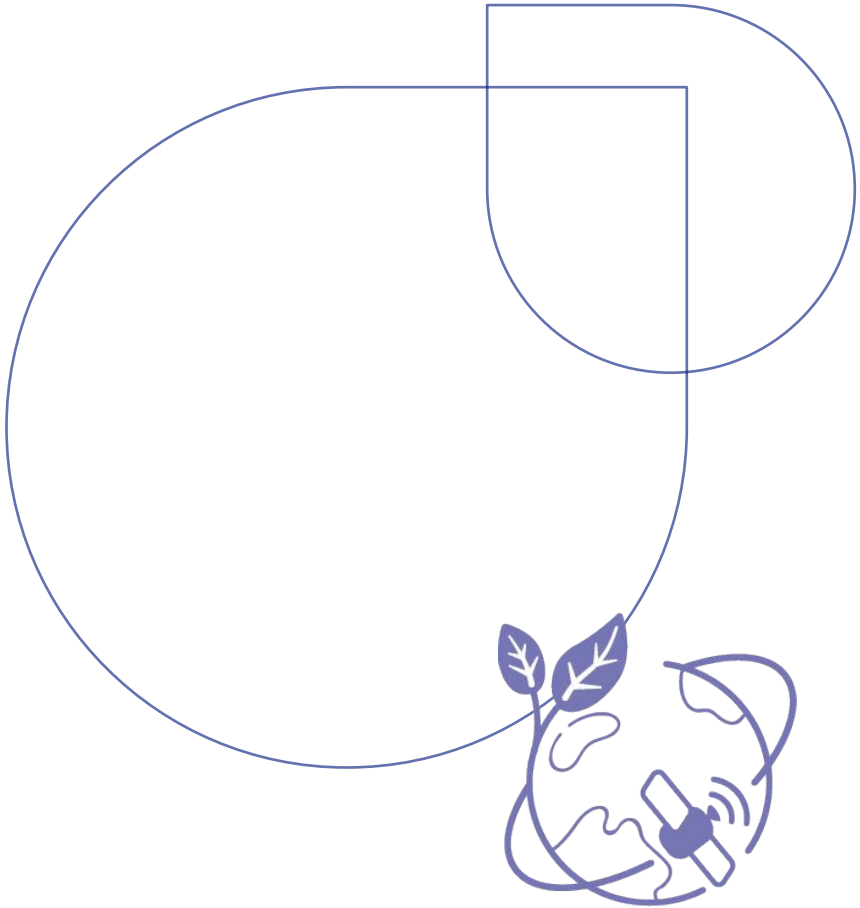
Rare Gases Market update

Workshop on Xenon Detector 0vββ Searches: Steps Towards the Kilotonne Scale

Global Markets & Technologies

25/10/2023



Agenda

1. Air Liquide Group & Big Science
2. Focus on Xe production
3. Drivers of Xenon production
4. Focus on Xe markets

Air Liquide Group & Big Science

2022 Key Figures

~66,400
EMPLOYEES

PRESENT IN
75 COUNTRIES

MORE THAN
3.8 MILLION
CUSTOMERS & PATIENTS

REVENUE
€29,9 bn

NET PROFIT (GROUP SHARE)
€2.7bn

INVESTMENT DECISIONS
€4bn

Why AL is interested by Big Science

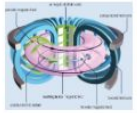
Most of the machines used for Big Science use **superconducting magnets** to create large magnetic fields.

Superconducting magnets work at **temperatures close to absolute zero**, an expertise of Air Liquide.

Air Liquide provides the **helium** used as coolant and the **equipment** able to liquefy helium.

Segments covered

Nuclear fusion



Energy production with no long-lived nuclear waste by using hydrogen.

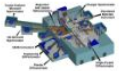
Colliders

Used for fundamental research. Size range from few meters to 26Km.

Cold neutron source

The CNS generates cold neutrons used for matter observation.

Spallation neutron source

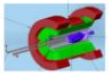


'Spallation effect' emits large number of nucleons used for research in biotechnology, pharmacology, new materials.

Light source

Generate photons which target the sample for scientific and industrial use of imaging and molecules interactions.

Heavy rare or ion source



Used for the production of synthetic elements mainly for medical research applications.

