STIRLING CRYOGENICS

since 1954

Hydrogen Liquefaction & Zero-BOG Systems

Company Profile

- Home base in Eindhoven, The Netherlands
- Successor of Philips Cryogenics; in business since 1954
- Sales offices in USA, Germany, Sweden and Italy
- 55+ staff
- Worldwide agency network with 25 agents
- Worldwide service network with 20 service engineers
- More than 4,000 cryogenic systems in operation in more than 100 countries

- Sister company Hysytech Srl. Turin, specialized in green chemistry and gas purification

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Core Products: Stirling Cryogenerators

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- Range of Stirling Cryogenerators:
  on-site production of 18 to 200K cooling power
- Used to (re-)liquefy cryogenic gases like N_2, O_2, CH_4, Ar and H_2
- Used in closed loop cryogenic cooling systems for applications such as superconductivity, space-chambers, magnet cooling, etc.

1-Stage
50 to 150 K

2-Stage
18 to 60 K

Markets Served

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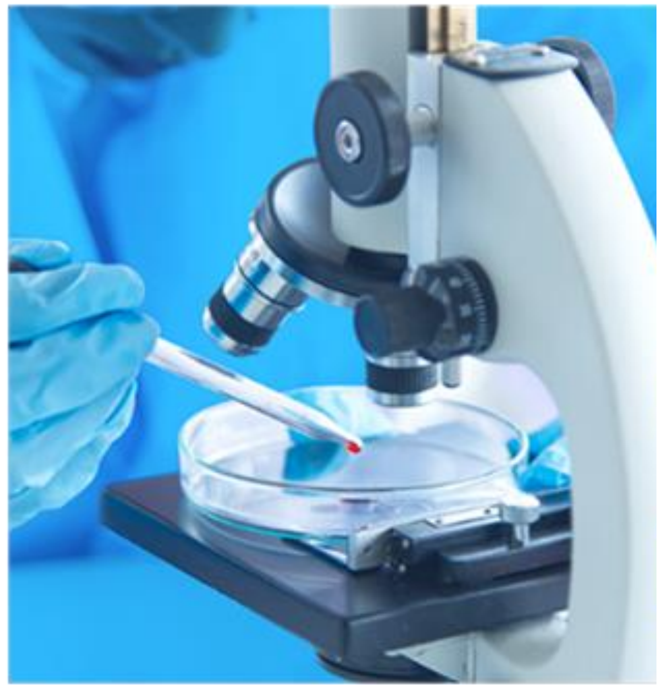
LNG

