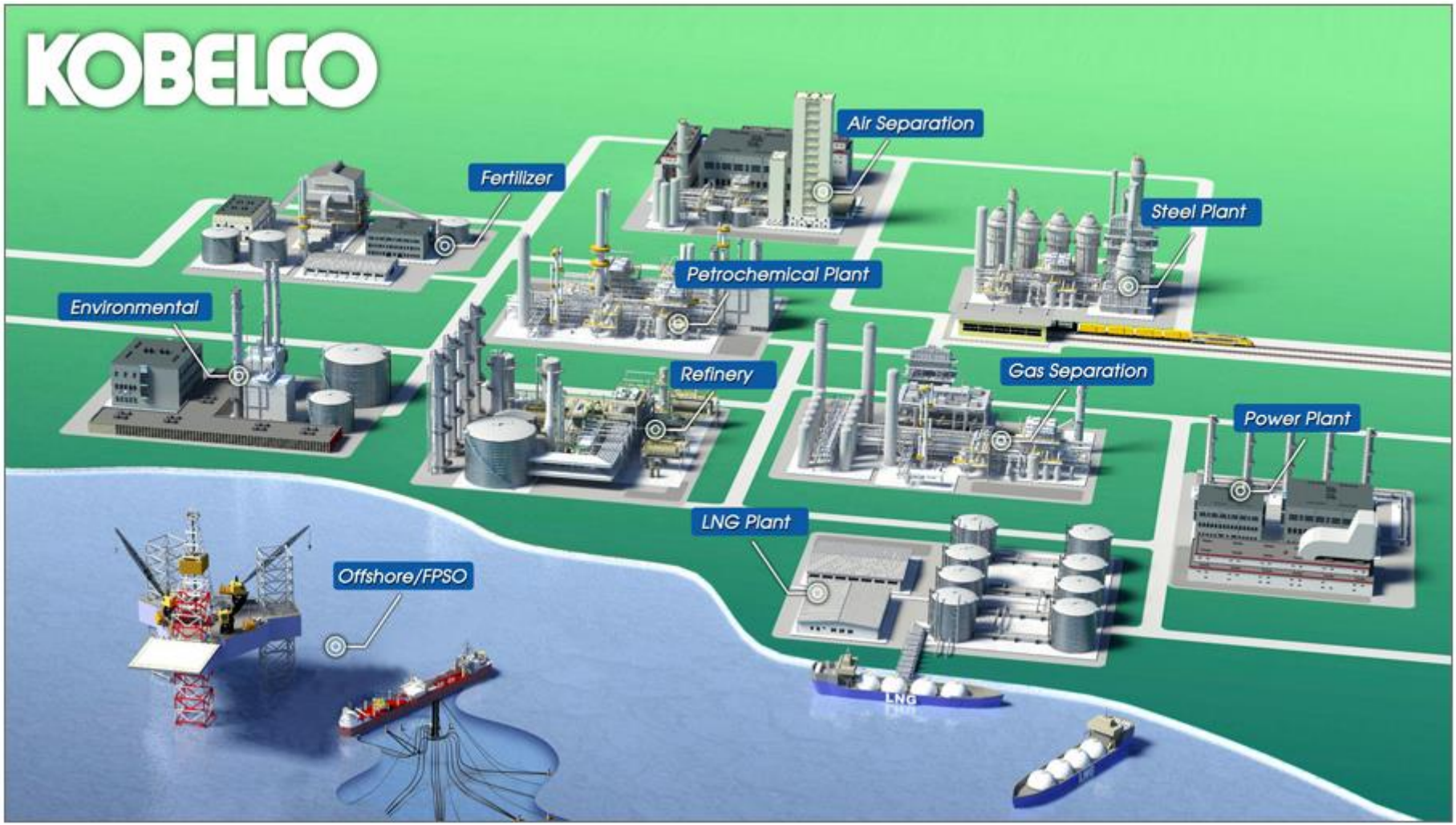
	Reciprocating	Centrifugal
Flow/capacity	Limited by geometry	Limited by Surge point (function of geametry and gas conditions)
Pressures	up to 3500 barg (HYPER)	up to 770 barg (experimental)
Flow Range	Throughput from 0-100%	Limited by surge
Reliability	Many moving parts, high forces in changing directions, gas contamination	One moving part, availability to 95%
Maintenance intervals	1 year on valves and wearing 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)
Operating Costs	High ($75-150/Hp yearly)	Low ($5-10/Hp yearly)
Power	up to 30 MW	Up to 100MW
Lead time	10-40 weeks	30-70 weeks

