When extremely low temperatures enable human space flight, fundamental physics and global monitoring
■ Air Liquide Advanced Technologies in Brief
■ Introduction to Cryogenics
■ Cryogenics in Space today
■ Other Cryo technologies necessary for **Human in space** and available on ground
Since 1962, AL-aT is the high technology subsidiary of the Group dedicated to innovation and industrial solutions in the field of cryogenics and gas engineering.

A fast cycle from the innovative idea to the market since all competencies/capabilities are available in Sassenage:

- R&D
- Design
- Manufacturing
- Factory Test
- Installation & start-up
- After Sales

Around 700 employees
About 140 m€ turnover in 2015

AL-aT's site in Sassenage, France
CRYOGENICS IN SPACE

■ What is it? Cryogenics is a set of technologies and know-how needed to reach very low temperatures,
  ▪ Usually below the permanent gases boiling point, i.e. around -180°C = 93K
  → Initially developed for air liquefaction in order to separate O₂ & N₂

■ For what purpose?
  ▪ Liquefaction, purification, handling and storage of most gases (O₂, N₂, H₂, Ar, Xe…)
  ▪ Many space applications:
    ▪ Launchers (A5, Delta, HII,…)
    ▪ IR focal planes cooling
    ▪ food and biological samples storage
  ▪ But also:
    ▪ Healthcare
    ▪ Submarines air purifying
    ▪ Cryo milling, Superconductivity, ..and many others….

(0 K = -273° C)
2 - Cryogenics in Space today

CRYO FOR SPACE FLIGHT
CRYO FOR GLOBAL MONITORING
CRYO FOR FUNDAMENTAL PHYSICS
215 Launches for Ariane during 50 years more than 360 tanks delivered

**Main Storage**

- **LOx/LH₂ tank**
  - 25 T of LH₂ / 150 T of LOX
  - Ø 5.4 m ; h 25 m
  - Mini Th. = 1.3 mm

**Cryogenic arms for ESC**

- **LOxTank**
  - 12 T of LOX
  - Ø 2.6 m ; h 2.8 m
  - Mini Th. = 1.4 mm

**Fluids liquefaction, feeding & Storage**

- **Liquid He Tank**
  - 166 kg of LHe
  - Ø int 1.4 m
  - Mini Th. = 4.3 mm

- **LH₂ Tank**
  - 2.7 T of LH₂
  - Ø 5.4 m ; h 3.5 m
  - Mini Th. = 1.6 mm
Cryogenic fluid behavior prediction is at utmost importance to optimize the design of future launchers and any reignitable spacecraft.

For more than 10 years AL is developing simulation tools (fluid dynamics, temperature, pressure) correlated with µg tests such as magnetic levitation, 0g flights or specific launch experiment (Cryofenix)
CRYO FOR GLOBAL MONITORING

Earth Observation,
Weather forecast
Fire Detection
Understanding of climate change:
CO2, Biomass, vegetation

1 FM delivered,
23 FM’s to follow

Cooling of infra red sensors
High Stability, High reliability
Very low micro vibrations

3W@50K Pulse Tube Cooler
Survey of the CMB by PLANCK (2009 -2011)

ESAB Mission

Dilution of $^3$He into $^4$He at 4K / 20 b creates cold from 1.6 K to 0.1 K

- Launch lock mechanism using shape memory alloy
- Thermalization of all sensor wires from 1.6 K down to 0.1K
- Passive damping of temperature fluctuations with rare earths
- 4 onboard storage spheres @300b / 51 L
  - 2.5 year autonomy (extended)
  - 20,000 hours continuous operation: no failure!
Air Liquide’s contribution to Herschel ESA mission

- Detailed design & manufacturing of:
  - He I & He II tanks (He II is superfluid, H I is normal)
  - Vapor cooled thermal shields
  - Thermal links
  - Piping
  - All assembled in class 100

2400 L superfluid He tank
3.5 year autonomy
1.6K during all the mission
Cryogenic storages (below -80°C or 190 K) are mandatory to perfectly preserve scientific biological samples or food for long duration mission (>3 months).