LH2

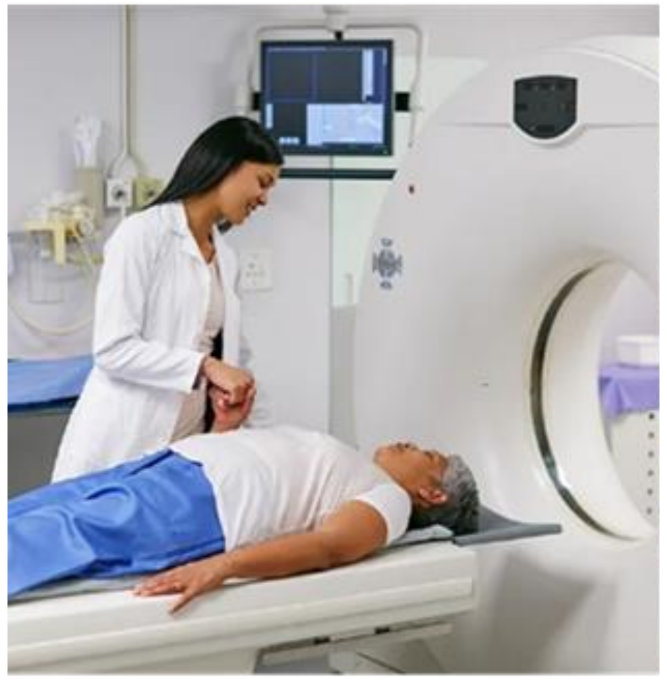
Aerospace

Food & Beverage

Research

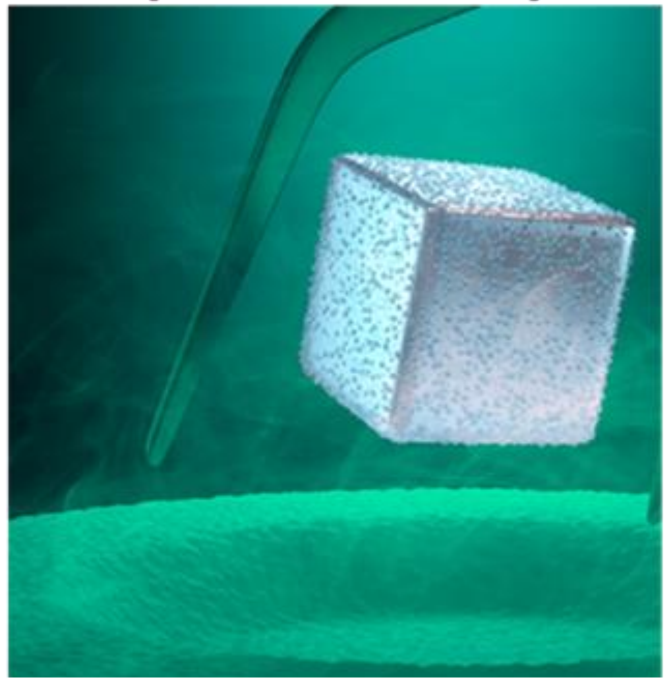


Healthcare

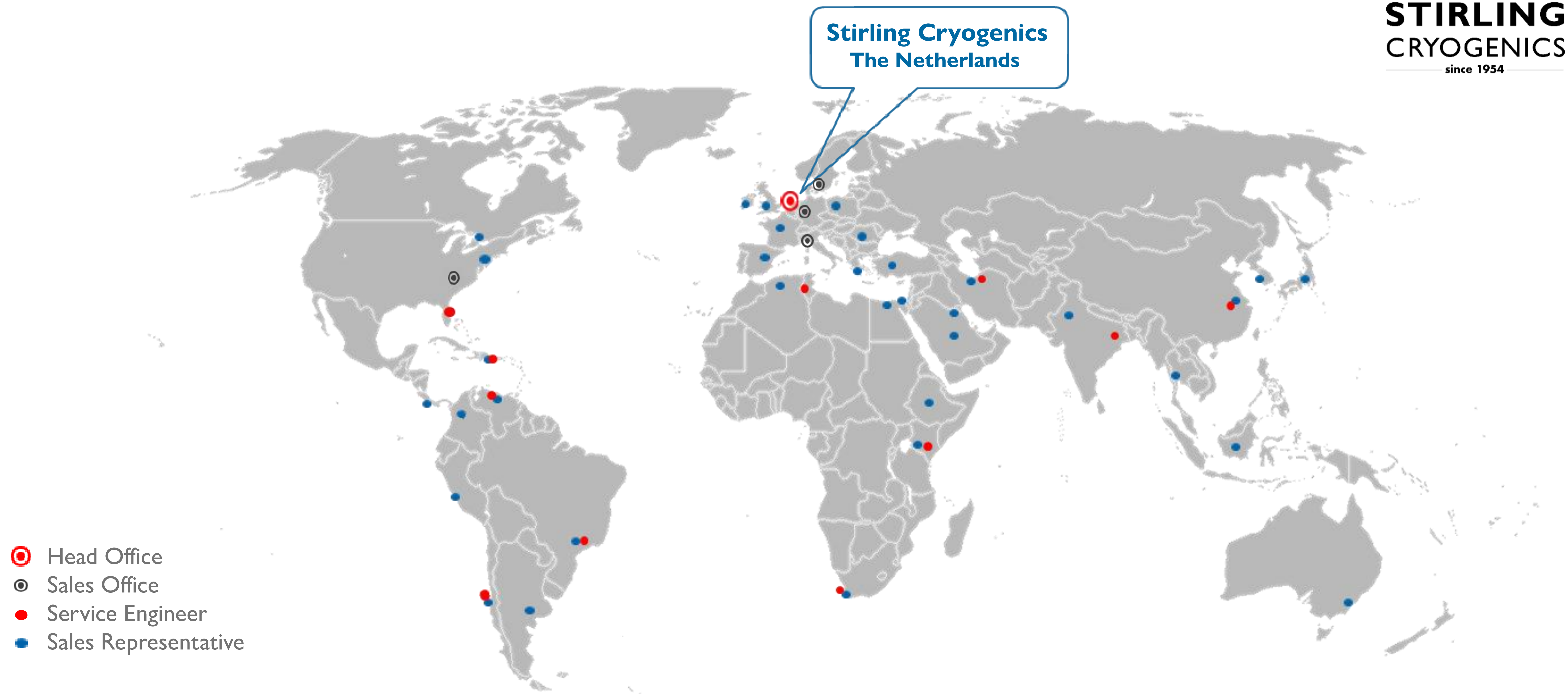


Biostorage

Superconductivity



Sales and Service Network



Stirling Hydrogen Liquefaction System Features

- The range of capacities offered are from 5.5 up to 2,000 kg/day Zero-BOG from 12 to > 350 kg/day, using multiple Cryogenerators for larger capacities
- Larger systems are containerized as standard
- To allow for future growth, systems can be supplied for current size requirement, but prepared for future growth, allowing a later addition of Cryogenerators and extension of liquefaction capacity

