

Helium refrigerators and liquefiers



Outline

- Air Liquide range of cryogenic plants at 4.5K and below
- Few thermodynamical concepts
- Refrigerators and Liquefiers main equipments

Helium refrigerators and Liquefiers

Why ?

■ Why to use helium refrigerators and liquefiers ?

- Supraconductivity (magnets, fusion, light sources,...)
- Industrial market (gas transportation,...)
- Cavities for particles linear accelerators (2K)
- Cold neutron sources (20K)
- Space activities

Air Liquide range of cryogenic plants

Standard Liquefiers

- Standard liquefiers range from **15 L/hr to 650 L/hr**
- Fully automatic operation

Recent references

- SL - 33 l/h - IEE (China-2016)
- ML - 100 l/h - STFC Daresbury (UK-2016)
- XLL - 2x600 l/h - AL DGRH (Germany-2016)
- XLL - 620 l/h - BUAA (China-2015)
- SL - 40 l/h - Nancy univ. (France-2014)
- ML - 120 l/h - Kobe univ. (Japan-2014)
- ML - 120 l/h - LNCMI (France-2013)
- SL - 50 l/h - Fukui univ. (Japan-2013)
- SL - 15 l/h - Strasbourg Univ. (France-2012)



Air Liquide range of cryogenic plants

Standard Refrigerators

- Standard refrigerators range from **100W to 1000 W @ 4.5K**
- Fully automatic operation

Recent references

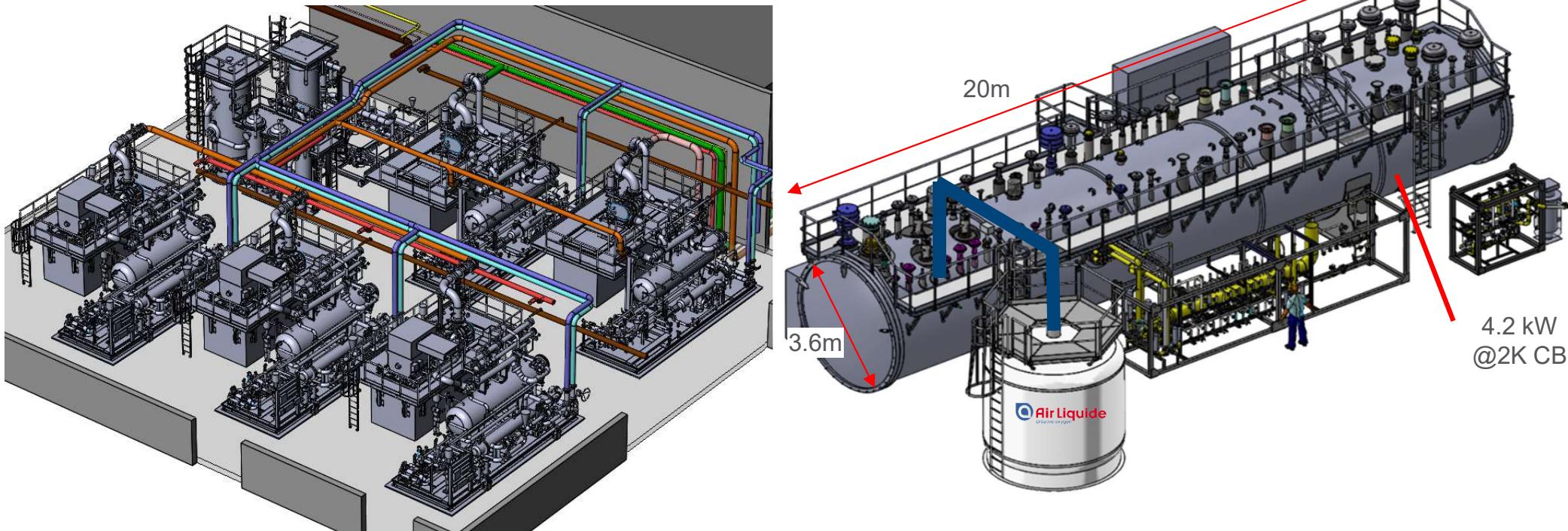
- MF - 350W - MAST-U (UK - 2018)
- MF - 450W - RIKEN (Japan - 2017)
- LF - 935W - SARAF (Israël - 2017)
- LF - 800W - F4E MITICA (Italy-2016)
- MF - 390W - ESS TICP (Sweden-2016)
- MF - 650W - SSRF2 (China-2016)
- MF - 230W - IFMIF / CEA (Japan-2014)
- SF - 50W - Ganil (France-2014)



Air Liquide range of cryogenic plants

Specific refrigerators and liquefiers

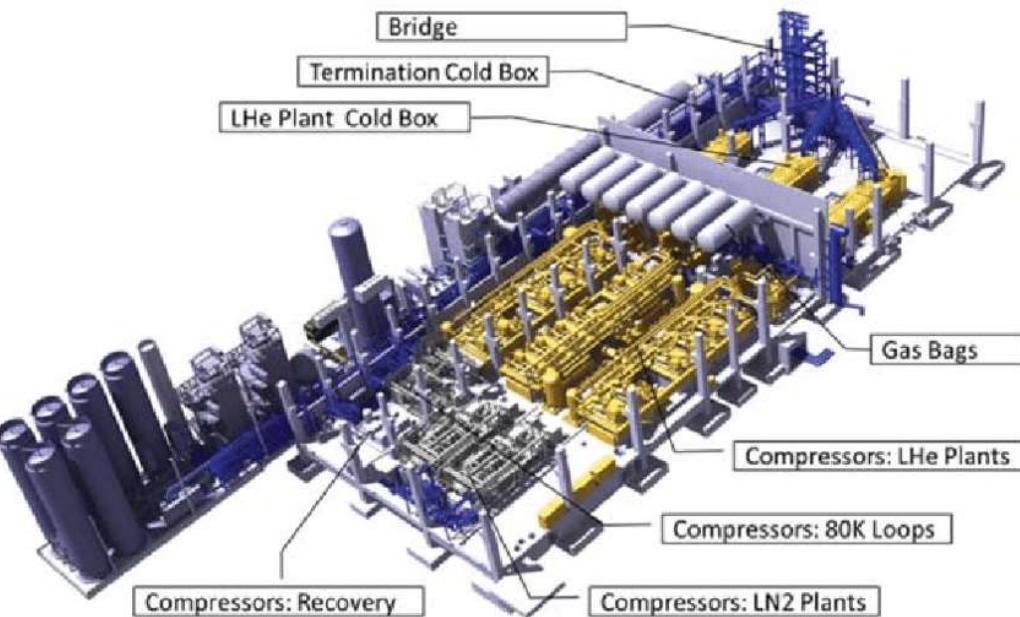
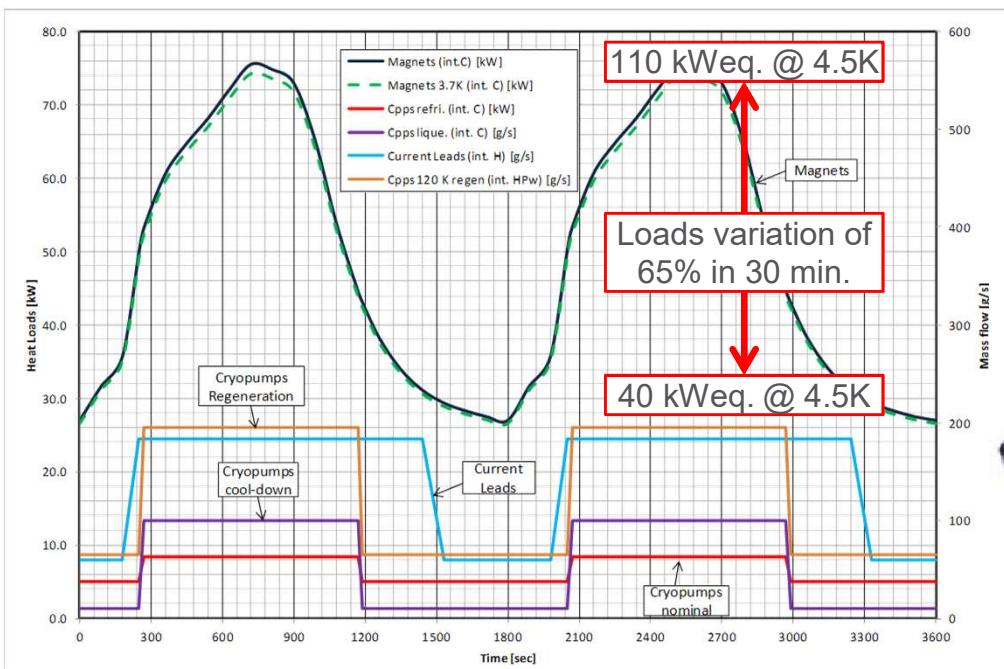
- Specific customized liquefiers and refrigerators above **650 L/hr and 1000 W @ 4.5K**
- Example: SCL2 - Korea - 4.2 kW @ 2K - ~4 MW of installed power



