Advanced Technologies

When extremely low temperatures enable human space flight, fundamental physics and global monitoring

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PRESENTATION OUTLINE

- 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

AIR LIQUIDE ADVANCED TECHNOLOGIES IN BRIEF

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

Space

Gas & Cryogenics

Aeronautics

New Energies

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 **-180ºC** =93K
  - → Initially developed for **air liquefaction** in order to separate O_2 & N_2
- **For what purpose?**
  - Liquefaction, purification, handling and storage of most gases (O_2, N_2, H_2, 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

CRYO FOR SPACE FLIGHT

Main StorageLOx/LH_2 tank

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

LH_2 Tank

- 2,7 T of LH2
- Ø 5.4 m ; h 3.5 m
- Mini Th. = 1.6 mm

215 Launches for Ariane during 50 years more than 360 tanks delivered

Fluids liquefaction, feeding

Liquid He Tank

- 166 kg of LHe
- Ø int 1.4 m
- Mini Th. = 4.3mm

LOxTank

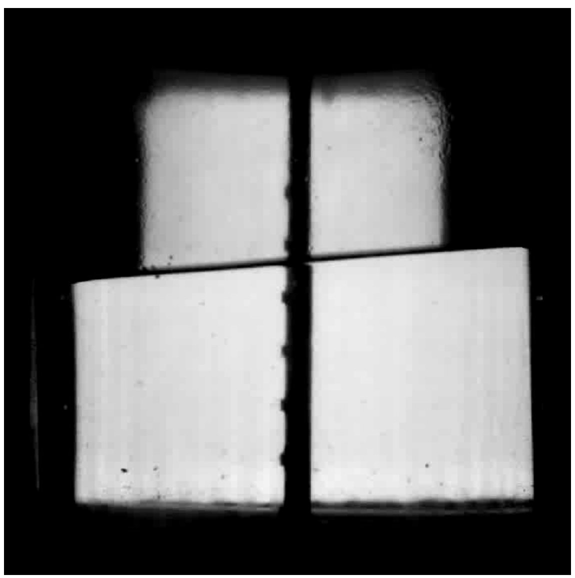
- 12 T of LOX
- Ø 2.6 m ; h 2.8 m
- Mini Th. =1.4 mm