Stirling Hydrogen Liquefaction System Features

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- Cryogenerators can be stopped and started regularly, allowing capacity control when less GH_2 is available due to wind or solar power fluctuations.
- As GH_2 production increases, Cryogenerators are restarted
- Additionally, liquefaction capacity can be varied by rpm depending on GH_2 supply
- Cool-down time to liquefaction from warm start is 20 minutes, less after short stops

Stirling Hydrogen Liquefaction Capacity

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- Liquefaction temperature depends on chosen liquid pressure while Stirling cooling power depends on liquefaction temperature
- Higher liquefaction pressure results in higher production capacity and better kWh/kg ratio
- No LN_2 required: a Cryogenerator internally creates cooling power at 80K level
- Ortho-Para conversion will create heat and evaporated GH_2.
  Stirling LH_2 liquefaction systems have integrated catalysts causing the O-P conversion to be immediate.
  This assures the delivered LH_2 is fully para hydrogen.
- In cases the Cryogenerators are in contact with H_2, they are built according ATEX

Hydrogen Liquefaction Concept

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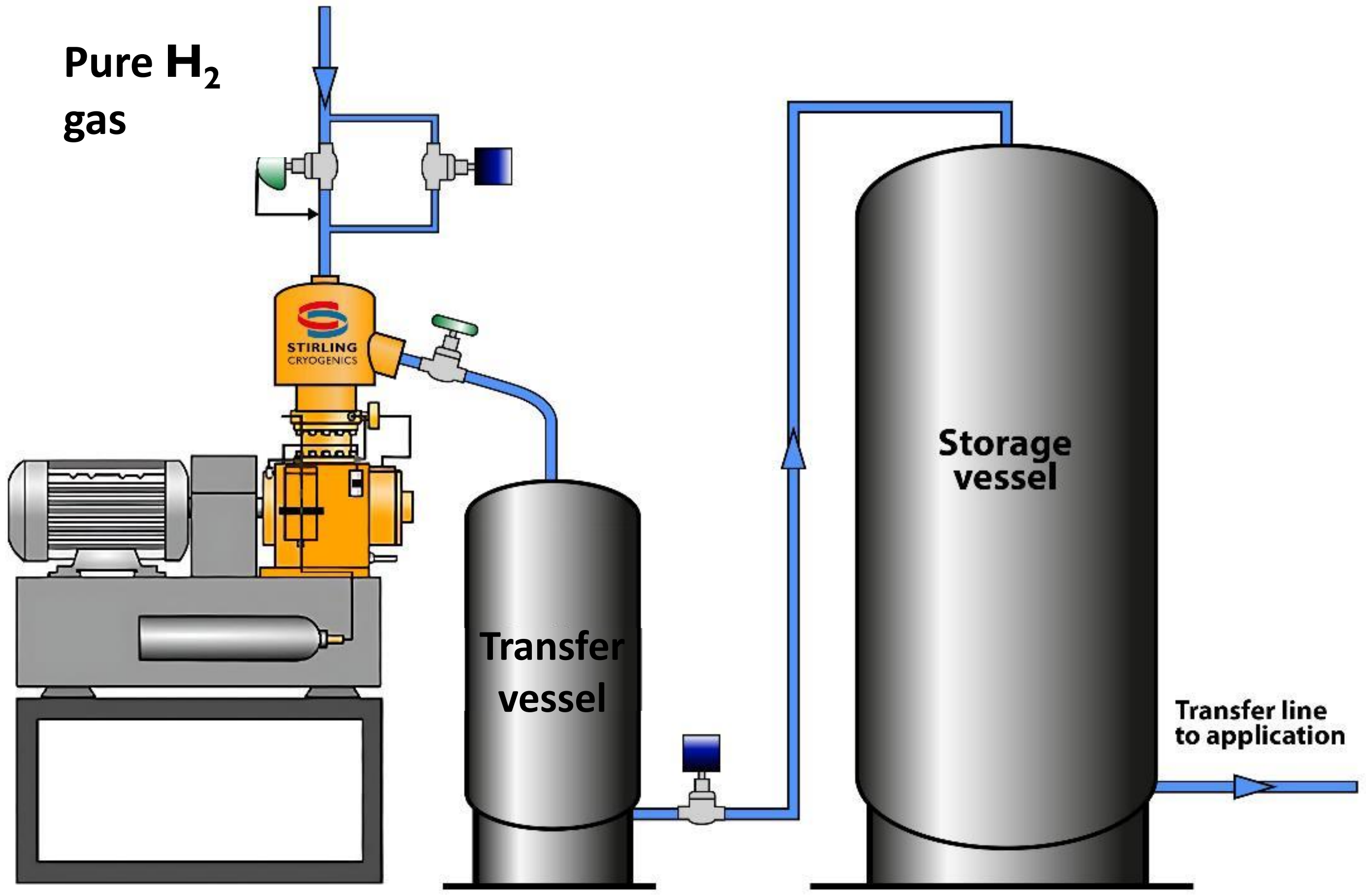
- H_2 gas is fed from a source to the Cryogenerator and internally pre-cooled at 80K in the first stage
- Liquefaction is achieved by the second stage cold head
- Ortho-Para conversion by catalyst inside the cold head
- Para LH_2 produced is stored in a transfer vessel
- When full, the inlet gas pressure reducing valve is by-passed, increases the transfer tank pressure. The bottom LH_2 valve opens, creating a pump free transfer of LH_2 into a main storage vessel 2-3 times a day