Air Liquide & Big Science
Our Contribution

Nuclear fusion
Superconducting magnets,cryopumps

Equipments: Cryoplant 80 K / 20 K /4 K / 2 K/ Cryolines, Valves boxes
Isotopes : Deutérium, tritium
Cryogenic fluids: LHe, LN2

Particle accelerators & colliders
Superconducting magnets, RF cavities, detectors

Equipments: Cryoplant 80 K / 20 K /4 K / 2 K/ Cryolines, Valves boxes
Isotopes : Deutérium, tritium
Cryogenic fluids: LHe, LN2, Ar

Light Sources
Superconducting magnets, RF Cavities, detectors, undulators, wigglers

Equipments: Cryoplant 2K & 4K, Dilution Refrigerators
Cryogenic fluids: LHe, LN2, He3

Cold Neutron Sources
Neutrons moderator, Superconducting magnets, RF Cavities, neutrons detectors

Equipments: Cryoplant 4K & 20K
Isotopes: Deutérium
Cryogenic fluids: LHe, LN2

Physics laboratories
Experiments for Big Science research

Equipments: Helium Liquefiers
Cryogenic fluids: LHe, He3

Quantum computing
Superconducting electronic circuits

Equipments: Dilution refrigerators
Cryogenic fluids: LHe, He3

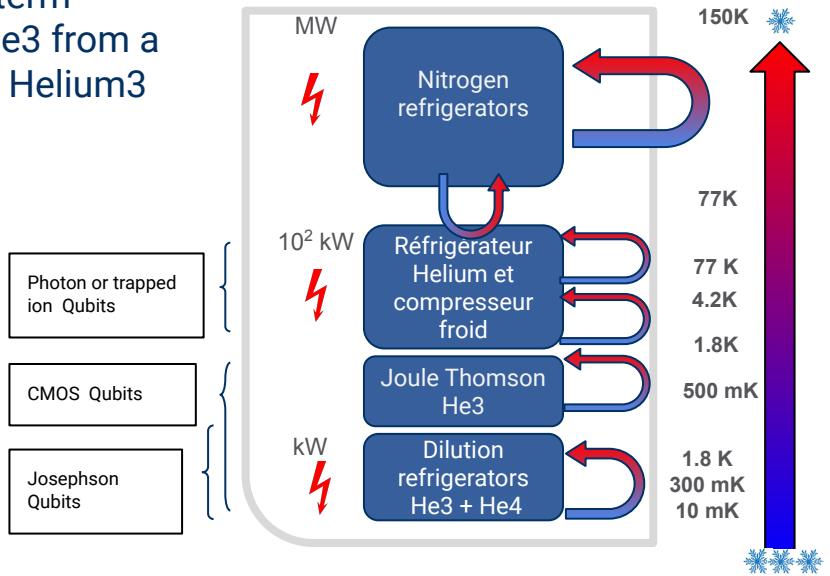
Helium3
Anticipating the Quantum Computing boom

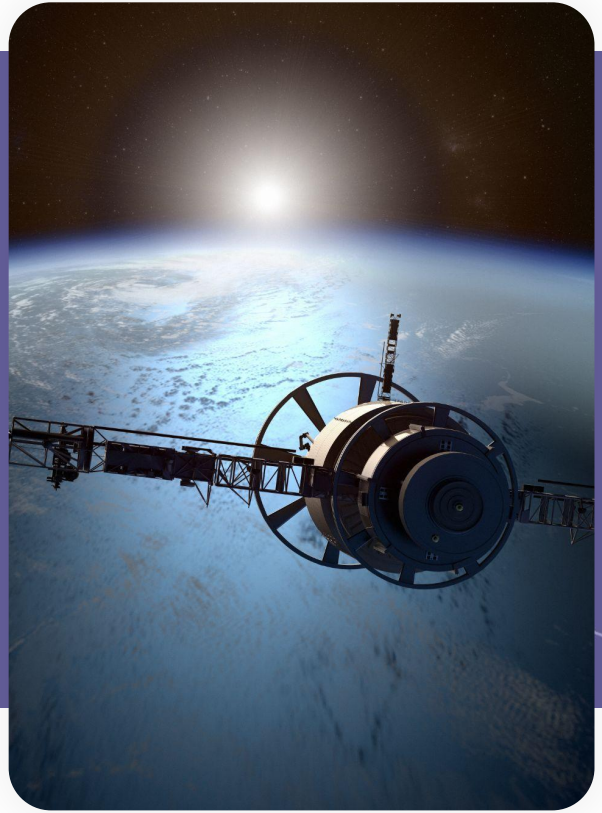
Until 2021, Air Liquide was present in deep cooling technologies until 1.8K.

Driven by its ambition to support the Quantum segment development, that needs to get close to 0mK, Air Liquide entered into a long-term Agreement in **2022** with Laurentis Energy Partners to extract He3 from a Candu reactor located in Canada, creating the first non military Helium3 source.

This new source of He3 allows Air Liquide to make He3 a less scarce isotope, enabling the development of quantum computing.

In order to reach high level of purity, the He3 coming from Canada is purified in France using a one of a kind purification plant.