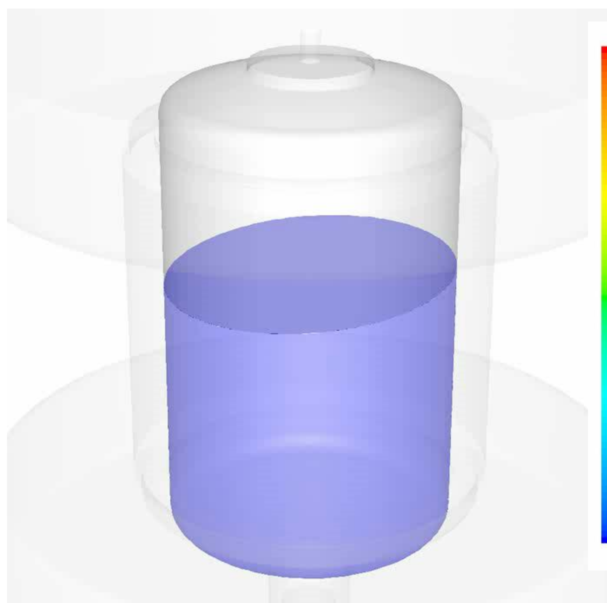
Cryogenic arms for ESC

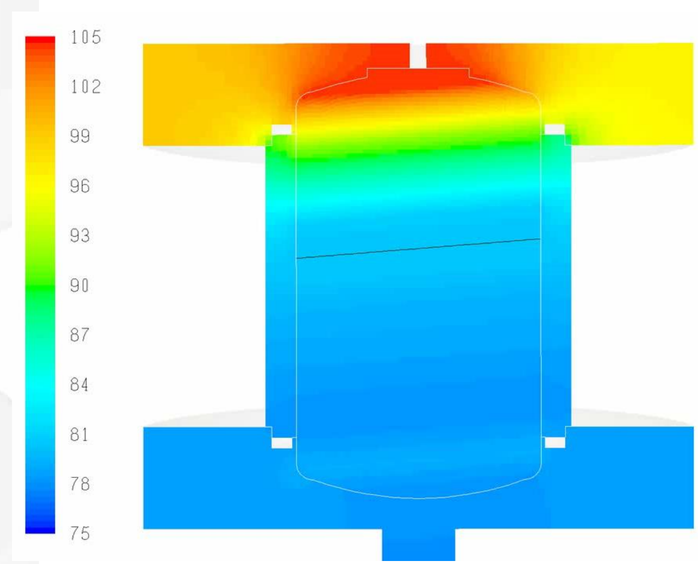
& Storage

CRYO FOR SPACE FLIGHT: FLUIDS IN µGRAVIT

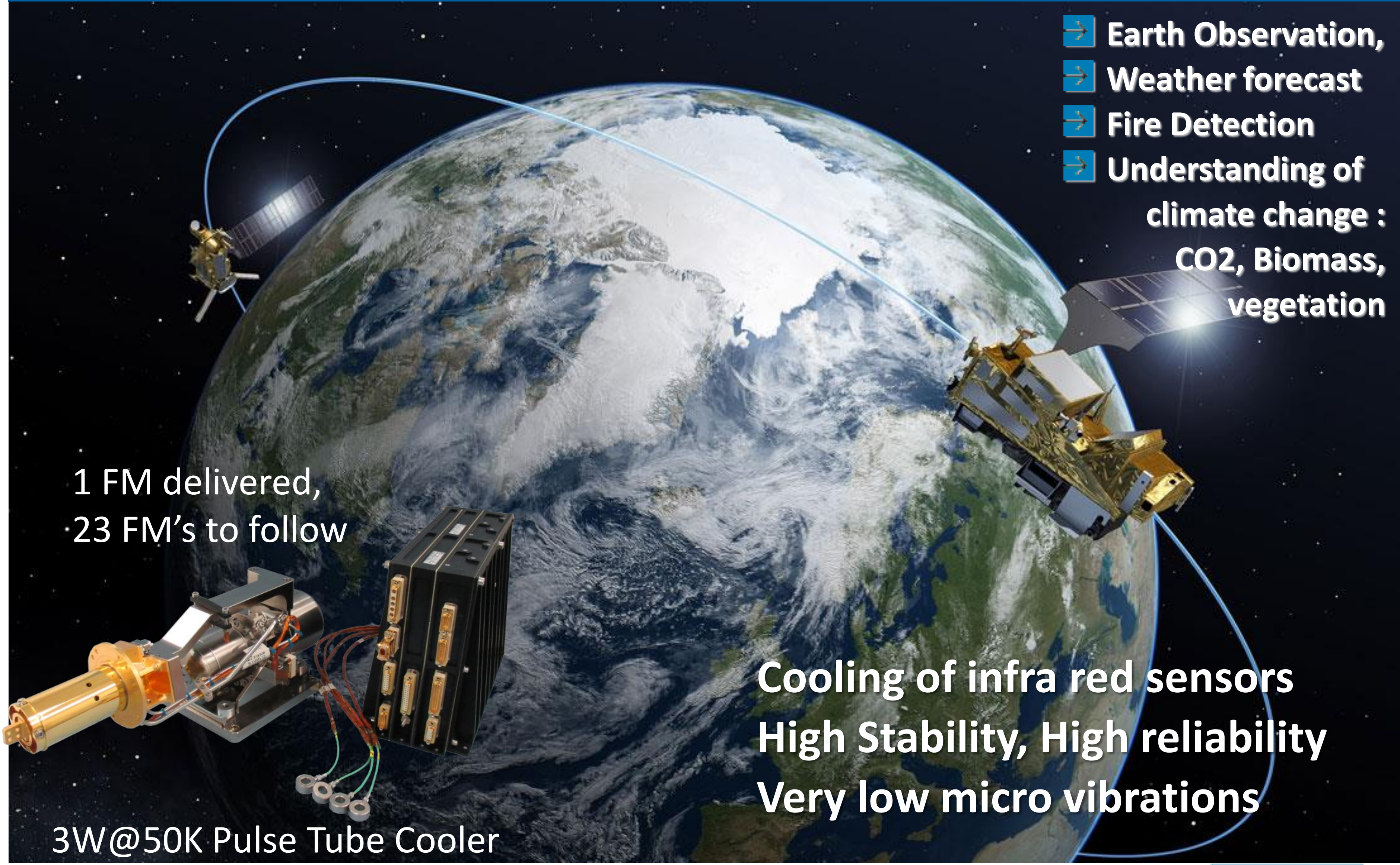
- Cryogenic fluid behavior prediction is at utmost importance to optimize the design of future launchers and any reignitable spacecraft.
- For more than 10 years AL is developing simulation tools (fluid dynamics, temperature, pressure) correlated with µg tests such as magnetic levitation, 0g flights or specific launch experiment (Cryofenix)