Air Liquide range of cryogenic plants

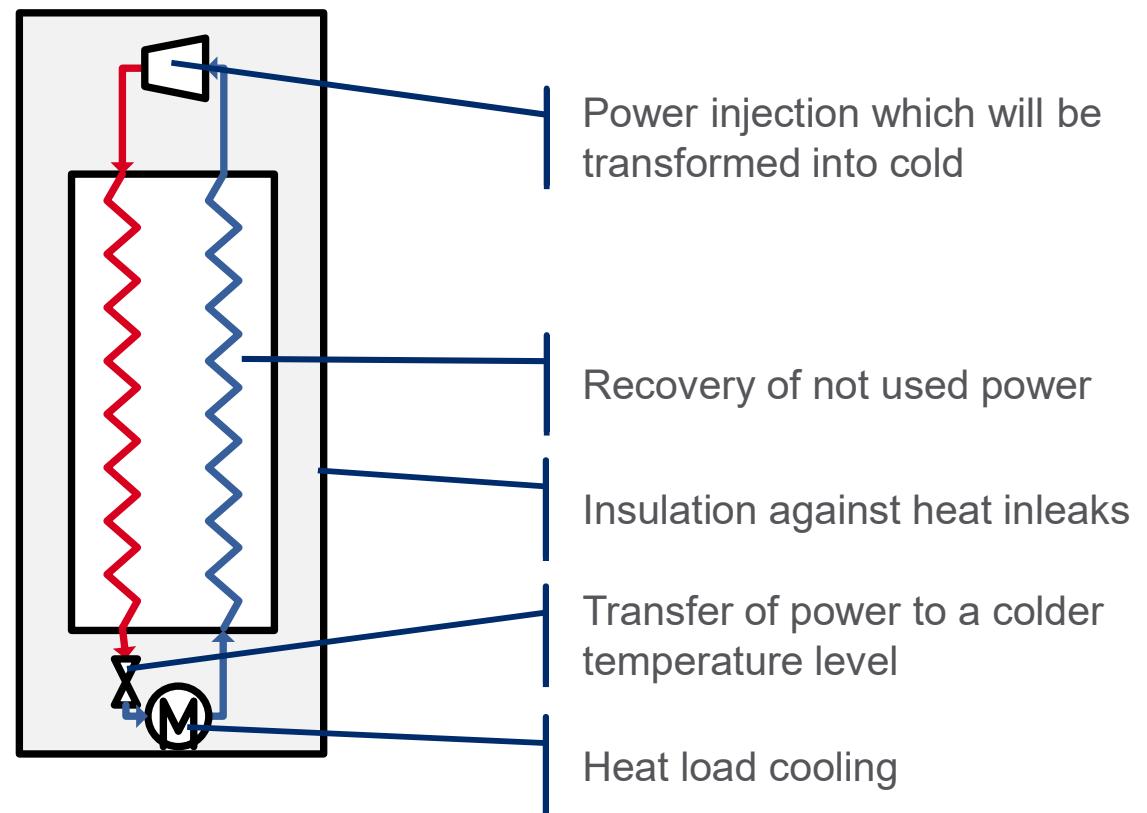
Specific refrigerators and liquefiers

- Specific customized liquefiers and refrigerators above **650 L/hr and 1000 W @ 4.5K**
- Example: ITER - France – **3 x 25 kW @ 4.5K** with pulses operation
~24 MW of installed power



Few thermodynamical concepts

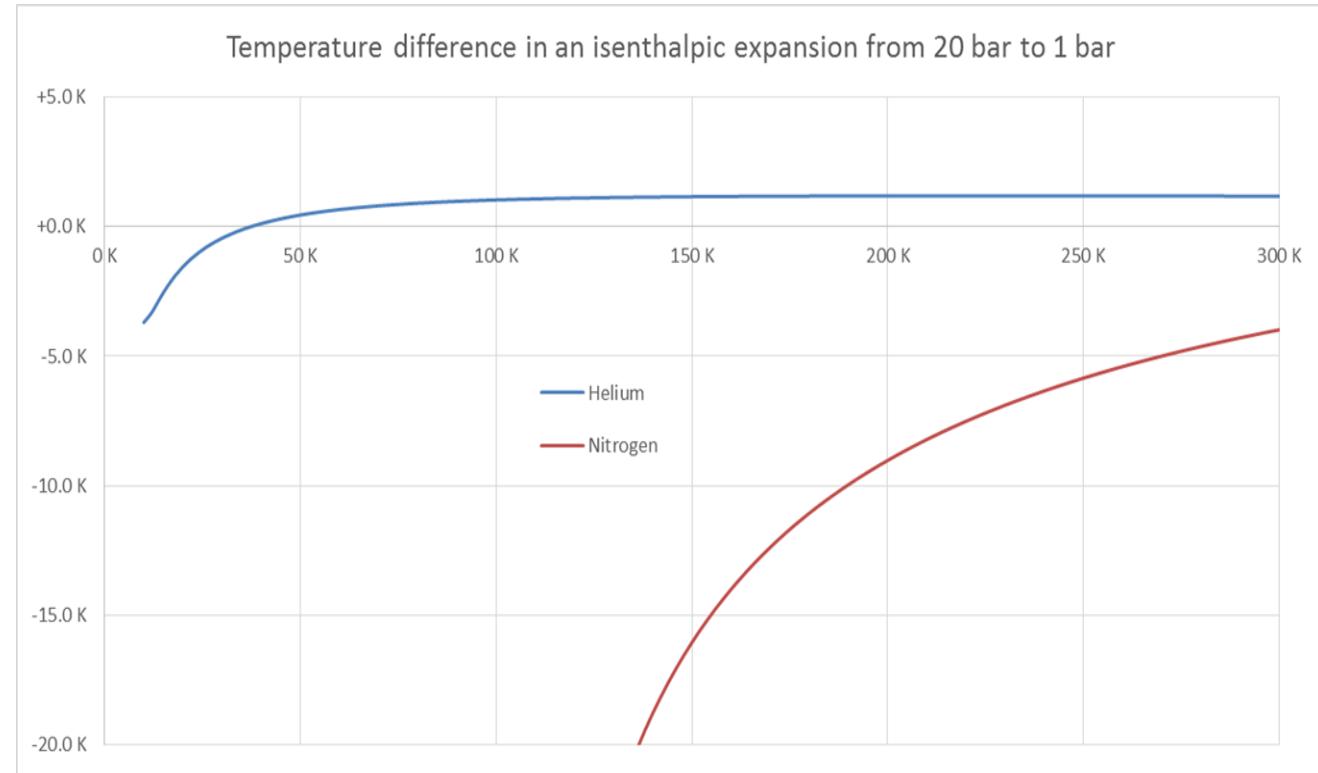
General principle



Helium properties

Helium particular properties...

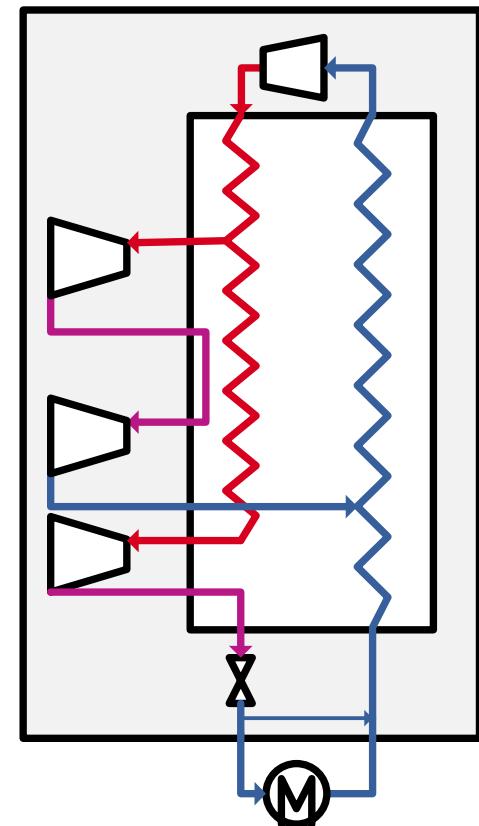
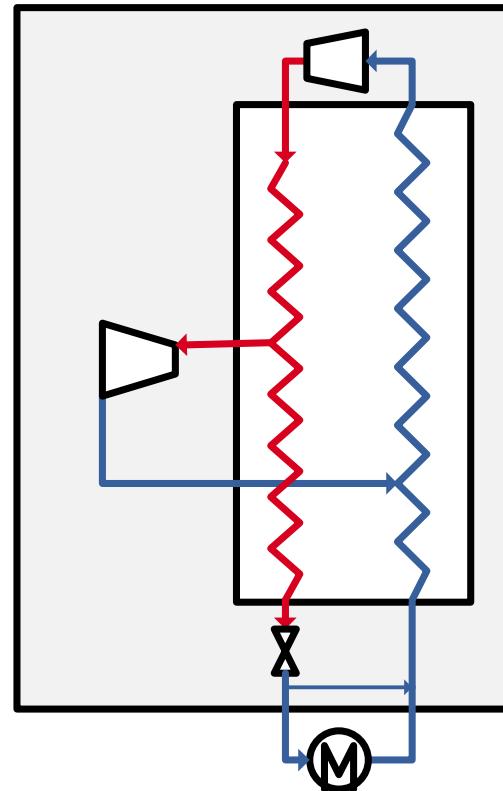
- Problem: during expansion in a valve, helium warms-up above ~40K
- A valve can be used to cool-down helium only below ~40K.
Above ~40K, energy needs to be extracted with turbines