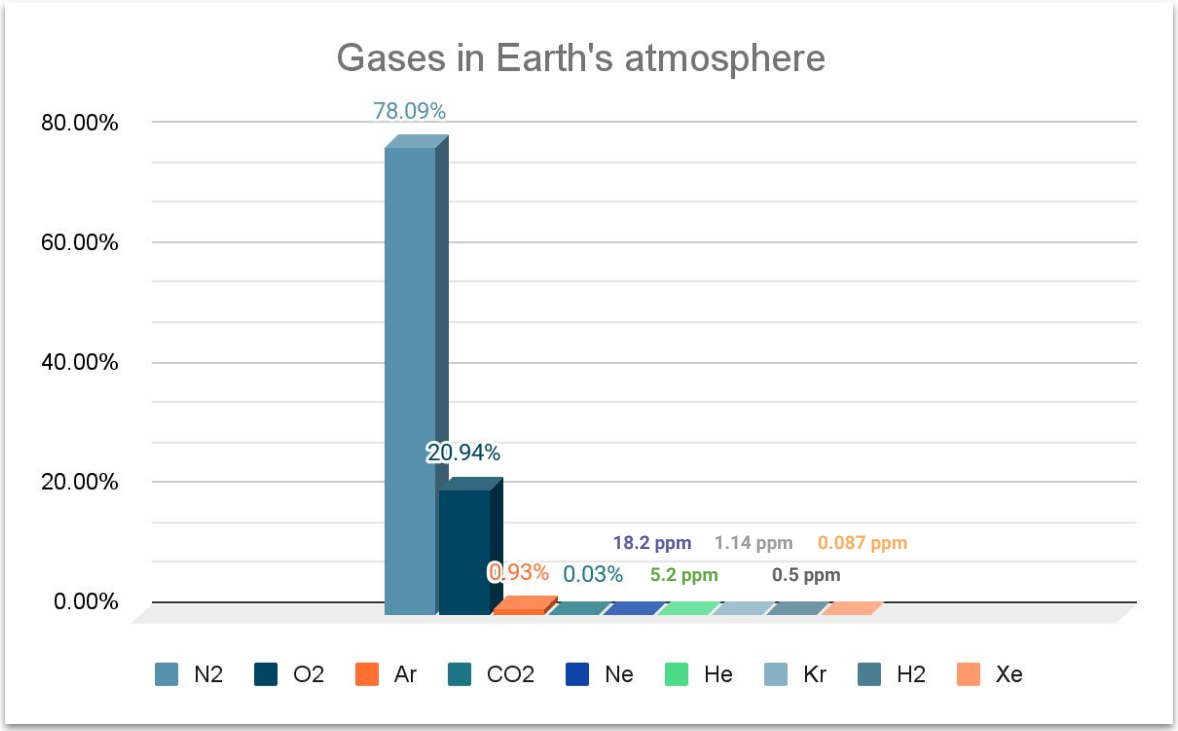


Focus on Xe production

© ©Jose Luis Stephens

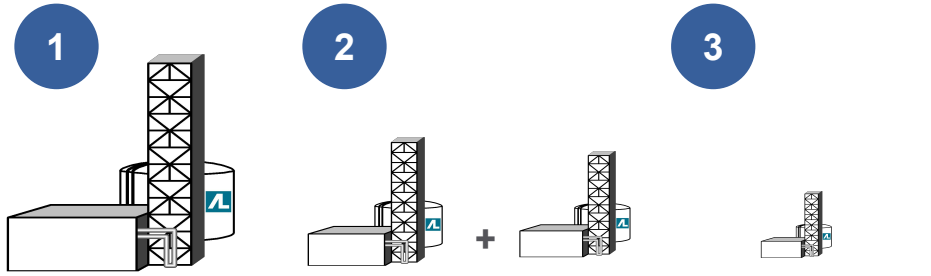
Krypton and Xenon in the Earth's atmosphere

Krypton and Xenon are obtained from air, where it is present in extremely small amounts.



Gaz	Abundance
N2	78,09 %
O2	20,94 %
Ar	0,93 %
CO2	350 ppm
Ne	18,2 ppm
He	5,2 ppm
Kr	**1,14 ppm**
H2	0,5 ppm
Xe	**0,087 ppm**

Kr and Xe extraction from the air requires multiple steps



	Air Separation Unit (ASU)	Concentration + Extraction		Purification Multiple step distillation
Geography		Geography 1: usually abroad		Geography 2: France
Processed vol.	1 000 000 m^3	500 m^3	1 m^3	Kr 0.9 m^3 / Xe 0.1 m^3
KrXe%	1 ppm	0.2%	99%	99.9999%

Key facts:

- KrXe are **by-products** of Oxygen
- Only very large ASUs can justify extraction of Kr and Xe
- ASUs need to be specially designed in order to produce KrXe
- Even if large, the selected ASUs can only produce a small amount of Kr and Xe
- Increasing Kr/Xe capacity on existing ASUs requires significant investments

⇒ Production of Kr and Xe is managed globally in order to maximize reliability of supply

Krypton and Xenon are byproducts of oxygen

1

AIR SEPARATION UNIT

Oxygen production
Specially designed for KrXe extraction

Liquid Oxygen

2

KRYPTON-XENON EXTRACTION

Removal of oxygen

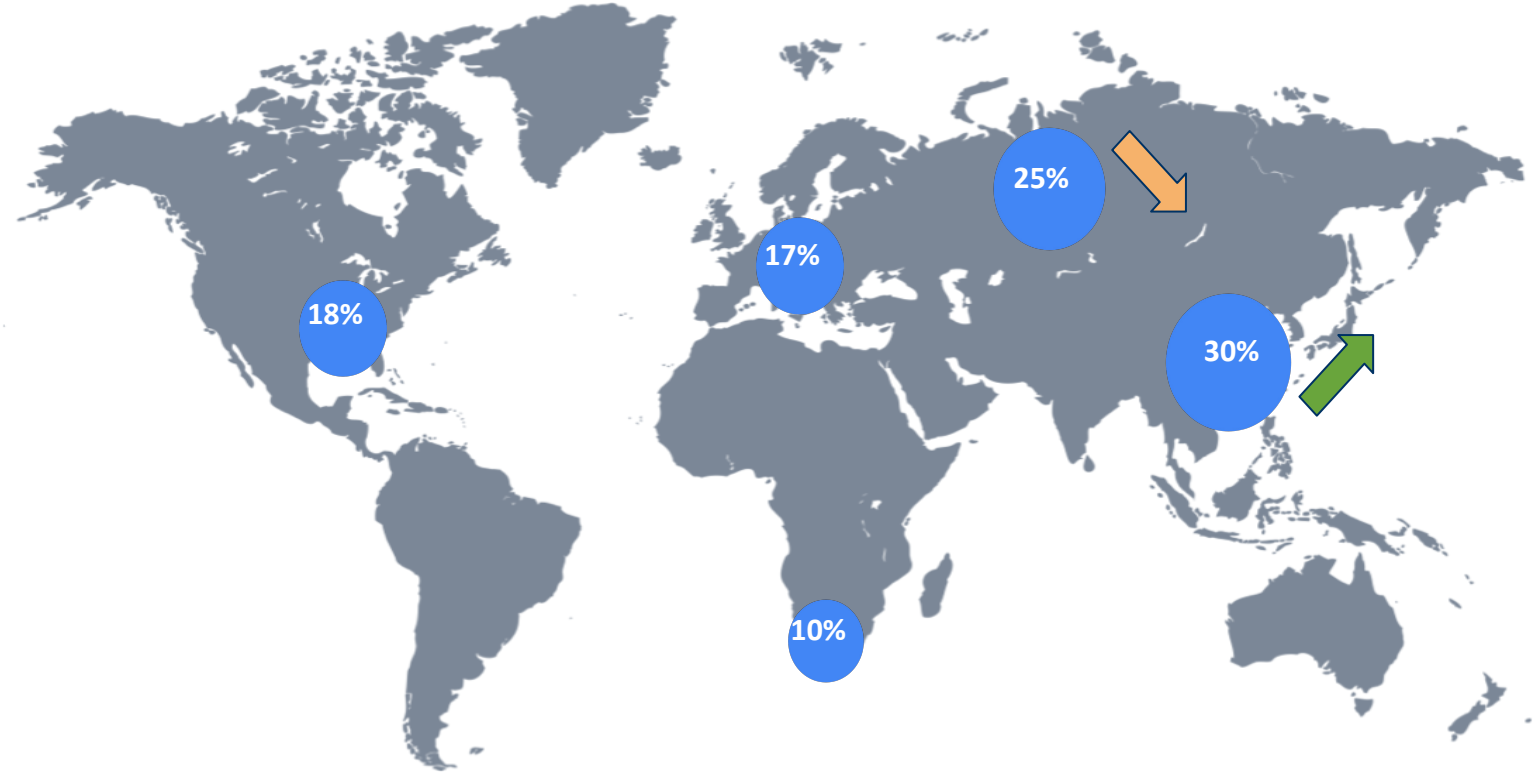
KrXe mixture

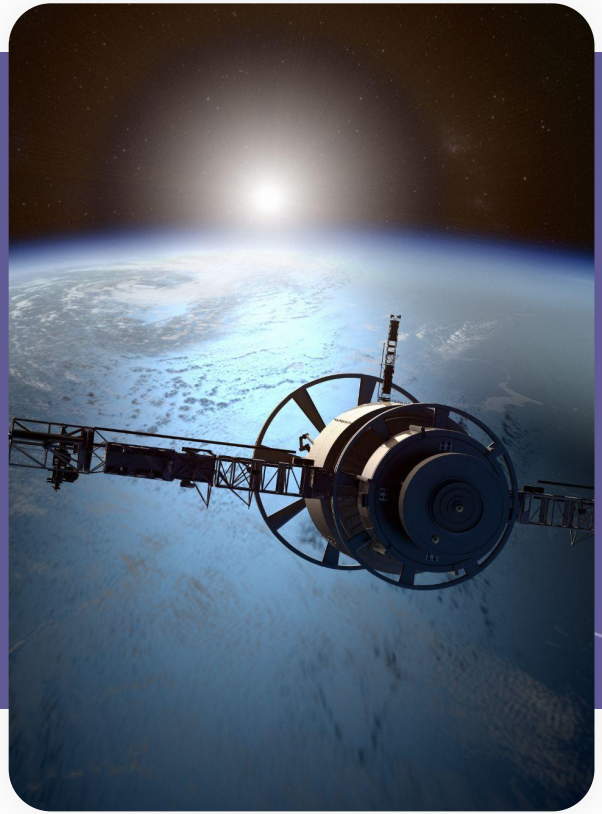
3

PURIFICATION PLANT

Separation of Krypton and Xenon

Global production of KrXe
(AL estimation)





Drivers of Xenon production

© ©Jose Luis Stephens