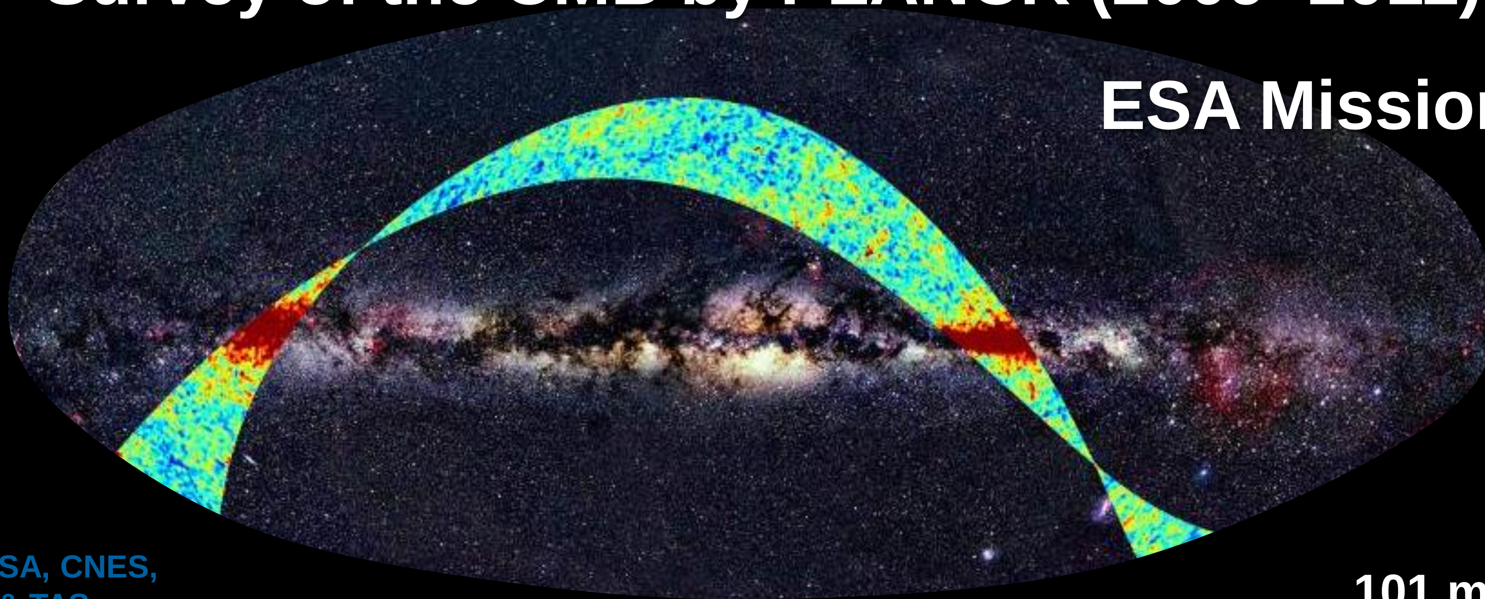




CRYO FOR GLOBAL MONITORING



Survey of the CMB by PLANCK (2009 -2011)



ESA Mission

Courtesy ESA, CNES, CNRS & TAS

101 mK

Dilution of ^3He into ^4He 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!