Few thermodynamical concepts

General principle

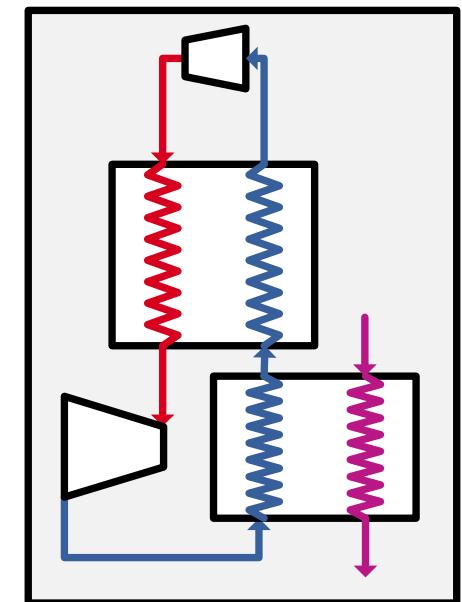
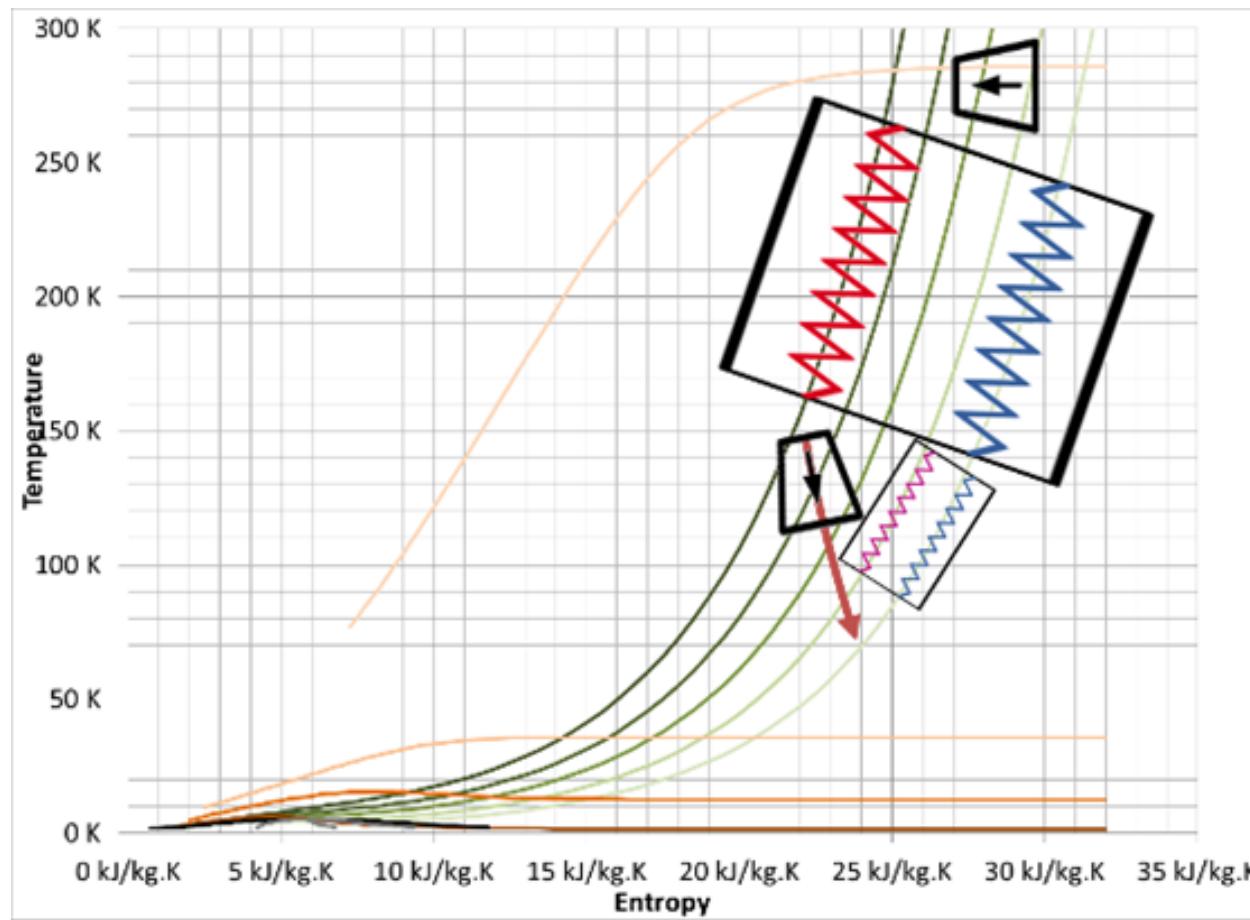
- Turbines are used to extract energy
- Increasing the number of turbines steps increases the efficiency