Hydrogen Re-Liquefaction in Stirling Cold-head

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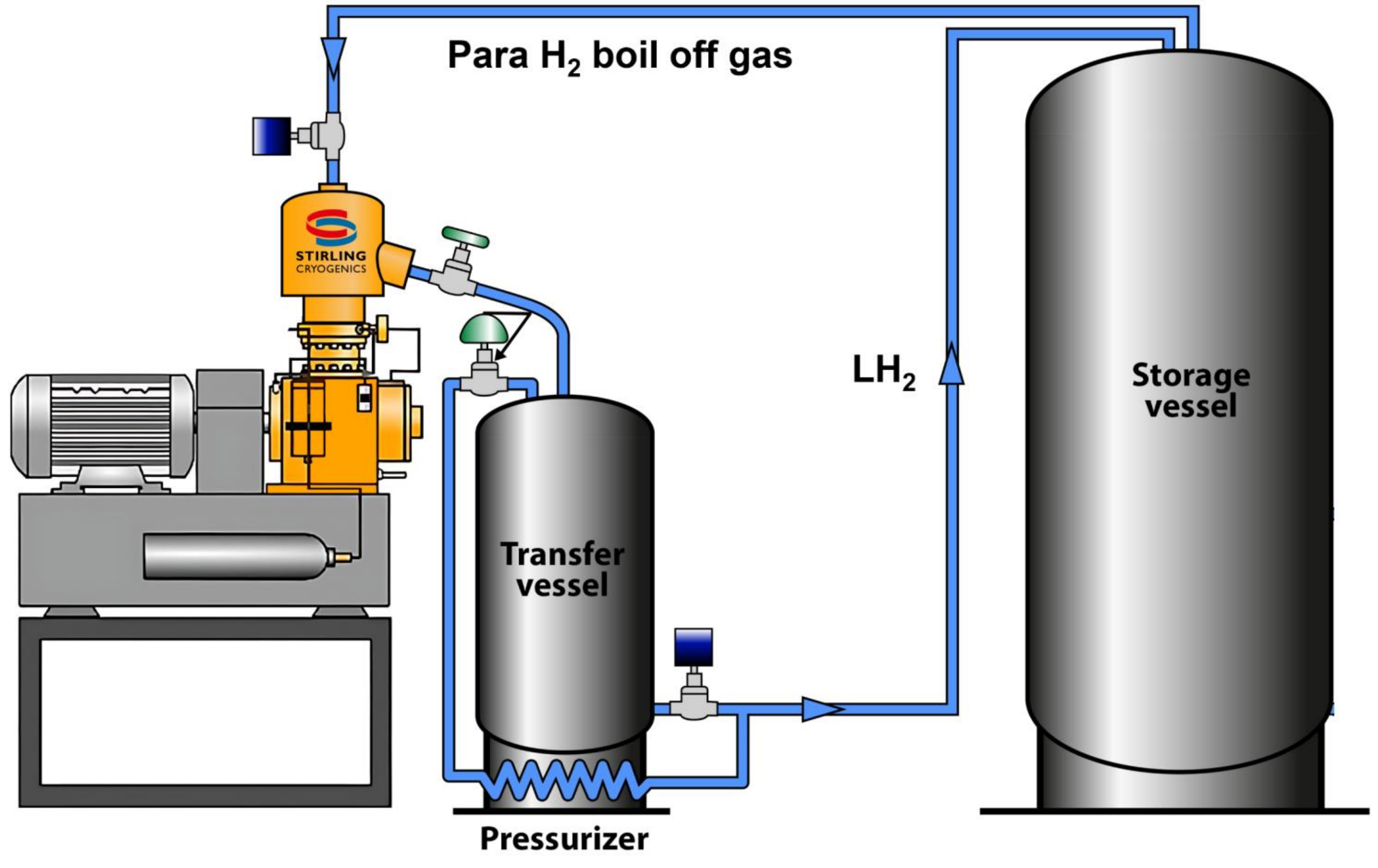
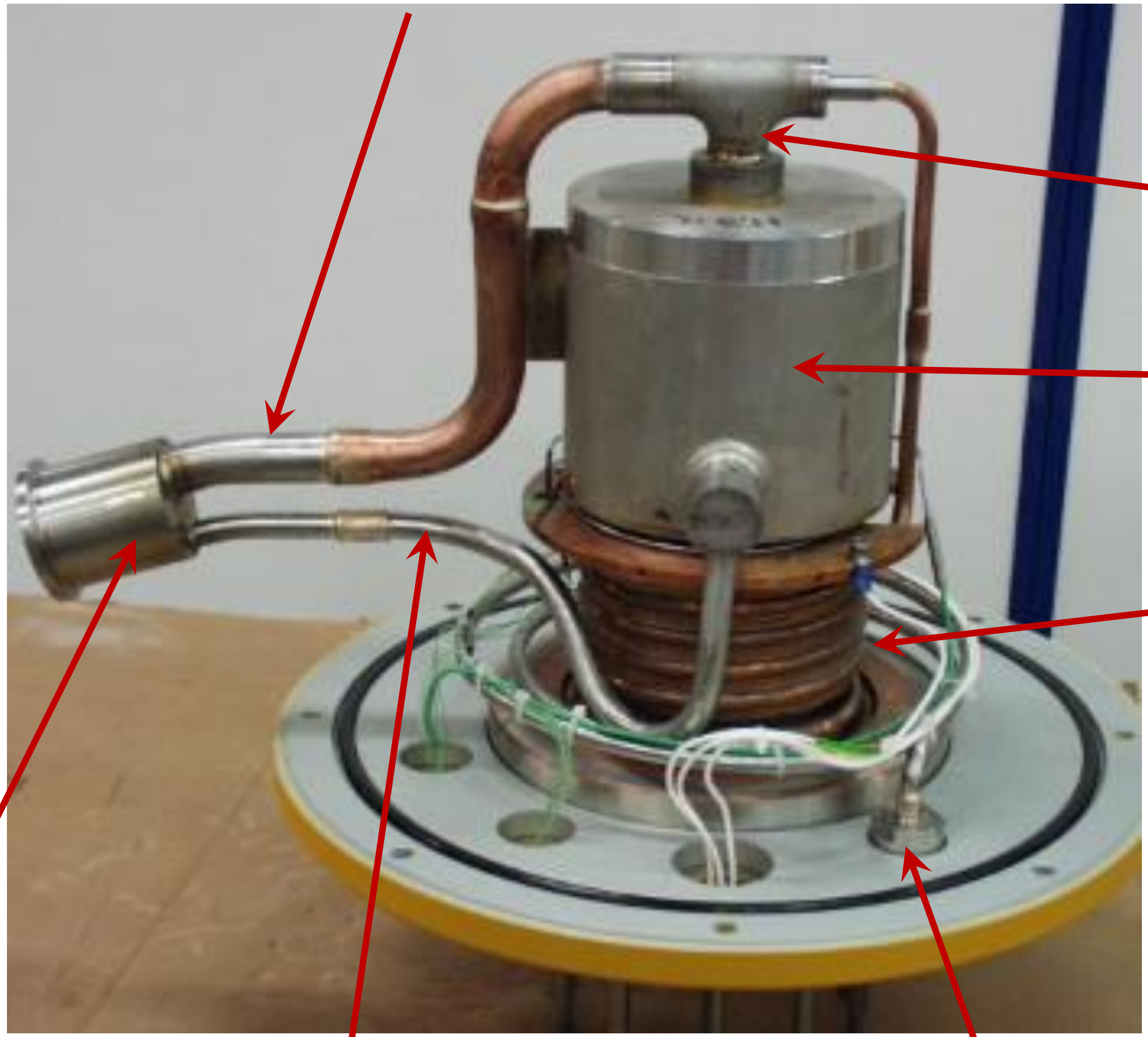
- Boil-off gas, being 100% para H_2 from the storage vessel is fed to the Cryogenerator
- Re-liquefaction by second stage cold head no 80K pre-cooling required
- LH_2 produced is stored in a transfer vessel
- When full, gas feed valve closes and bottom valve opens
- LH_2 is pressurized and transferred to the storage vessel batch wise 2-3 times per day