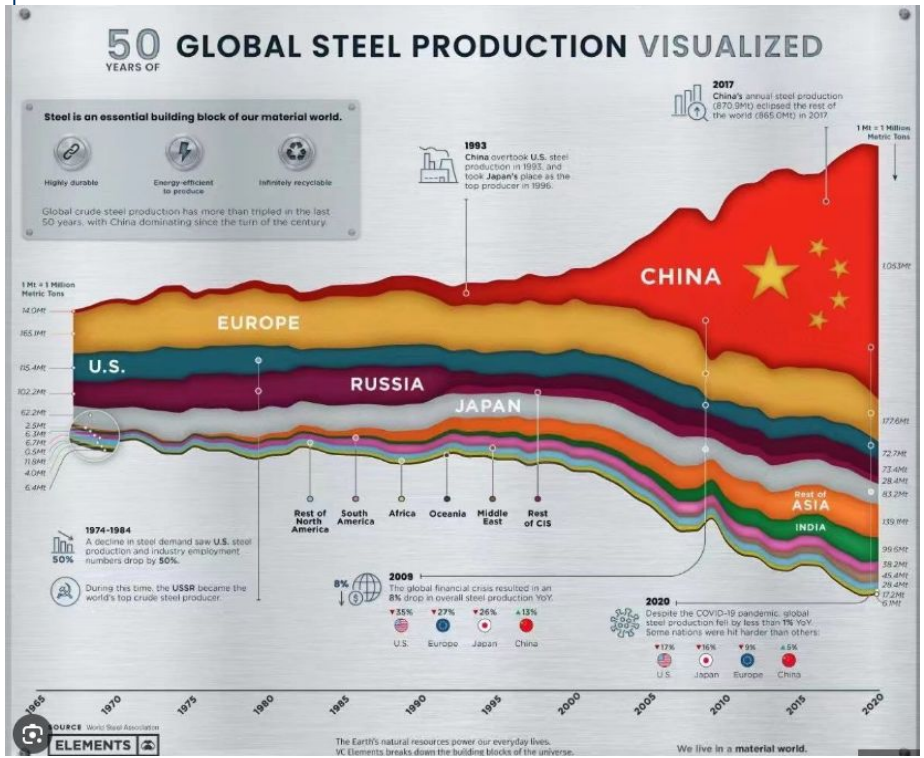
Steel production and KrXe production are connected

To produce KrXe mixture, we need large ASUs and most of the times, the largest ASUS are dedicated to steel production, as it needs significant amount of Oxygen.

Therefore we consider that monitoring the steel production is a good indicator to better appreciate the Xe production capacity worldwide.

Today the steel production is facing several different challenges that can be seen as risks or opportunity for the KrXe production.

China is leading the global steel production



Over the past years, the mature countries initiated a policy of desindustrialisation that became controversial since the beginning of the war between Ukraine and Russia.

This event showed our dependency towards certain countries and the geopolitical associated risks.