* See other presentations on Valves and wearing parts

Types

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

Application map



Applications where recips are used

Air	Chemical	Refining	Natural Gas	Technical Gas
PET bottle blowing	Polyethylene production, Fertilizers,…	Refinery products	Gas gathering	Steel production, Nitrogen,…

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)

Air

PET
bottle blowing

Chemical

Polyethylene
production,
Fertilizers,…

Refining

Refinery
products

Natural Gas

Gas
gathering

Technical Gas

Steel production,
Nitrogen,…

POLYETHYLENE PRODUCTION

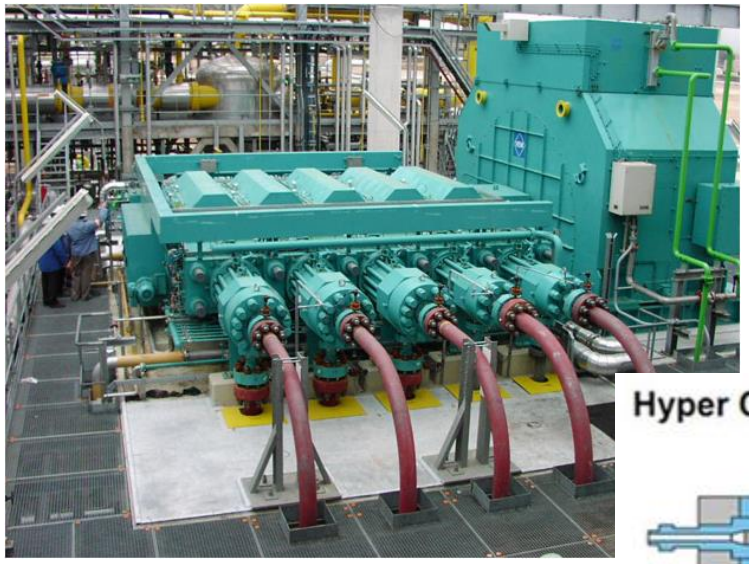
- Polyethylene production can be either high density polyethylene (HDPE) produced using low pressure, typically 30 bar, or low density polyethylene (LDPE) produced using high pressure, up to **3500** bar

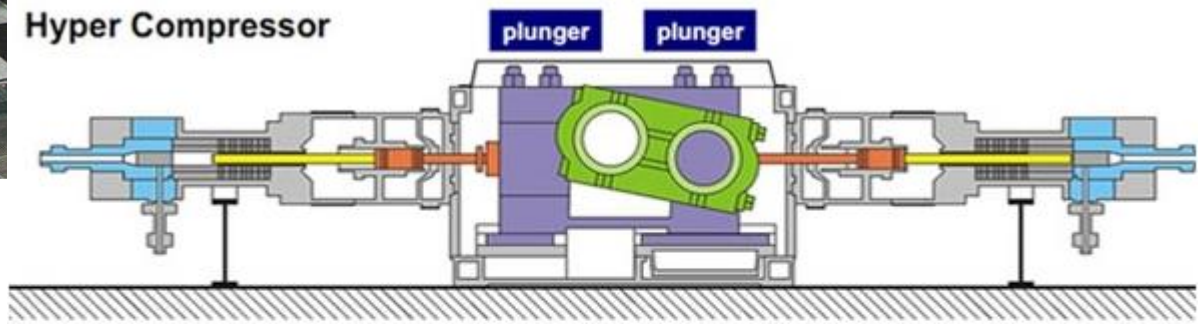
- Both processes use compressors but the LDPE process must use reciprocating compressors to generate this very high pressures necessary for polymerisation of ethylene gas to LDPE (HYPER compressors).