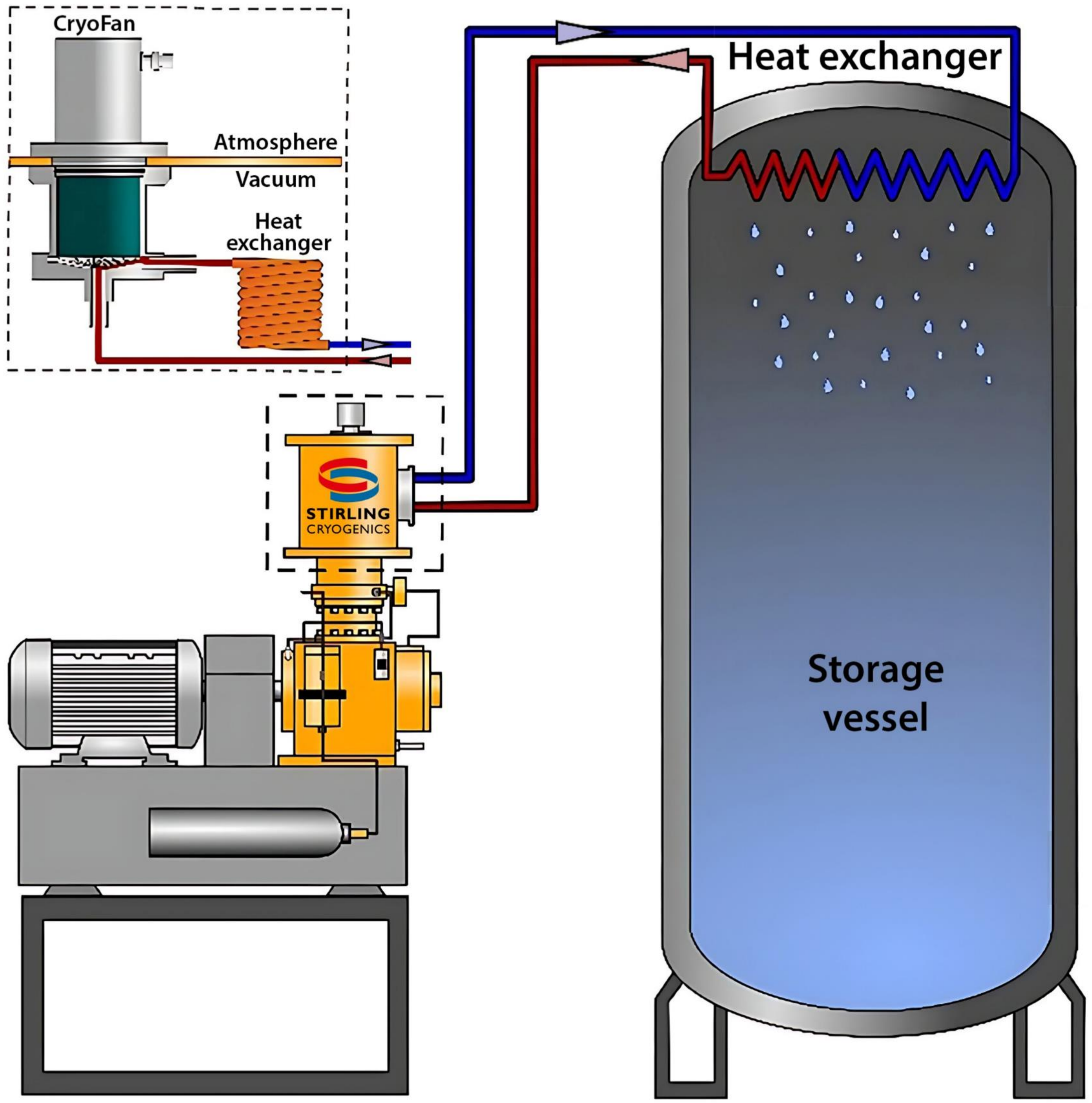
Hydrogen Liquefaction inside Stirling Cold-head

- 1-Cylinder, 2-Stage Cold Head for GH_2
  Pre-cooling of inlet gas at first stage
- Liquefaction of cooled gas
  in second stage
- Re-liquefaction of boil-off gas
- Two phase flow pipe connection
- Liquid produced flows into transfer vessel
- From here batch-wise push over to main vessel



Hydrogen Re-Liquefaction in a vessel

- In case it is preferred to re-liquefy the H_2 gas inside the vessel, e.g. for classification reasons, this can be achieved by a flow of cold He coming from the Cryogenerator.
- The He flow is driven in a loop by a Stirling CryoFan, thermally connecting the Cryogenerator to the heat-exchangers in the tank
- A heat-exchanger @ 20K inside of the LH_2 vessel will re-liquefy the GH_2.
- A second heat-exchanger can be placed in the liquid, so this is cooled to prevent evaporation
- With the Cryogenerator in a safe area, no ATEX is required reducing the ATEX zone



Large Set-up Hydrogen Liquefaction

- 6x 4-Cylinder, 2-Stage Cryogenerators
- Individual start/stop and connection to the main flow by valves

Hydrogen Liquefaction

- Picture of two stage, 4-cylinder Cryogenerator type SPC-4T
- Vacuum insulated cold head
- At the front the boil-off gas inlet and liquid outlet connections