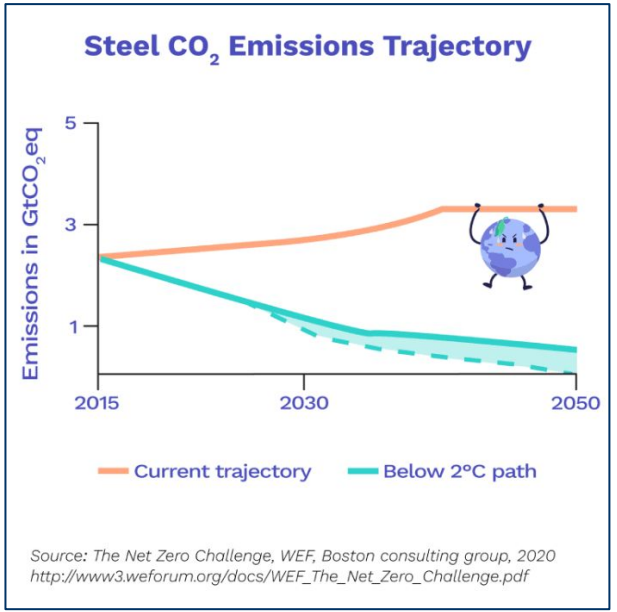
Today China represents 60%* of the steel production while Europe counts for only 10% making our dependency toward China significant.

Emerging countries are still far behind and it's difficult to have large ASUS in "non risky countries".

*data from ClimateScience.Org

Steel industry and decarbonisation: risk or opportunity?

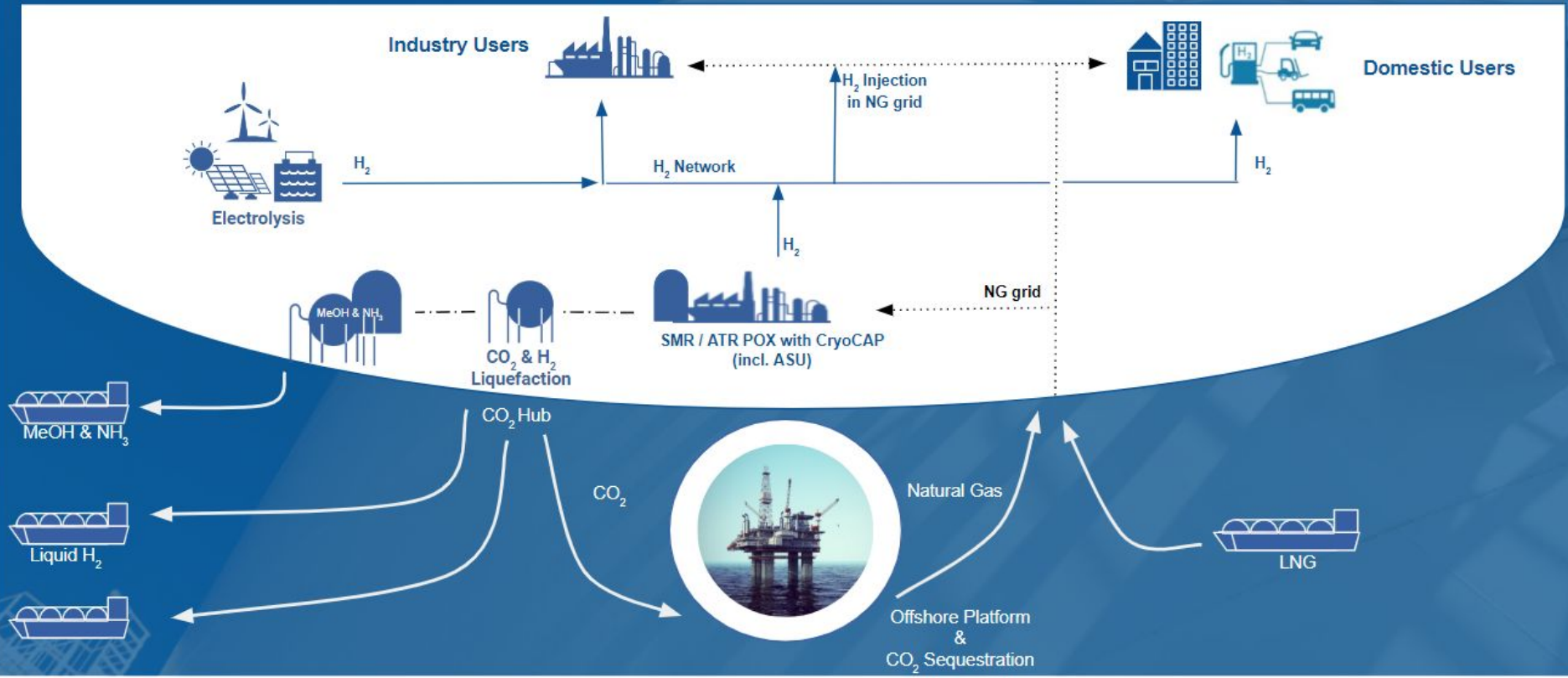
- Iron and steel industry alone contributed approximately **25% of global industrial CO_2 emissions in 2018**
- In 2019, 240kg of steel were produced for every person on Earth
- For every ton of steel produced, **around 1.8 tonnes of CO_2** are emitted
- To keep in line with net-zero by 2050 targets, the CO_2 intensity of steel would need to fall an average of 4% annually from now on until 2030.
- The most advanced technologies are :
  - replace O_2 by green-hydrogen made by electrolysis >>> decrease of O_2 consumption so less KrXe produced
  - replace by blue hydrogen made by CO_2 capture >>> O_2 consumption