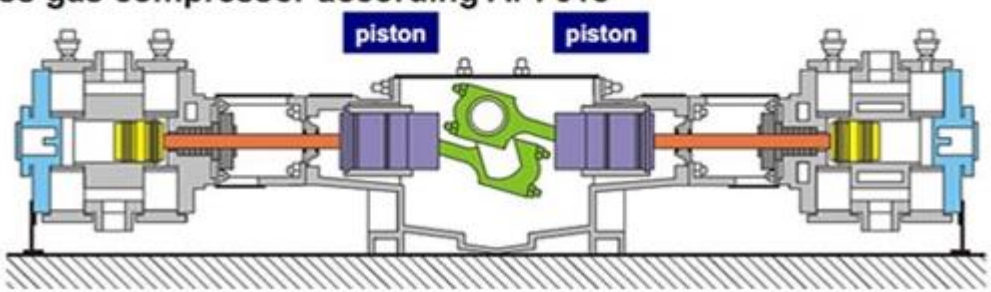
LDPE (Low Density Polyethylene)

- 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.

Hyper Compressors







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 NH_3-synthesis process a gas mixture of 74% H2 and 25% N2 (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.

Air

PET
bottle blowing

Chemical

Polyethylene
production,
Fertilizers,…

Refining

Refinery
products

Natural Gas

Gas
gathering