Few thermodynamical concepts

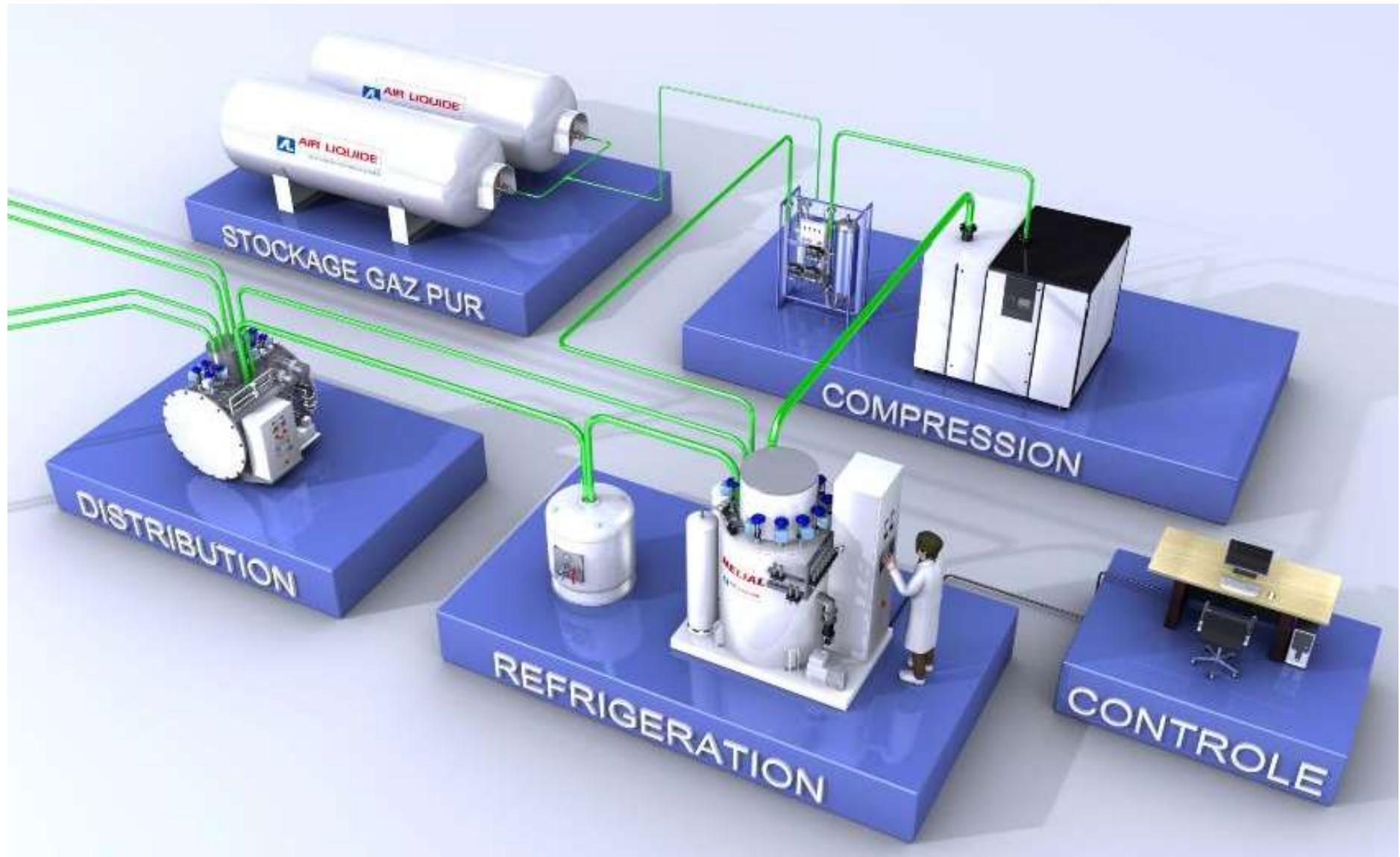
TS Diagram

A simple brayton cycle



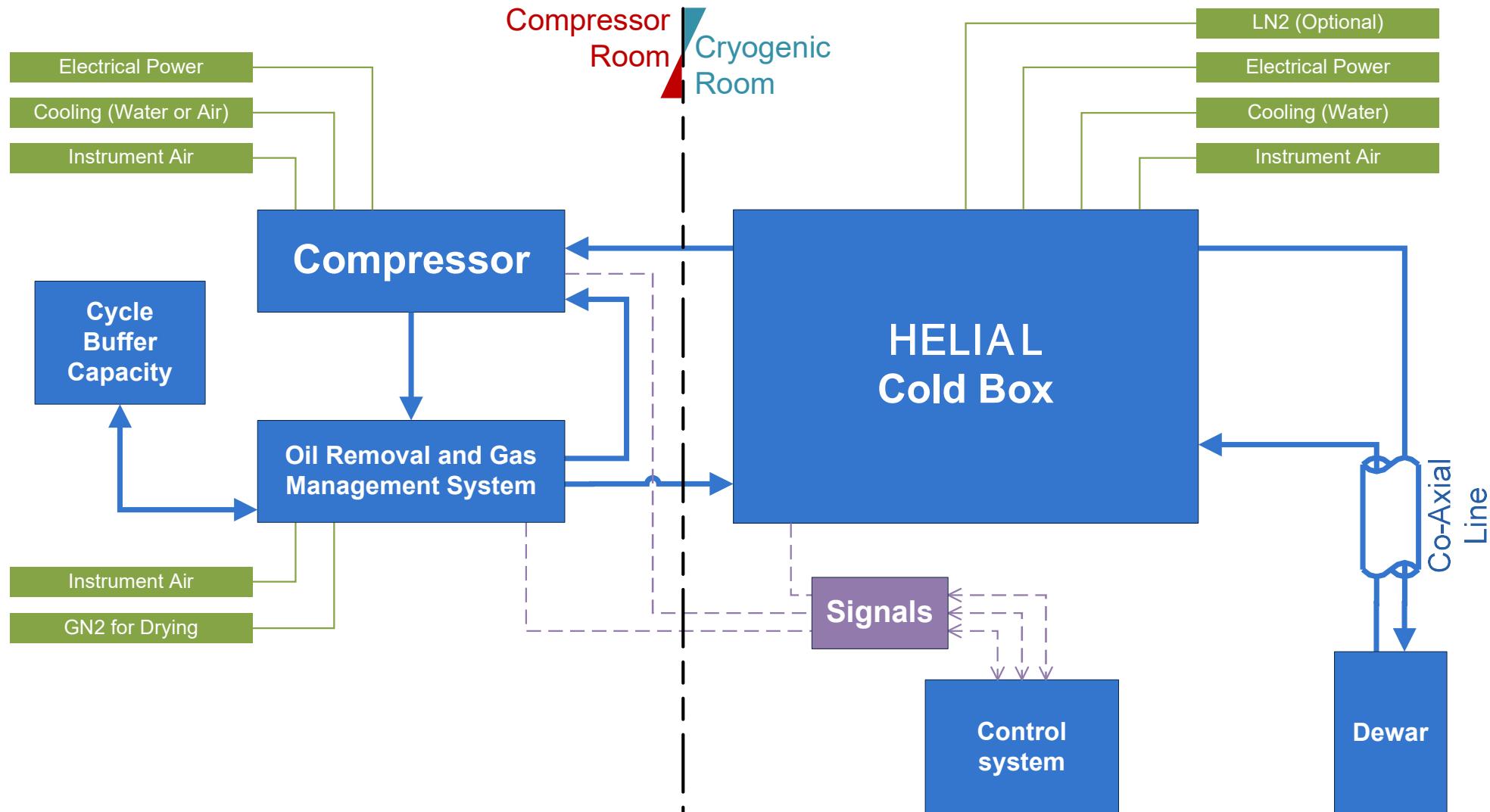
Cryogenic plants main components

Global view



Cryogenic plants main components

Global view

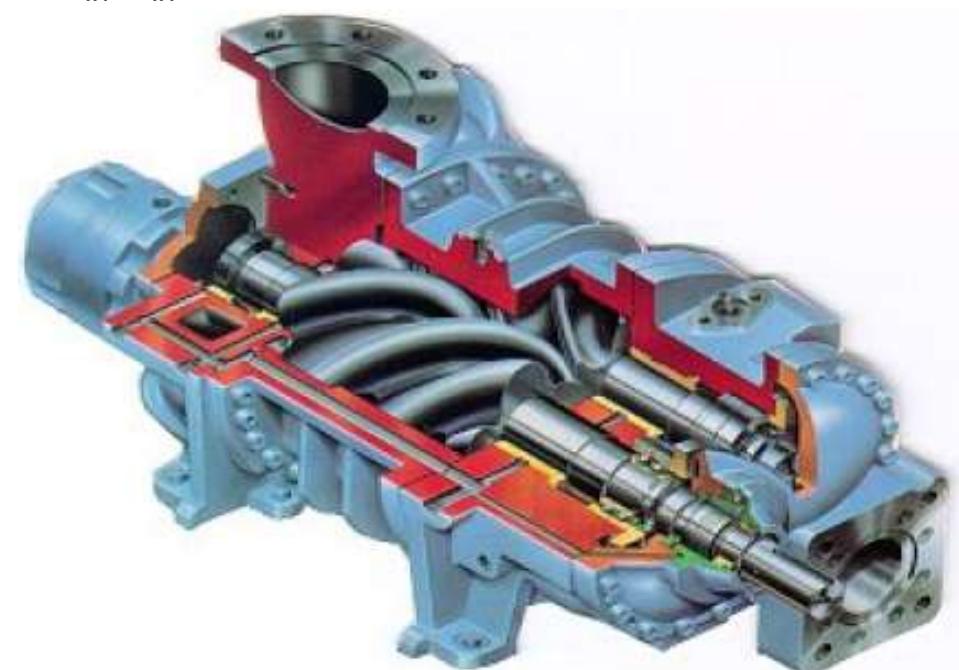
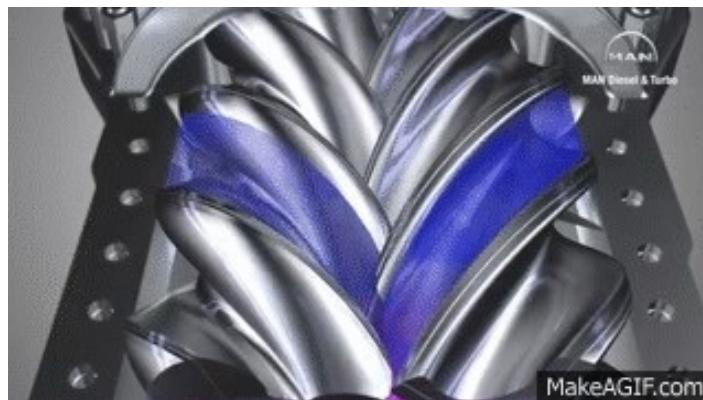


Cryogenic plants main components

Helium screw compressors

■ Main Characteristics :