CRYO FOR FUNDAMENTAL PHYSICS IN SPACE: HERSCHEL

Air Liquide's contribution to Herschel ESA mission

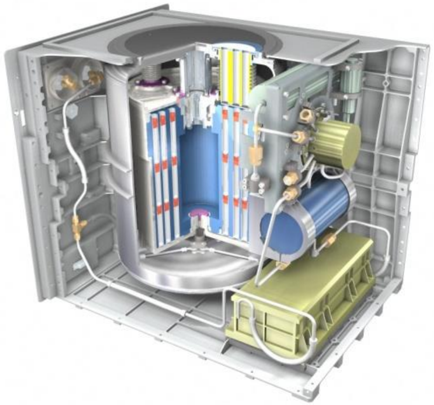
- Detailed **design** & **manufacturing** of :
  - He I & He II tanks *(He II is superfluid, H I is normal)*
  - Vapor cooled **thermal shields**
  - **Thermal links**
  - **Piping**
  - All assembled in class 100

2400 L superfluid He tank
3.5 year autonomy

1.6K during all the mission

Cryo For Fundamental Physics in Space: Freezers)

- **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 +4C 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_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_2**
  - Releases pure CO2 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

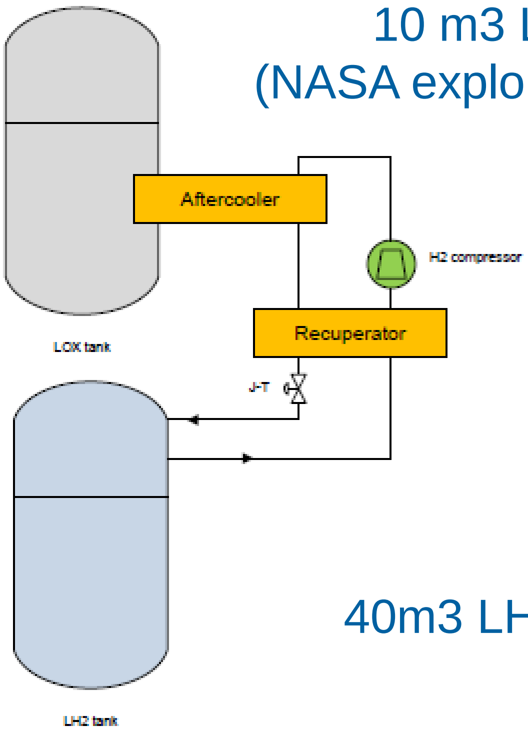
Crygenic crystalizer breadboard for 10 crewmembers

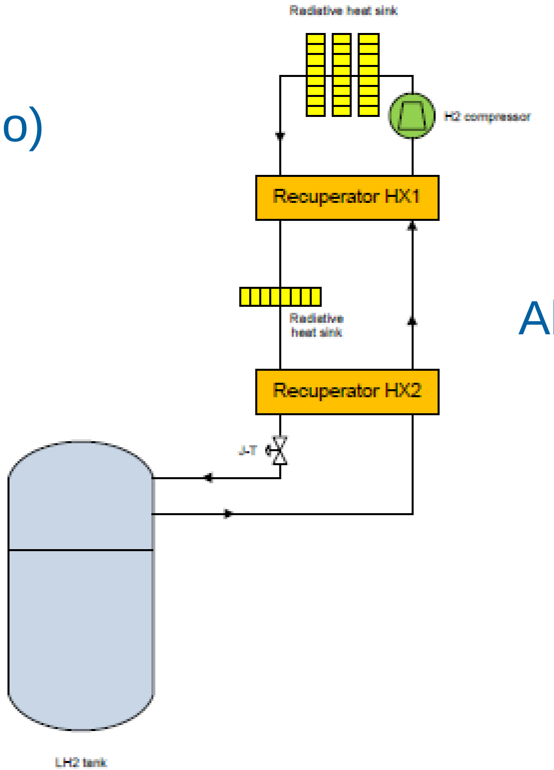
12 W@110 K, 200 We

CRYO FOR LONG RANGE VEHICLES PROPELLANT TANKS

- Liquid H_2 (20 K) boils-off
- Oxygen being at 90 K, can be cooled passively to avoid boil-off losses
- LH_2 loss can be reduced with cryocoolers (**ZBO concept**) for long -term mission spacecraft.