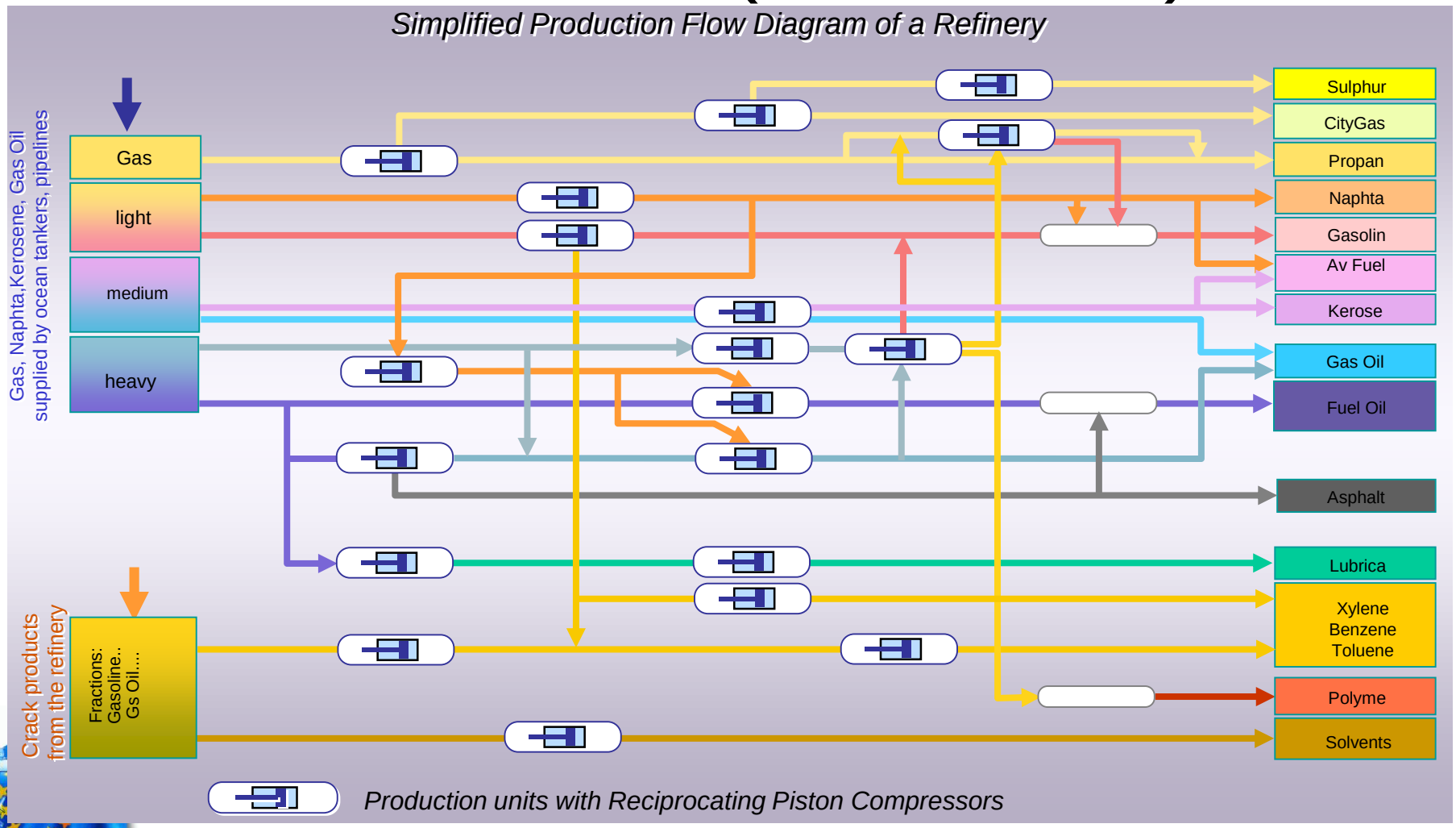
Technical Gas

Steel production,
Nitrogen,…

APPLICATIONS OF RECIPROCATING COMPRESSORS IN REFINING INDUSTRY

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

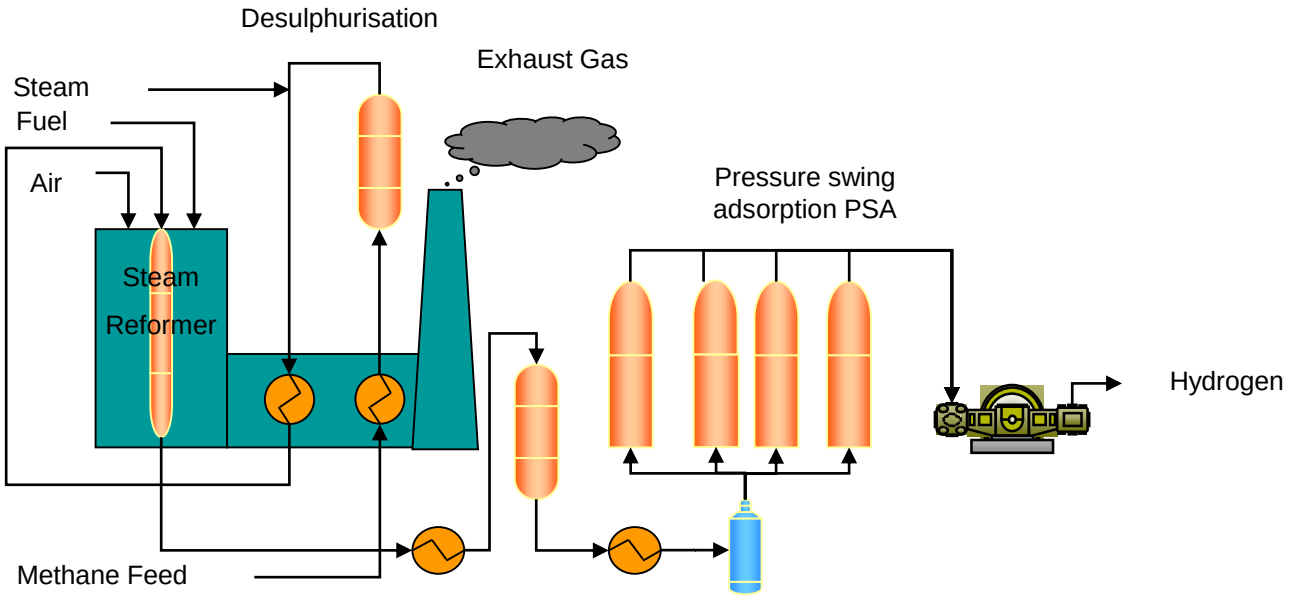
NUMBER OF RECIPs USED IN REFINERY (EXAMPLE)



HYDROGEN MANUFACTURING UNIT (HMU)

- Hydrogen generation in a high temperature, high pressure, thermal cracking process to produce a very clean stream of hydrogen gas.