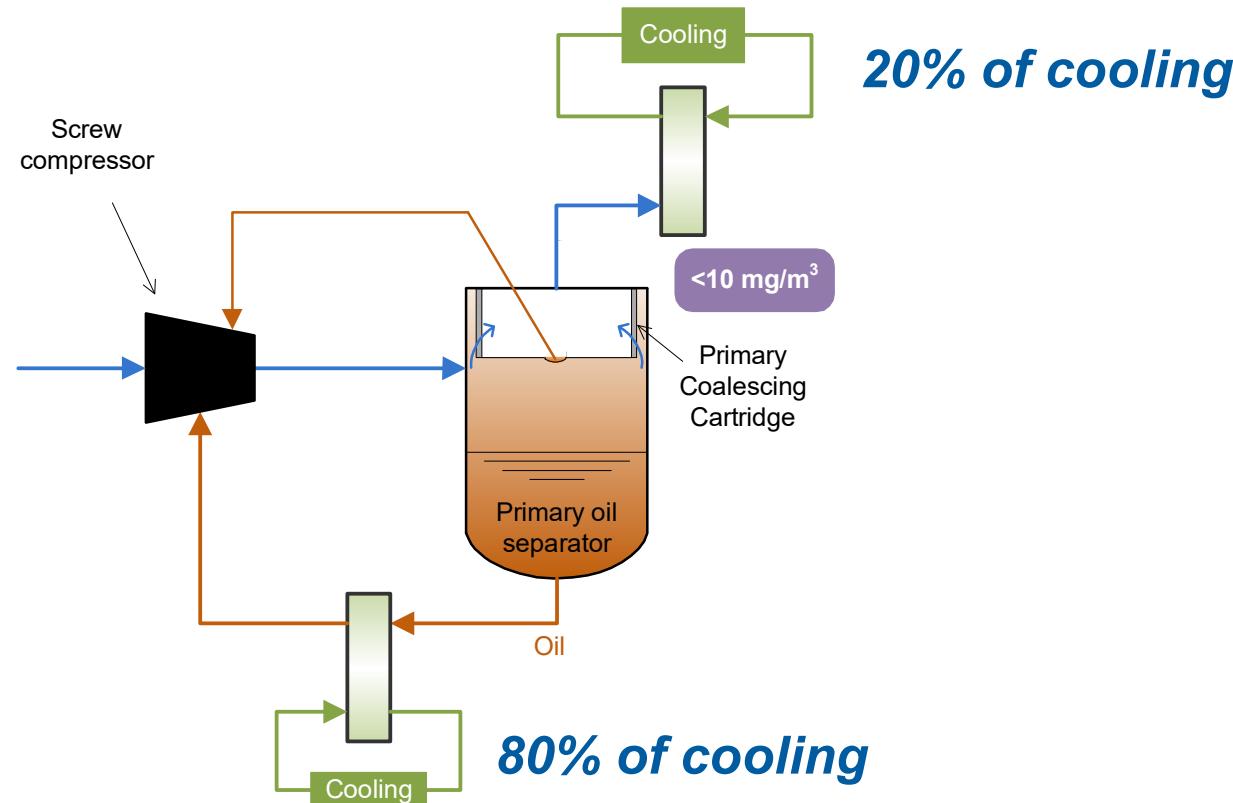
- ▣ Oil lubricated screw compressor
- ▣ High pressure up to 25 bar
- ▣ Special oil is used to avoid contamination of cryogenic circuits
- ▣ Variable Frequency Drive (VFD) can be used to reduce electric power when capacity reduction is required
- ▣ Volumetric compressors: mass flow $m \propto P_{in}/T_{in}$
- ▣ Power: $P_{id} = m \cdot R \cdot T_{in} \cdot \ln(P_{out}/P_{in})$
- ▣ Yield ~ 50%



Cryogenic plants main components

Helium screw compressors

- Ideal adiabatic compression of helium to 15 bar would lead to a temperature of 585°C.
- Oil is used to keep compressor outlet temperature around 80°C.
- To compress 1 g/s of helium to 15 bar, ~40 g/s of oil is required to limit temperature increase to 80°C



80% of cooling

Cryogenic plants main components

Helium screw compressors

- Helium "standard" Compressors
 - Up to 100 g/s and 300 kW



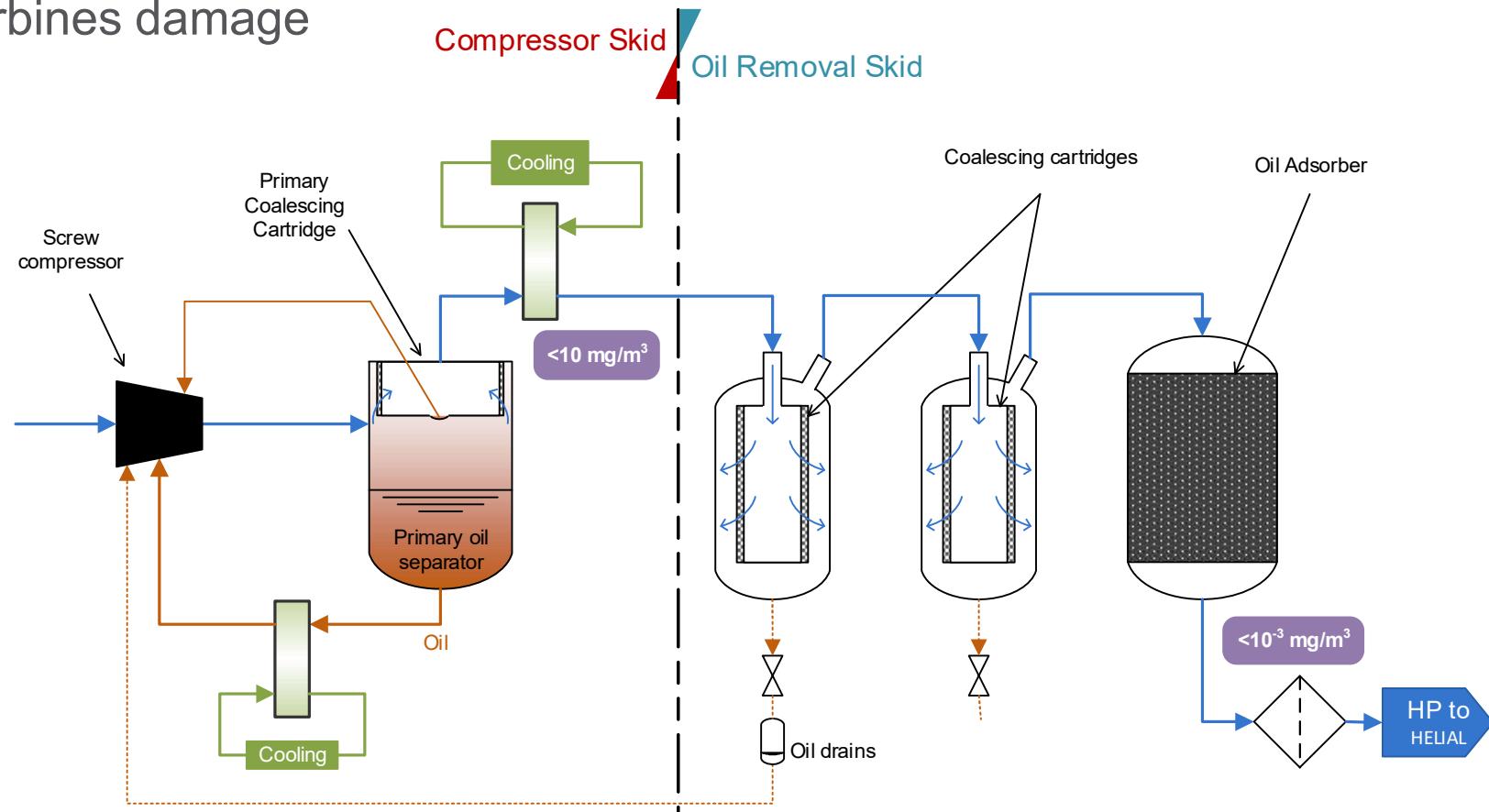
- Specific compressors skids
 - Above 300 kW and when number of machines decreases reliability and generates too much maintenance



Cryogenic plants main components

Oil Removal System (ORS)

- Oil Removal System (ORS) is used to remove traces of oil in helium
 - Coalescing cartridges remove oil aerosols (liquid droplets of μm size)
 - Charcoal adsorber remove oil vapours
- ORS efficiency is crucial to avoid cryogenic heat exchangers clogging and turbines damage



Cryogenic plants main components

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Cryogenic plants main components

Helium Buffers

- Gaseous helium storage is necessary to manage helium inventory during cool-down or warm-up.