10 m3 LOx tank
(NASA exploration scenario)

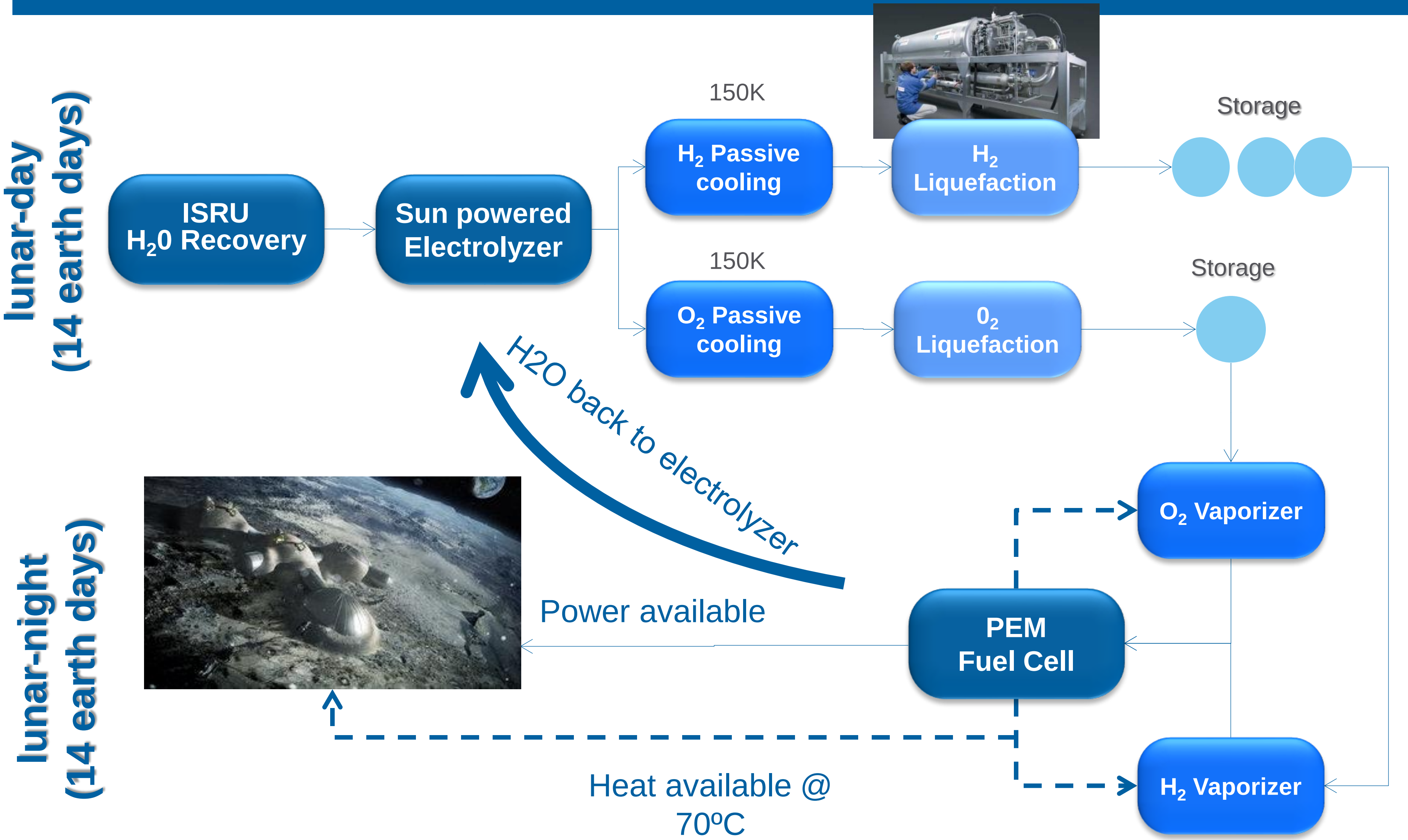




About 2 kWe

40m3 LH_2 tank

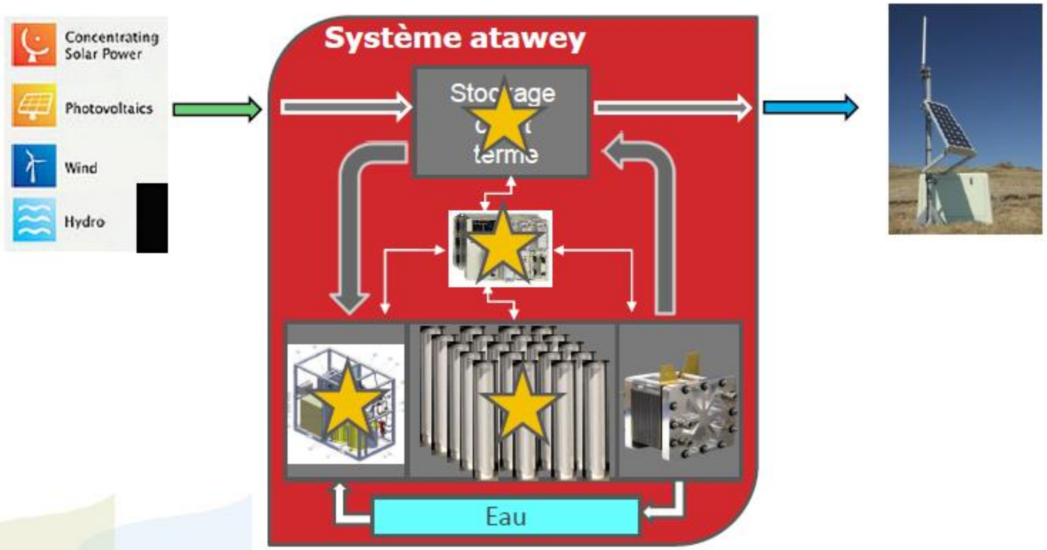
Energy storage: An Example for the Moon