Source: *The Net Zero Challenge, WEF, Boston consulting group, 2020*
http://www3.weforum.org/docs/WEF_The_Net_Zero_Challenge.pdf

Source: Technologies to decarbonize the Steel Industry in Europe et la décarbonisation des entreprises françaises

Blue Hydrogen based Energy Transition Projects

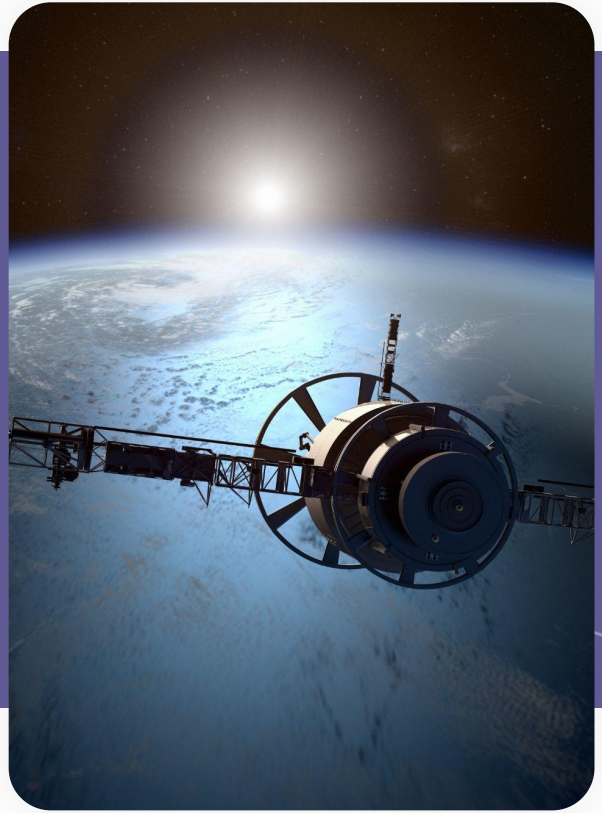


Summary

Xenon production depends on Oxygen needs from CO_2-emitting industries such as steel industry.

Key trends:

- Growing share of China in steel production has an impact on Xenon producing geographies
- Decarbonization of industry will have contrasted impacts on oxygen needs
  - Air Liquide is a partner in six out of seven Hydrogen Hubs announced by the DOE in the U.S.



Xe markets

© ©Jose Luis Stephens

Who are the main Xenon users today?

ELECTRONICS

Xenon and Krypton demands are driven by Electronics

Main use for etching of high density memory chips

Cyclical market

SPACE

Used for electric propulsion of satellites allowing important weight reduction

Krypton preferred to Xenon for ‘constellations’ of low earth orbit satellites

Market organised around projects

LIGHTNING

Gradually replaced by LEDs

Remaining uses for niche applications and replacement (eg for automotive)

Continuous market but very sensitive to price evolution

Xenon market: the global vision

Supply side:

- Russia: assumed to export through non-EU countries;
- New production capacity started - mainly in China but at risk on the long term;
- **New production capacity opportunities for Energy Transition projects by 2030.**

Demand side:

- Lower demand from semiconductor in 2023;
- Xenon purchases from other markets; reduced or delayed due to high prices for ‘spot’ purchases until mid 2023;
- Expected additional demand from Space and Research in the coming decade.

Xenon and the double beta decay experiments: key figures

AL Estimate of total natural Xe production WW: **60-100t/y**

Regular shortage situations

1 kg of ^{136}Xe = 12 kg of natural Xe

1000 tons of ^{136}Xe means minimum 120 years of the total natural Xe production

Getting ^{136}Xe supposes a separation process usually done through centrifugation. To perform this process in a reasonable timeframe, additional investment in centrifugation capacity is required.