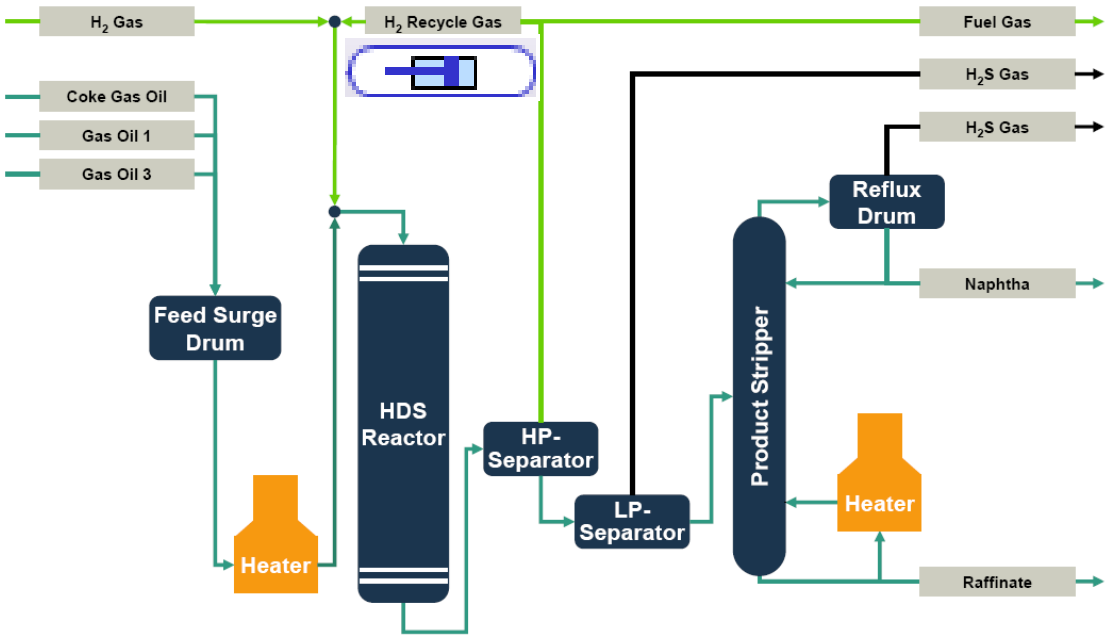
- The standard process route comprises feed de-sulfurization, steam reforming, shift conversion and hydrogen purification by means of Pressure Swing Adsorption (PSA). Even up to 300bar.