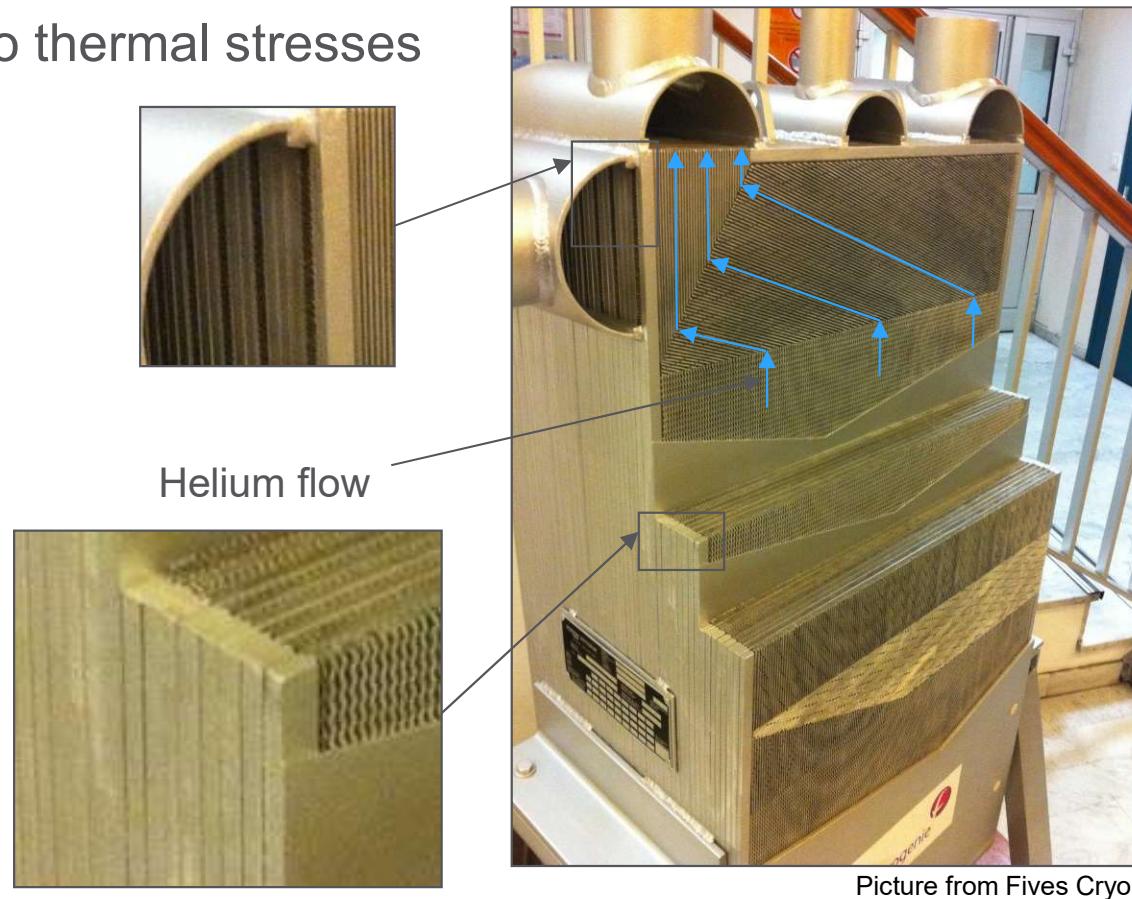
- Characteristics:
 - 3 bar abs <math>\le P_{\text{operation}} \le 13 \text{ bar}
 - At room temperature
 - Volume:
from 5 m³ (for HELIAL SL)
to 400 m³ (large cryoplants)



Cryogenic plants main components

Plate fin heat exchangers

- Brazed aluminium plate fin heat exchangers are used in cold boxes to transfer heat from low pressure circuits to high pressure circuits.
- High compacity => limit the size of vacuum vessels
- Design with multi-streams
- Sensibles to thermal stresses



Picture from Fives Cryo

Cryogenic plants main components

Turbines

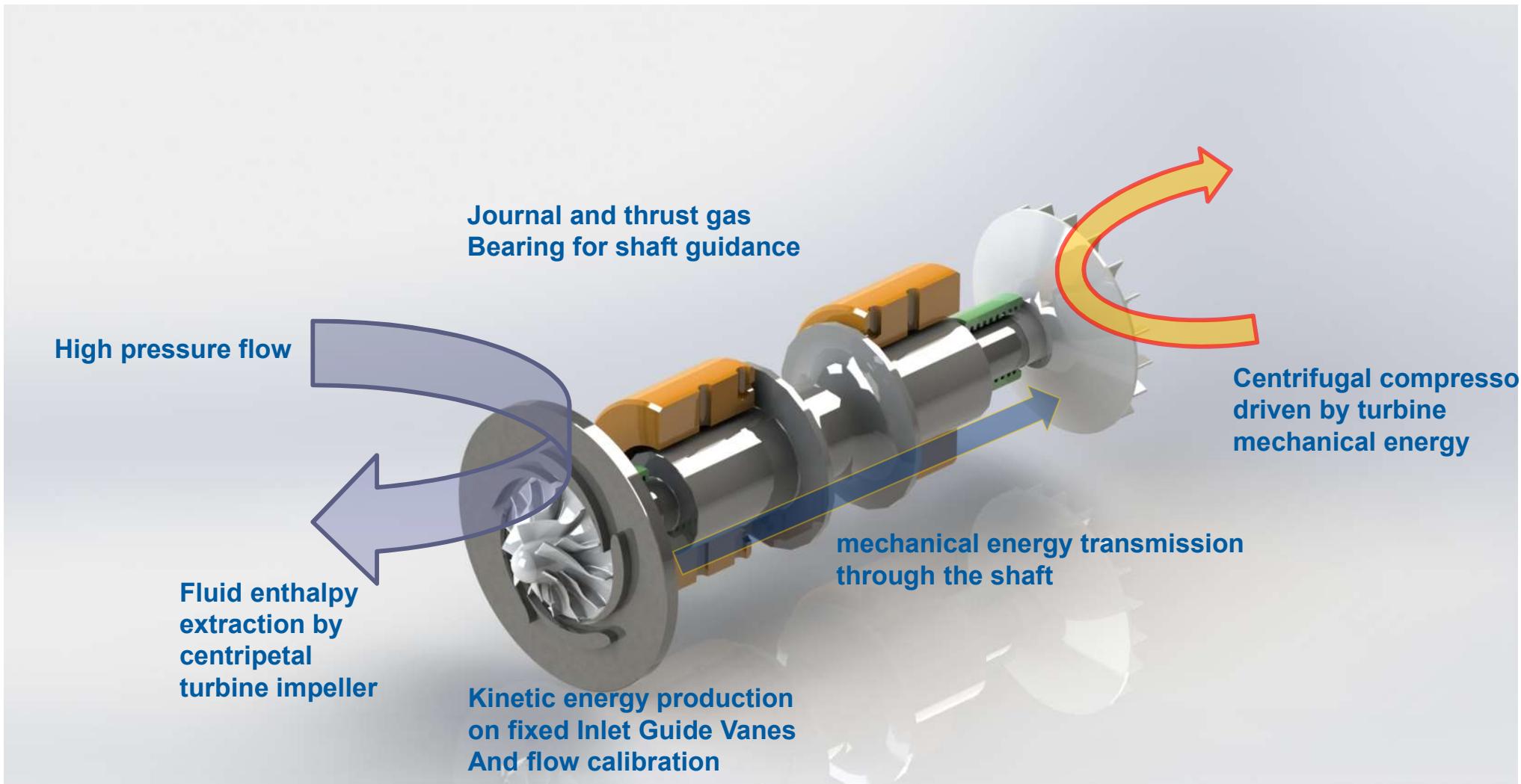
- Turbines are used to cool down helium (extract power from the gas)
- High speed turbines (up to 4 000 Hz) based on static gas bearings
- Large range of power: from 200 W to 200 kW
- Efficiency between 70 and 85%
- High reliability : MTBF > 100 000 hrs



Cryogenic plants main components

Turbines

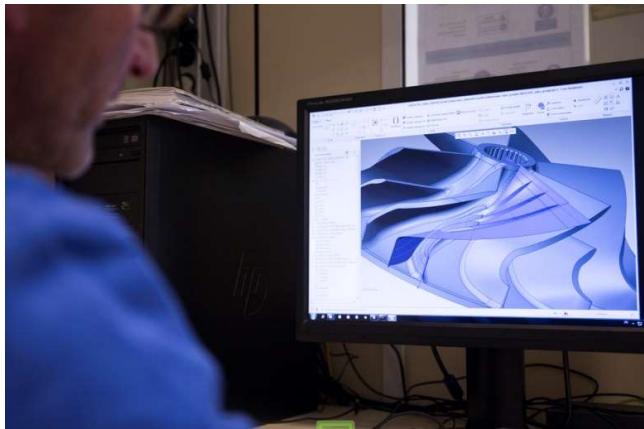
- Power extracted proportional to mass flow rate