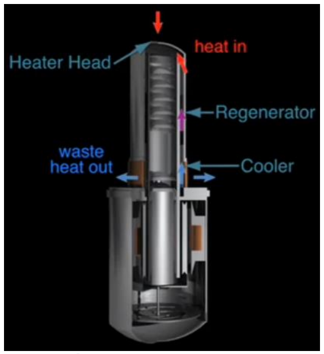
Moon base photo: Courtesy ESA

HYDROGEN ENERGY STORAGE PLANT

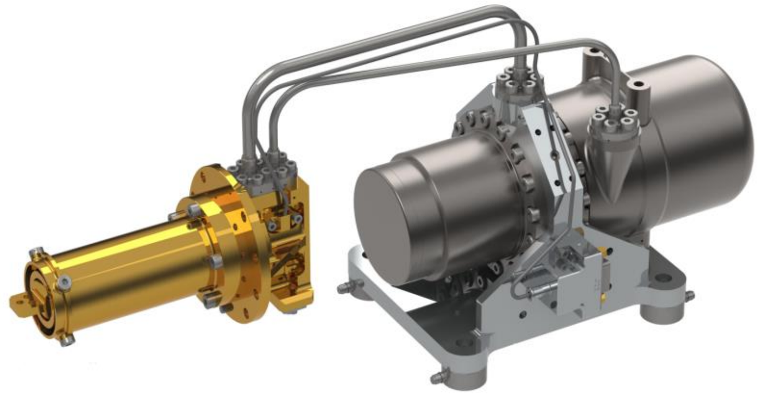
- Plant prototype working in Sassenage since july 2015
- 4-20 MWh/year (1.5 kW PEMFC)