Example for in the International Space Station (ISS):

- **Transportable cryogenic freezer at 80 K (-183°C)** to store more than 1000 biological vials
  - 11 liters, cooled by a Stirling machine, glove box compatible

- **MELFI freezer at 190 K (-80°C)**
  - Science storage (from +4°C to -80°C)
  - Turbo Brayton cooler built by Air Liquide

10 years in orbit, 3 freezers, 120,000h of cumulated lifetime
3 - Cryo technologies available for Human in space

CABIN AIR PURIFICATION
LONG RANGE VEHICLES PROPELLANT TANKS
ENERGY STORAGE
ENERGY PRODUCTION
SUPERCONDUCTIVITY
CABIN AIR PURIFICATION

- Based on a Cryogenic cristalyzer
  - The air cabin can be purified from CO\textsubscript{2} and VOC at very good level when passed onto a heat exchanger cooled down to 110 K,

- Case of sub-marine atmosphere purification
  - Prototype with 2 large pulse tubes, adequate for 8/10 crew members
  - Provides air at 50 ppm CO\textsubscript{2}
  - Releases pure CO\textsubscript{2} to be regenerated by Sabatier reactor for example

- Application to a space system
  - For 5 crew members 3 to 5 machines twice bigger than our current earth observation PT would be necessary

Cryogenic crystalizer breadboard for 10 crewmembers

12 W@110 K, 200 We
CRYO FOR LONG RANGE VEHICLES PROPELLANT TANKS

- Liquid H₂ (20 K) boils-off
- Oxygen being at 90 K, can be cooled passively to avoid boil-off losses
- LH₂ loss can be reduced with cryocoolers (ZBO concept) for long-term mission spacecraft.

10 m³ LOx tank
(NASA exploration scenario)

40 m³ LH₂ tank

About 2 kWe

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ENERGY STORAGE: AN EXAMPLE FOR THE MOON

150K

H₂ Passive cooling

H₂ Liquefaction

150K

O₂ Passive cooling

O₂ Liquefaction

H₂O back to electrolyzer

Power available

Heat available @ 70°C

Moon base photo: Courtesy ESA
HYDROGEN ENERGY STORAGE PLANT

- Plant prototype working in Sassenage since July 2015
- 4-20 MWh/year (1.5 kW PEMFC)
ENERGY PRODUCTION : ONBOARD AND ON A BASE

- Solar concentration and Stirling engines

Stirling à Radio-isotope NASA

Solar Concentration Stirling INFINIA
600K – 300K

Cryogénérateur Miniature Pulse Tube

5kW 300K-77K

LN2 tanks energy recovery
When very high electrical power density systems are required, like intense magnetic fields, it is necessary to cool down some electrical parts below a given critical temperature $T_c$ in order to suppress any Joule dissipation.

Superconductive materials have been discovered working under different $T_c$ levels,

- **Liquid Helium** for CERN-LHC
  NiTi magnet at $T_c < 4$ K with

- **Sub-cooled liquid Nitrogen** for power transportation (Long Island Power Authority’s project)
  YBaCuO/BSCCO cables at $T_c < 70$K

- **Helium gas or liquid Hydrogen** for MgB$_2$ cable at $T_c 20$K at CERN

**Cryo-cooler**
- Helium refrigerator
- Turbo-Brayton
CONCLUSION

- Cryogenic temperatures are already well mastered for:
  - Space launchers propulsion
  - Infrared detectors cooling down to 50mK for space astronomy
  - Long term storage of critical supplies (O2, H2, etc…), food and biological samples

- Some ground based technologies are existing and suitable for space
  - Hydrogen power plant (production, storage, electricity)
  - Cryogenic Air purification systems
  - Energy storage and recovery (Electrolyser, liquefier, FC,..)
  - Cable cooling for superconductivity

- Cryogenics are key technologies for Human in space

- Air Liquide Advanced Technologies is ready to continue developing and bringing them into space
Advanced Technologies
Thanks for your attention

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