Cryogenic plants main components

Turbines

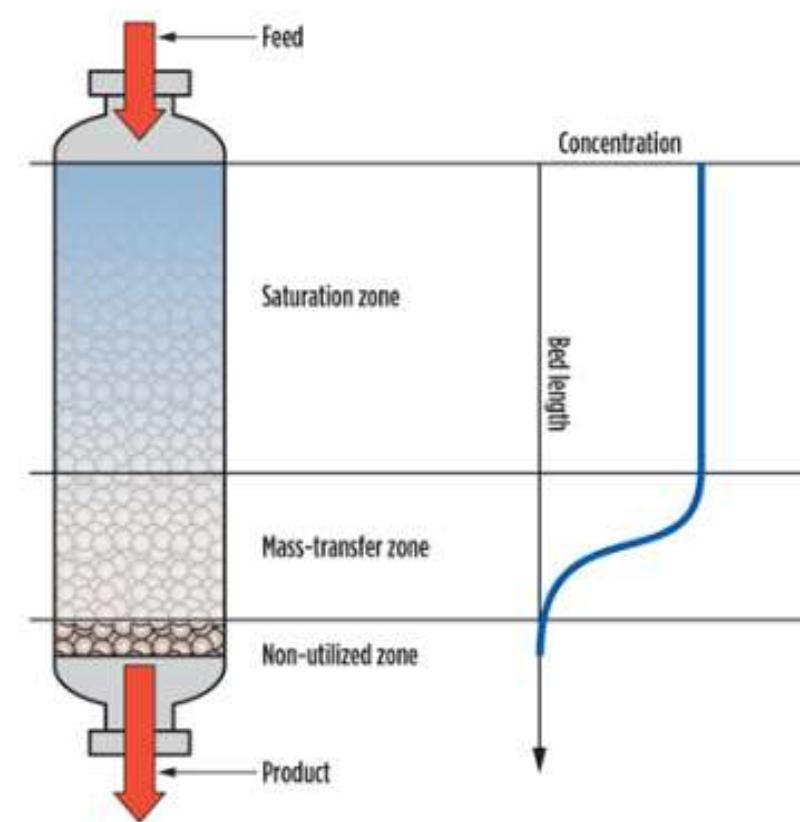
- A complete management of the production chain : from design up to test



Cryogenic plants main components

Adsorbers

- Adsorbers are used at ~80K and ~20K to remove small traces of impurities
- Molecular sieve or activated charcoal traps air impurities in the ppm range
- 1 single adsorber : stop of the plant for regeneration
or 2 adsorbers operating in push-pull for regeneration on-line



Cryogenic plants main components

Insulation system

- A vacuum vessel is used to install all cryogenic component
- Multilayer Insulation (MLI) is used to stop radiations
- Vacuum pumps are used to stop convection (vacuum $< 10^{-5}$ mbar)
- Material with low conductivity and long thermal path are used to reduce conduction



Cryogenic plants main components

Cold Compressors

- High efficiency cryomachines manufactured by AL-aT since 80's with new developments in 2009
- Technology based on magnetic bearings for high reliability (MTBF > 100 000 hrs)



- More than 40 cryomachines produced since new developments with flow rates from 10 g/s up to 220 g/s

Helium properties

A light gas

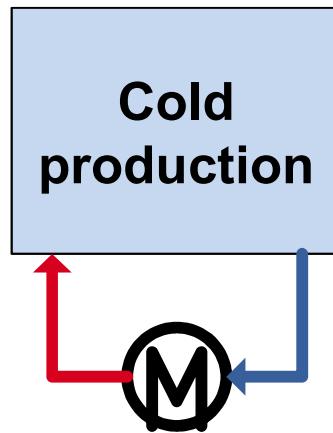
	Helium	Nitrogen
Gas density (1 bar, 300K)	0.16 kg/m ³	1.12 kg/m ³
Boiling temperature (1 bar)	4.2 K	77.3 K
Liquid density at saturation (1 bar)	125 kg/m ³	809 kg/m ³
Vapor density at saturation (1 bar)	16.6 kg/m ³	4.6 kg/m ³
Cp	5.2 J/(g.K)	1.0 J/(g.K)
Latent heat (1 bar)	20.7 J/g	199 J/g
Sensible heat (liq -> 300K)	1543 J/g	234 J/g

Risk of
Anoxia

Few thermodynamical concepts

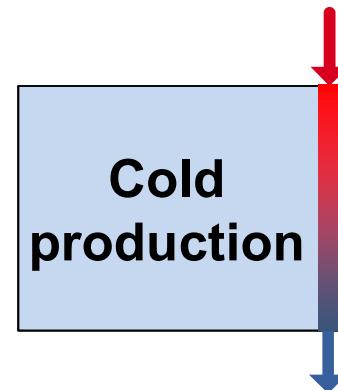
Refrigerator vs. liquefier

■ Refrigerator



Power is necessary at cold temperature

■ Liquefier



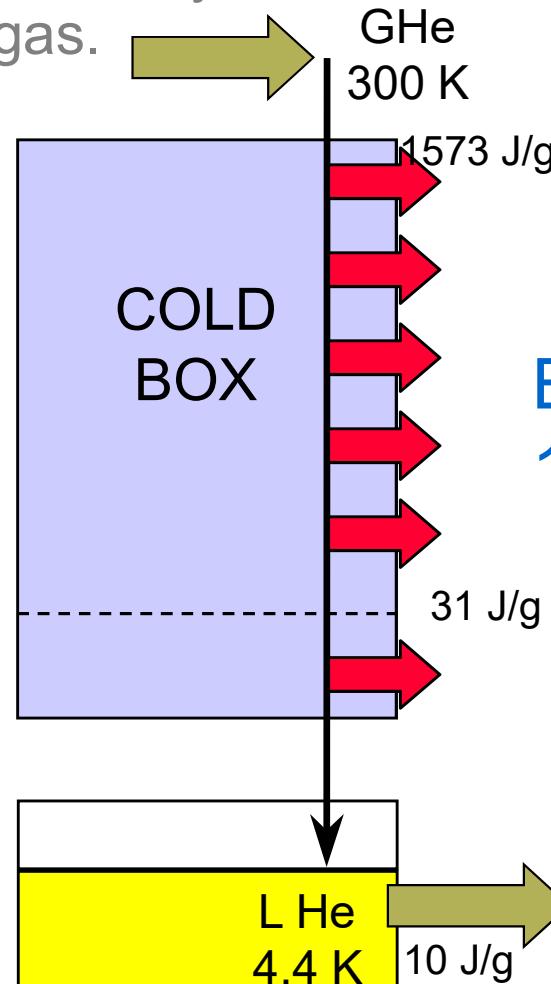
Continuous power is necessary between ambient temperature and cold temperature

Refrigeration vs. Liquefaction

■ Liquefaction :

→ To liquefy helium, extraction of specific heat from ambient temperature to 4.4K is necessary, then extraction from latent heat is necessary to liquefy the gas.

Large turbines are required to produce the cold required in all the temperature range

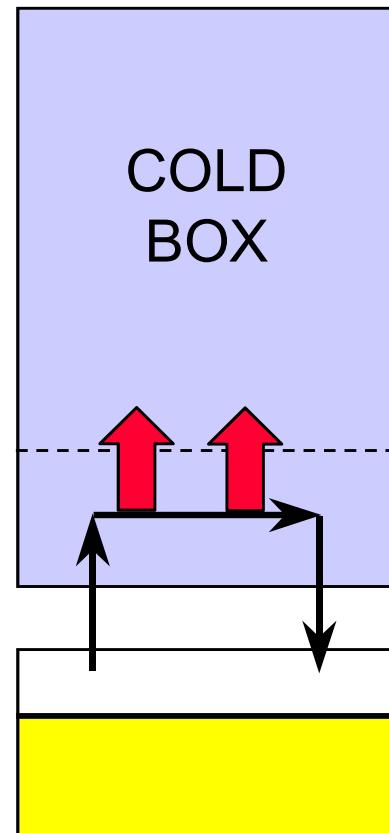


Energy to extract =
1563 J/g

Refrigeration vs. Liquefaction

■ Réfrigeration at 4.5K:

→ Extraction of latent heat at cold temperature



Large heat exchangers are required to transfer energy from vapour returns to helium supply