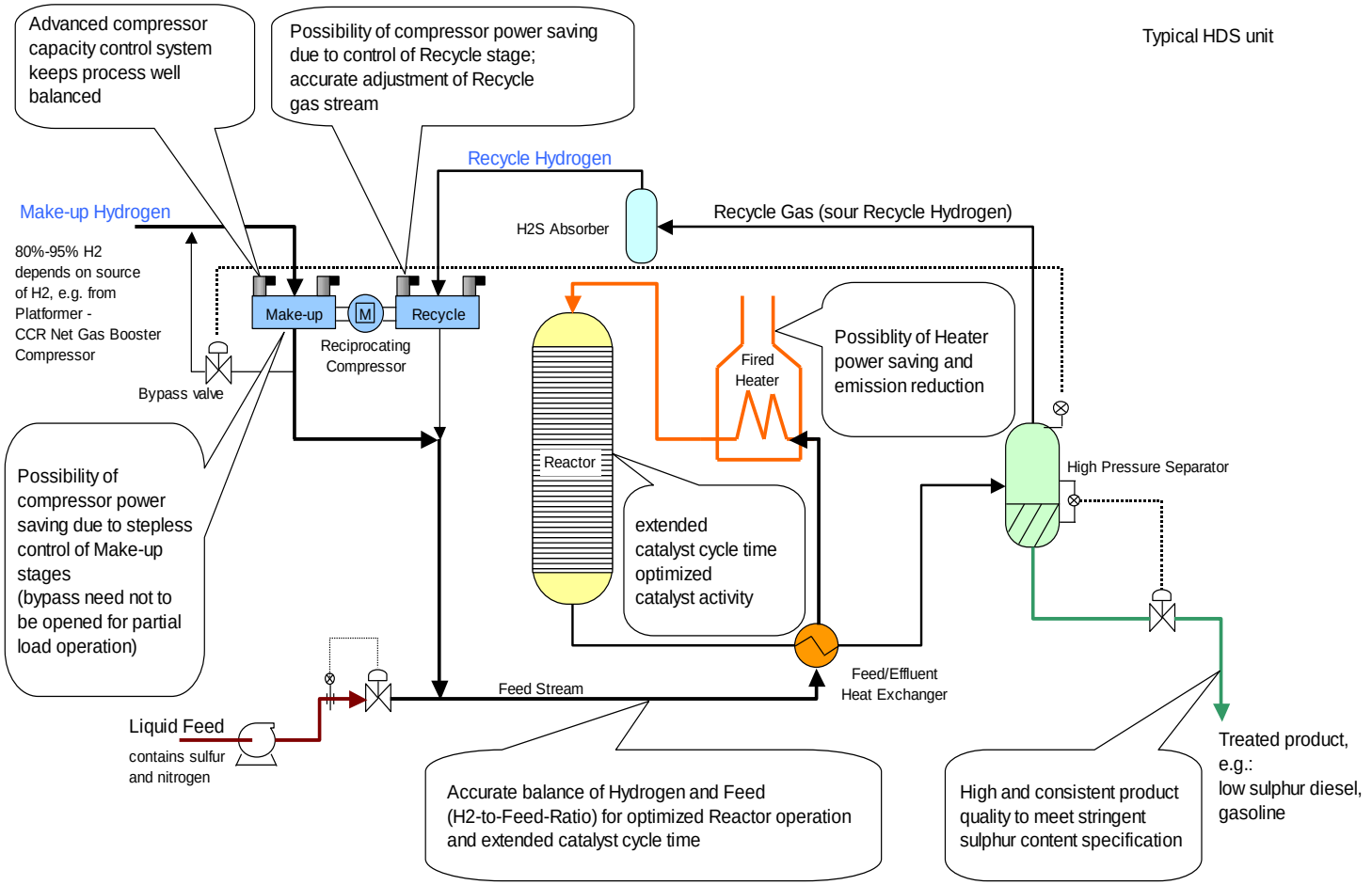
HYDRODESULFURIZATION (HDS)

- The hydrocarbon feedstock is mixed with recycled hydrogen. The desulphurisation comprises two process steps. In the first step organic sulphur compounds are converted to H2S at about 360°C on a cobalt-molybdenum or nickel-molybdenum hydrogenation catalyst. In the second step, H2S is adsorbed on zinc oxide, DiEthanolAmin (DEA), etc.

- These processes usually operate at 20 to 60 bar, depending on the content of H2S.



HYDRODESULFURIZATION (HDS)



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 (H2S).

Hydro cracker - Japan

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 H2S) 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 may different fouling agents (H2S, chrlorides, free water, liquids, etc)
- Flare gas may have varying MW, which recips are ideal to handle.

- Leads to €, but most important reduction of flaring (=legislation, reputation)

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 H2S) 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).