And we still have the other uses of Xe…

How to secure Xenon supply (natural Xenon)?

Two main routes:

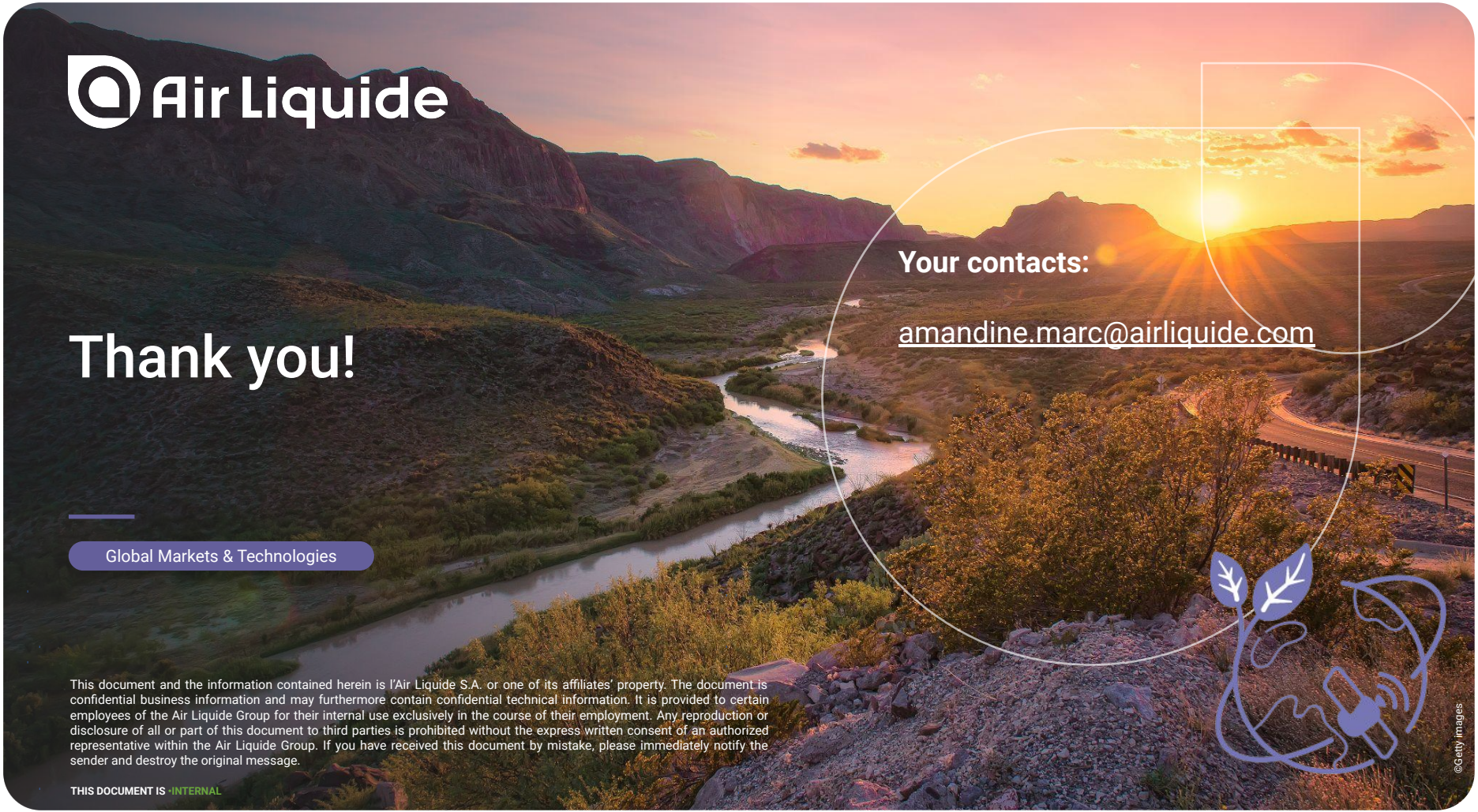
1. **'Open' market:**
   a. Non-guaranteed supply
   b. Availability and price depending on supply/demand balance

2. **Guaranteed supply**
   a. dedicated investment and related Xenon production capacity
   b. guaranteed availability & pricing
   c. several years of operation needed in order to pay off the investment
   d. lead time for development and construction of new production capacity

These 2 routes probably need to be combined in order to address the very large requirements

Topics & issues specific to ^{136}Xe:

1. Management of depleted xenon obtained after extraction of Xe136: acceptance by customers (eg semiconductor) & valuation of depleted Xe to define
2. Inventory of natural and depleted xenon immobilized for isotopic separation process



Thank you!

Global Markets & Technologies

Your contacts:

amandine.marc@airliquide.com