✓ Cold vapours returns

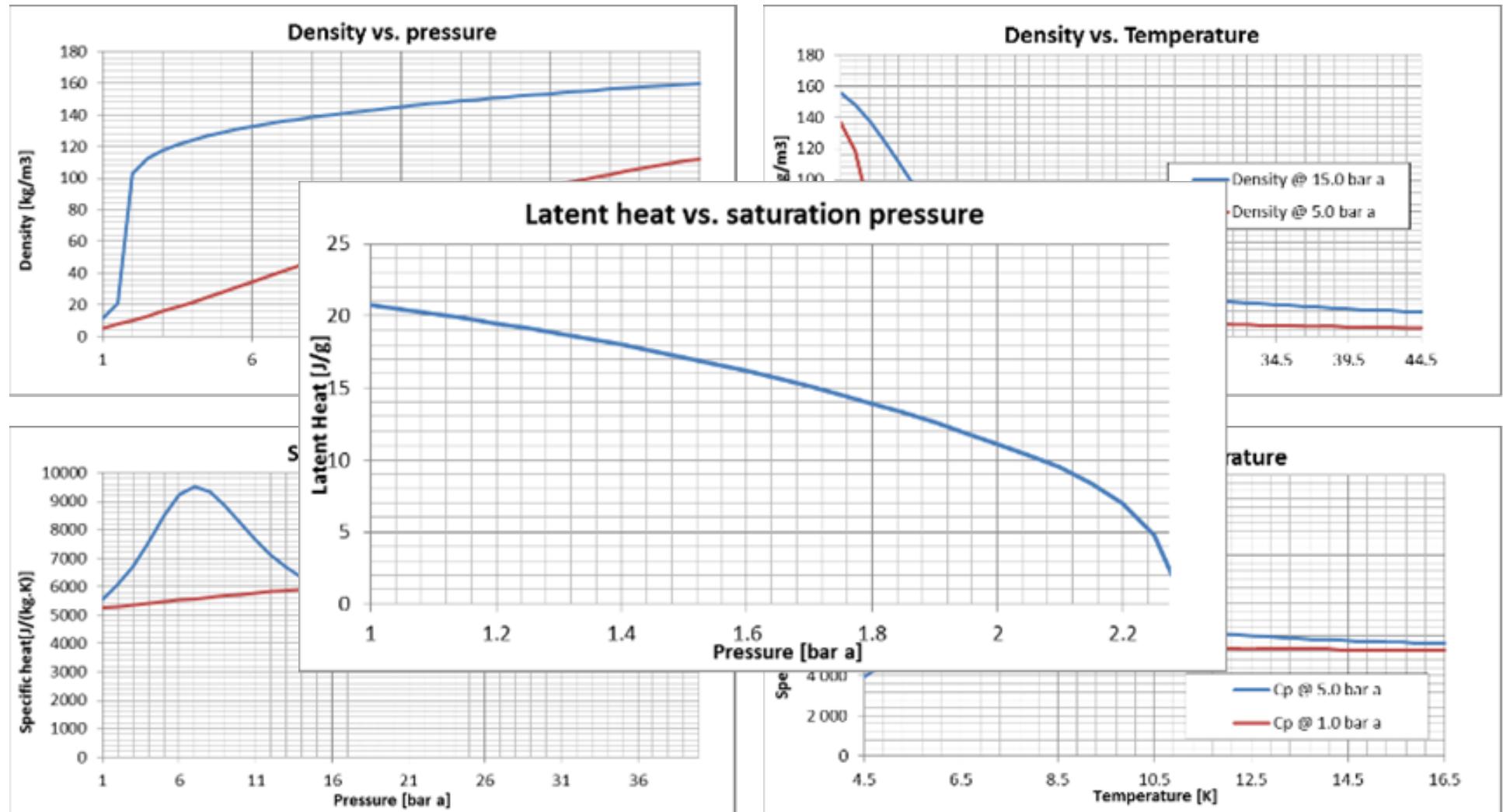
LHe
4.4 K

✓ Re-liquefaction

$$\text{Energy to extract} = 21 \text{ J/g}@4.4\text{K}$$

Helium properties

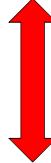
Particular properties...



Helium properties

Keep in mind !

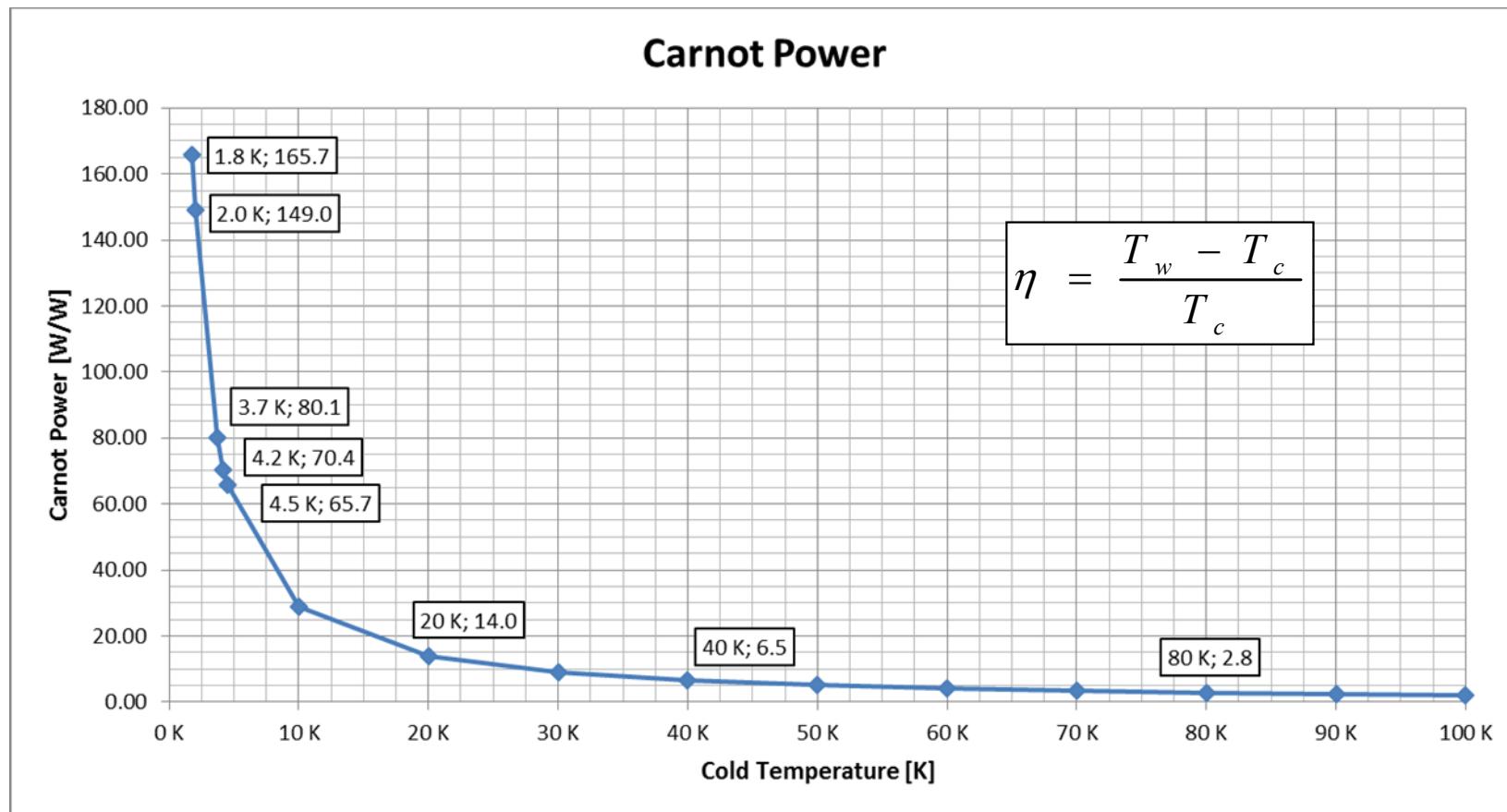
■ Liquid Helium:

- 1 g/s of Helium \Leftrightarrow $\sim 20 \text{ W} @ 4.4\text{K}$
 - 1 g/s of Helium \Leftrightarrow $\sim 30 \text{ L/hr}$
- 
- $20 \text{ W of heat inleak at } 4.4\text{K}$ vaporises
 $30\text{L/hr of liquid helium}$

■ Gaseous Helium:

- 1 g/s of Helium \Leftrightarrow $\sim 20 \text{ Nm}^3/\text{hr}$
- $C_p = 5.2 \text{ J/(g.K)}$ \longleftrightarrow $20 \text{ W of heat inleak warm up}$
 $1\text{g/s of } \sim 4\text{K}$

Specific power or Carnot efficiency



- Ideally, 70W at 300K are necessary to produce 1W at 4.2K.
- In practical, between 250 and 400 W are necessary to produce 1 W at 4.2K. The larger the installation, the higher the efficiency.

Summary

Helium refrigerators and liquefiers

- Standard helium liquefiers available from 15L/hr to 650 L/hr
- Standard helium refrigerators available from 100W to 1000 W @ 4.5K
- Specific customized plants for helium liquefiers larger than 650 L/hr and refrigerators larger than 1000 W @ 4.5K
- Several references at 1.8K or 2.0K with state of the art cold compressor technology.

End of the presentation