GAS TRANSMISSION AND STORAGE

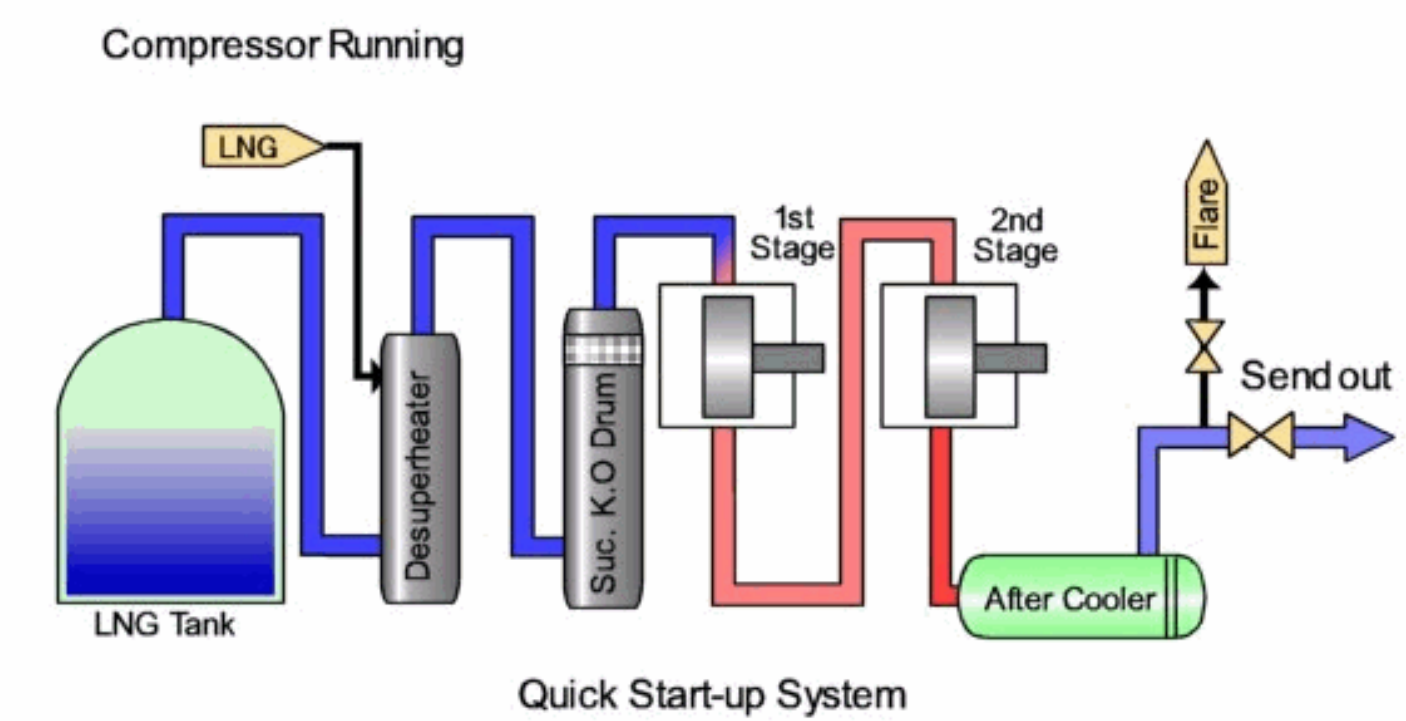
LIQUEFACTION

- If transportation by pipeline is not feasible then the gas is liquefied to 'LNG' (Liquified Natural Gas) at temperatures below -160°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.

LPG Terminal - Japan

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.