Stirling Cryogenerator

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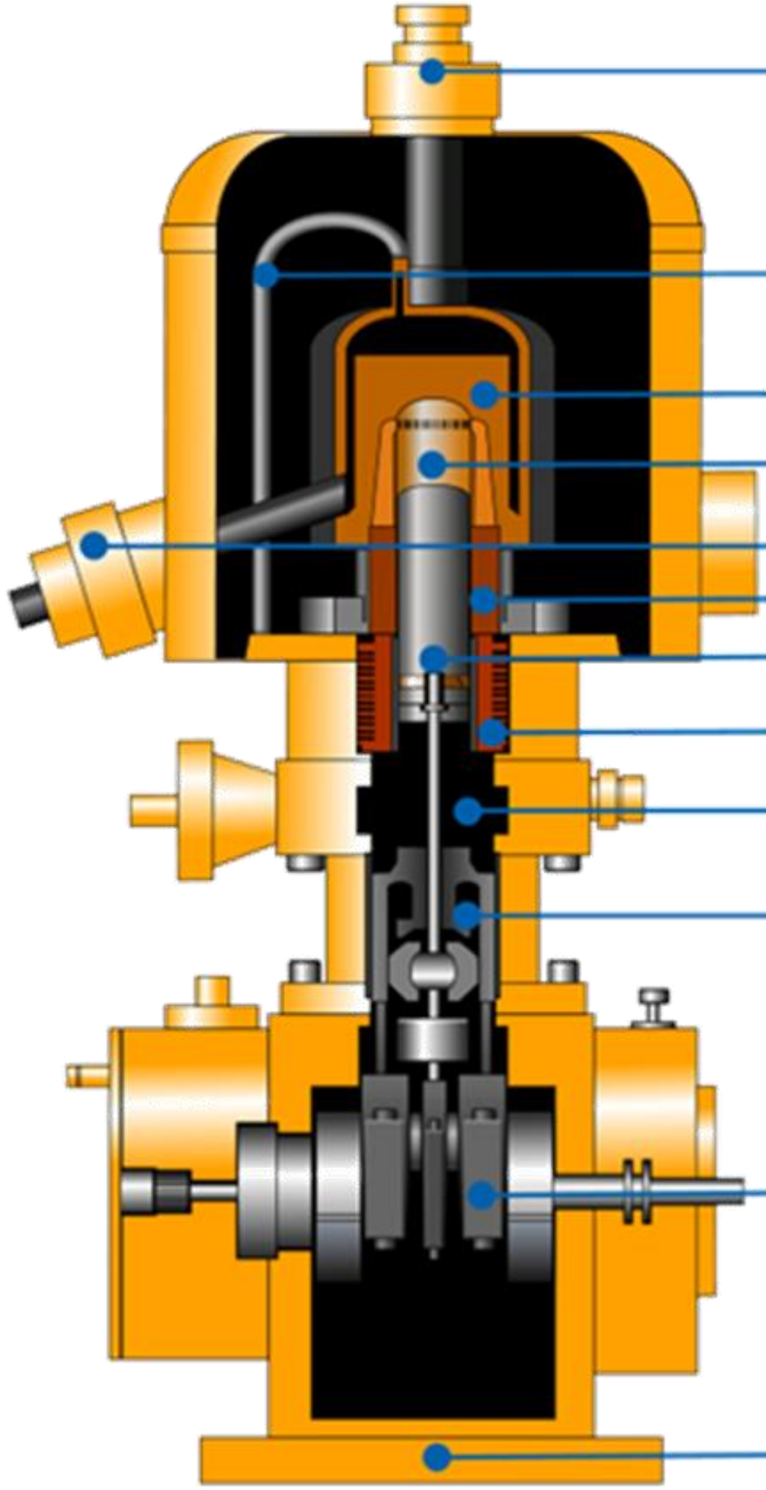
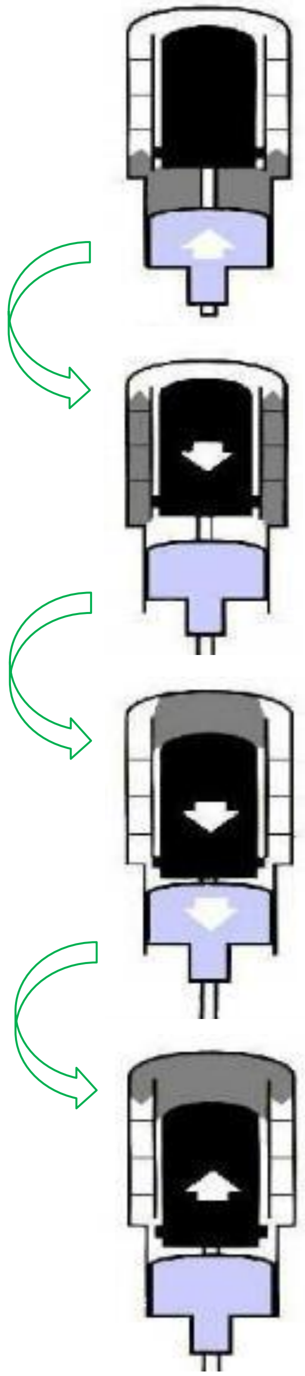
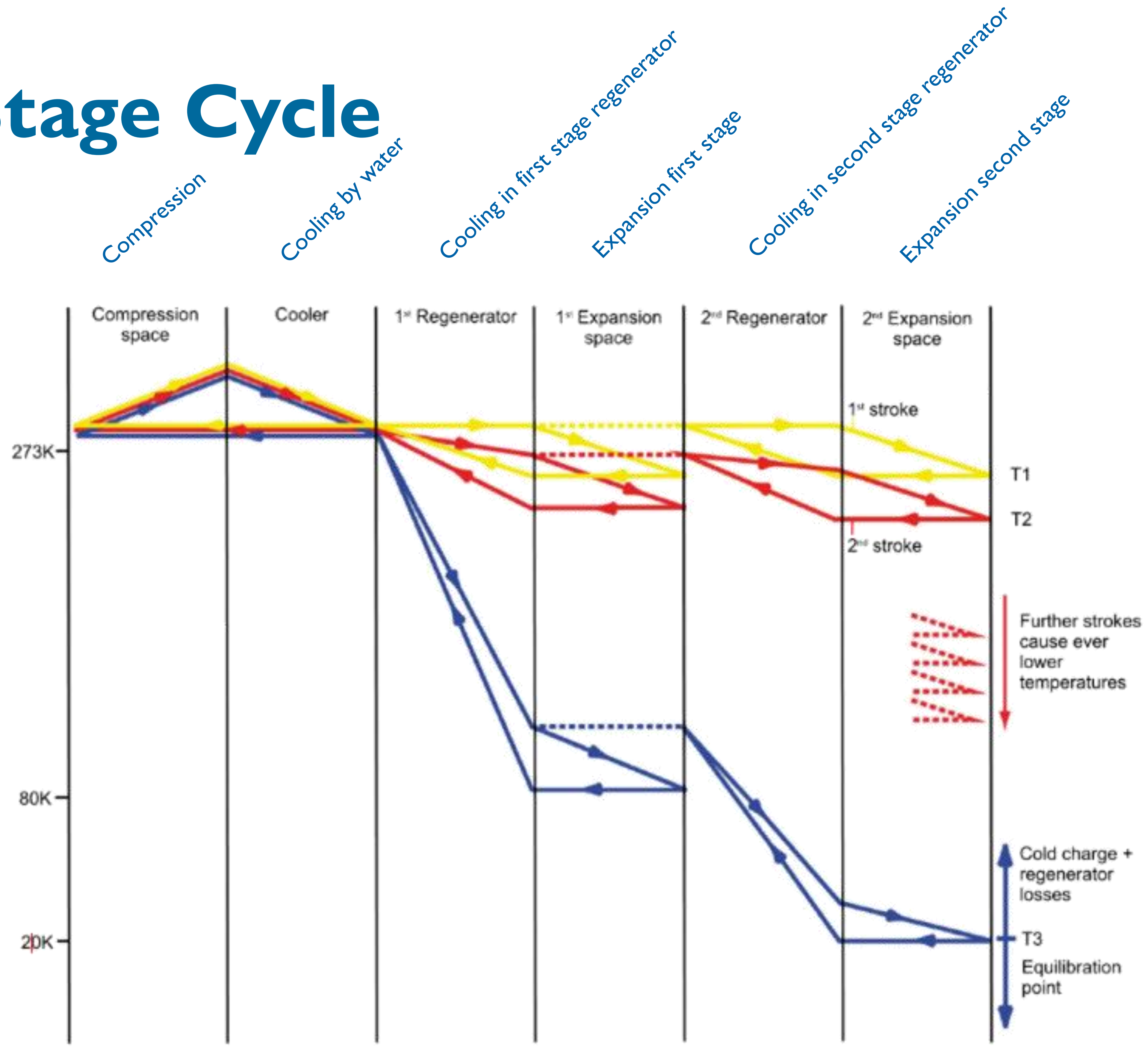


Stirling Thermodynamic 2-Stage Cycle



	Step 1: Compression Helium gas is compressed Gas temperature rises
	Step 2: Cooling Compression heat is removed; The helium gas is pre-cooled in the two regenerator before expansion starts
	Step 3: Expansion By expansion, energy is extracted from the gas and thereby the temperature goes down thus cooling the cold head
	Step 4: Displacement Gas is displaced back to the compression space; the cold from the helium gas is stored in the two regenerator during displacement to step 1



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