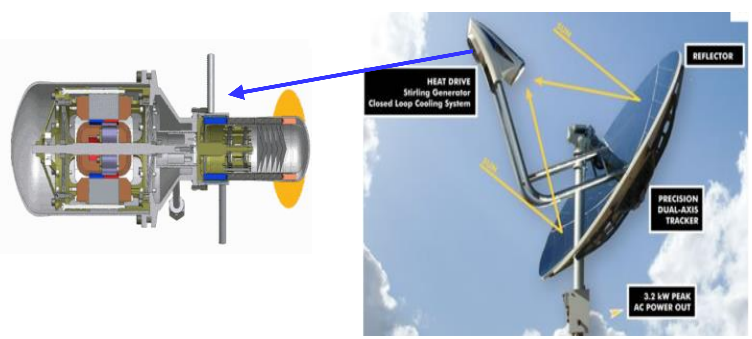
■ Solar concentration and Stirling engines



Stirling à Radio-isotope NASA

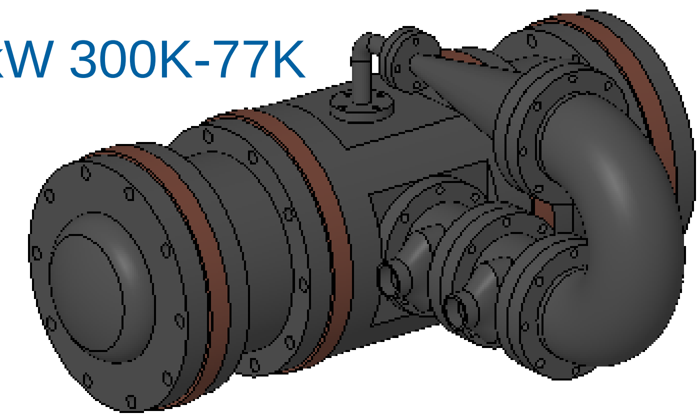


Cryogénérateur Miniature Pulse Tube



Solar Concentration Stirling INFINIA
600K – 300K

5kW 300K-77K

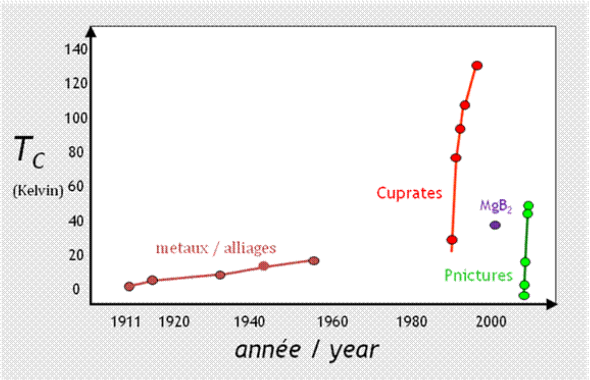


LN2 tanks energy recovery

Superconductivity

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 Tc in order to suppress any Joule dissipation.

Superconductive materials have been discovered working under different Tc levels,

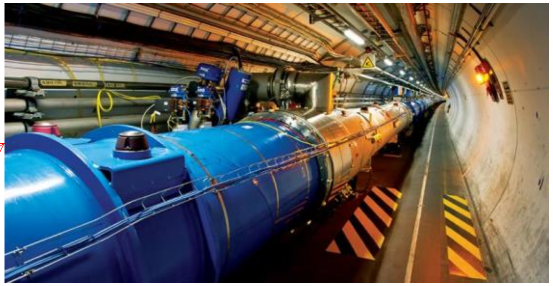


Sub-cooled liquid Nitrogen for power transportation (Long Island Power Authority's project)
YBaCuO/BSCCO cables at Tc< 70K

Cryo-cooler :
Helium refrigerator

Cryo-cooler :
Turbo-Brayton

Liquid Helium for CERN-LHC
NiTi magnet at Tc< 4 K with



Helium gas or liquid Hydrogen for
MgB_2 cable at Tc 20K at CERN

The test station, located in one of CERN's laboratories. The black tube contains the prototype MgB2 superconducting cable and its cryogenic envelope. (Photo credit: CERN).

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**

ESA courtesy

AIR LIQUIDE
ADVANCED BUSINESS & TECHNOLOGIES

Advanced Technologies
Thanks for your attention

2016 March 8th