Skid mounted integral compressor

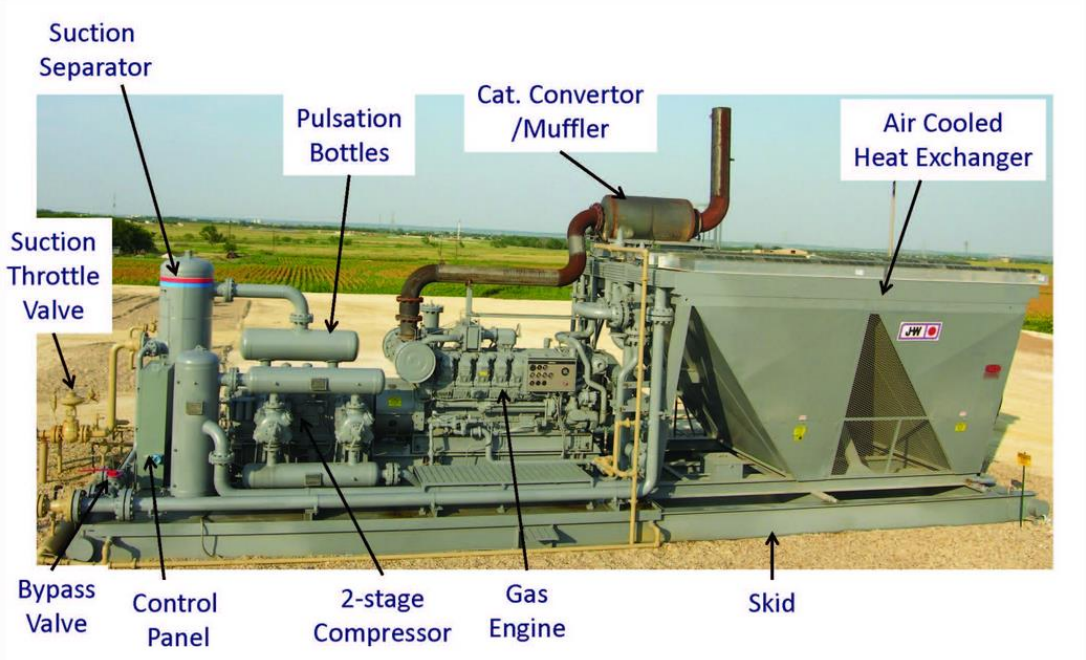
- The L.T.P. (liquid treatment plant) removes higher hydrocarbons such as butane and propane. After the L.T.P. the natural gas is relatively dry and clean, mostly methane. The natural gas, now containing more than 90% methane, is transmitted to the user.

- 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.

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.



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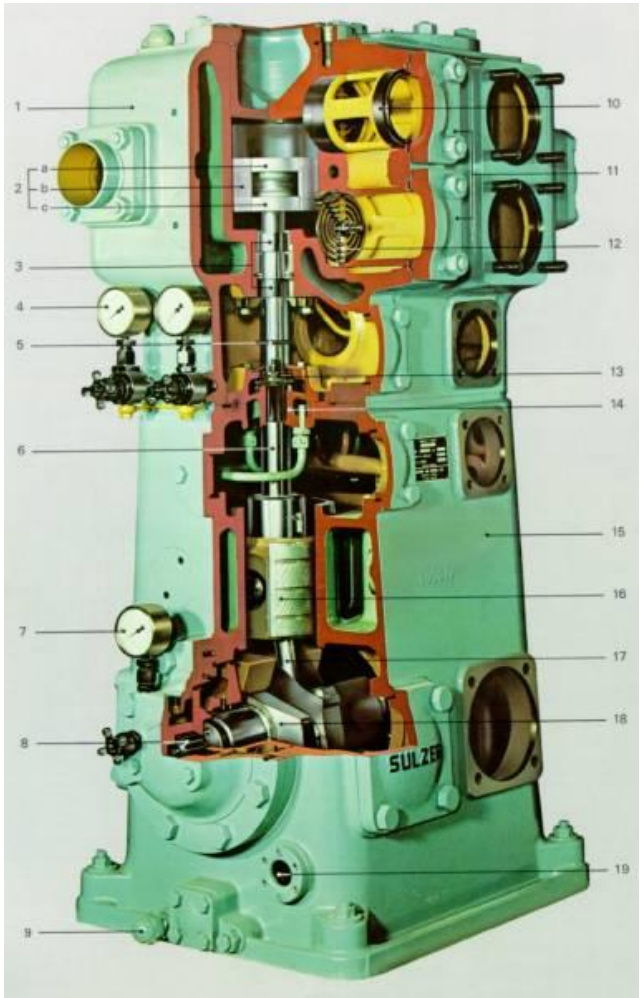
Nitrogen,…

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



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**

END