

Xenon gas for XLZD

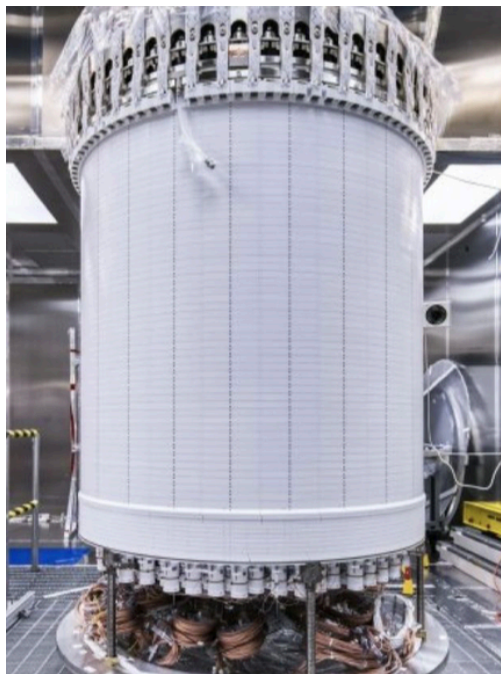


XLZD collaboration meeting
June 30, 2025 LNGS

Henrique Araujo (ICL), Laura Baudis (UZH) the Xe acquisition group

Total amount of xenon needed

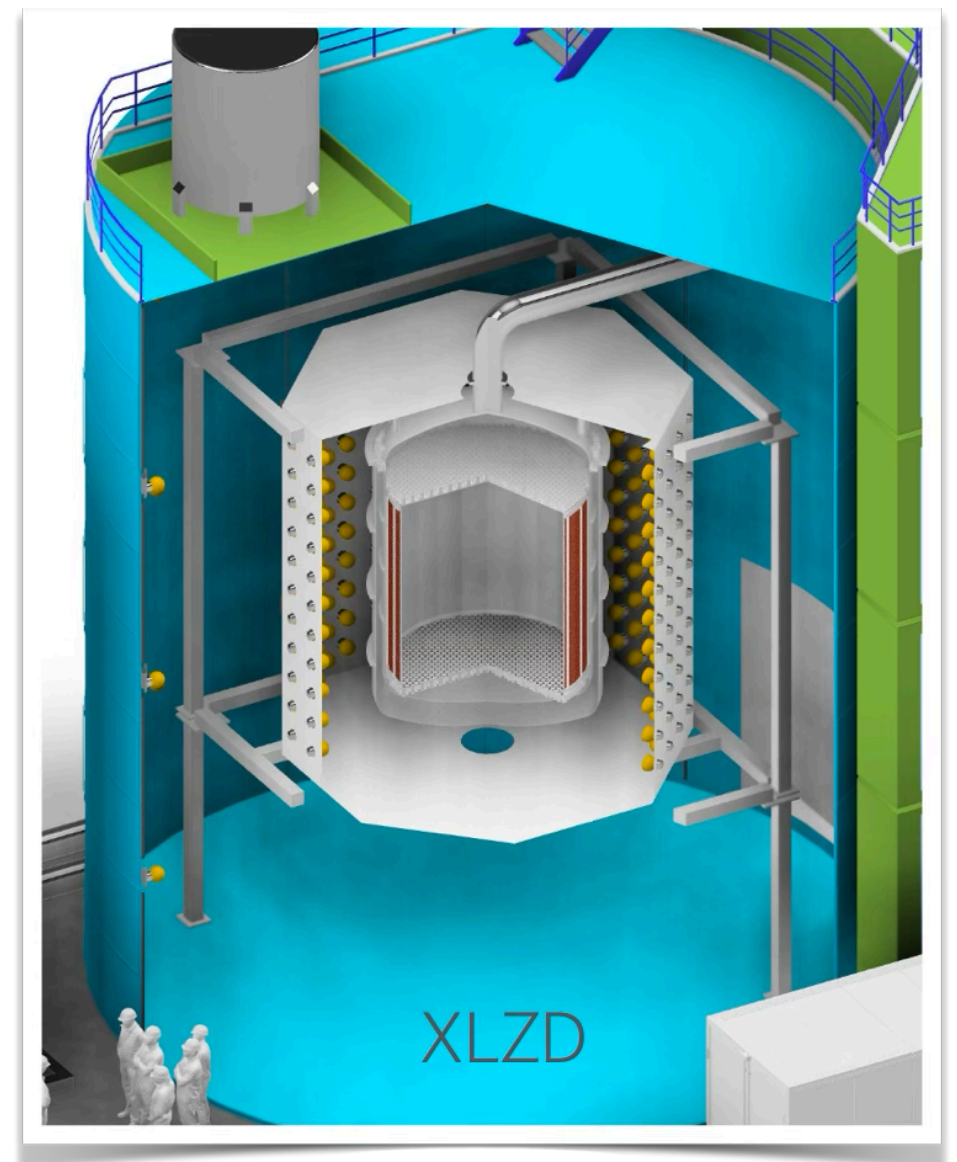
- ◉ Baseline for XLZD: 78 t in total (design book [arXiv:2410.17137](https://arxiv.org/abs/2410.17137))
- ◉ Favourable market: 100 t in total
- ◉ Assume we start with ~25 t



LZ: 7 (10) t



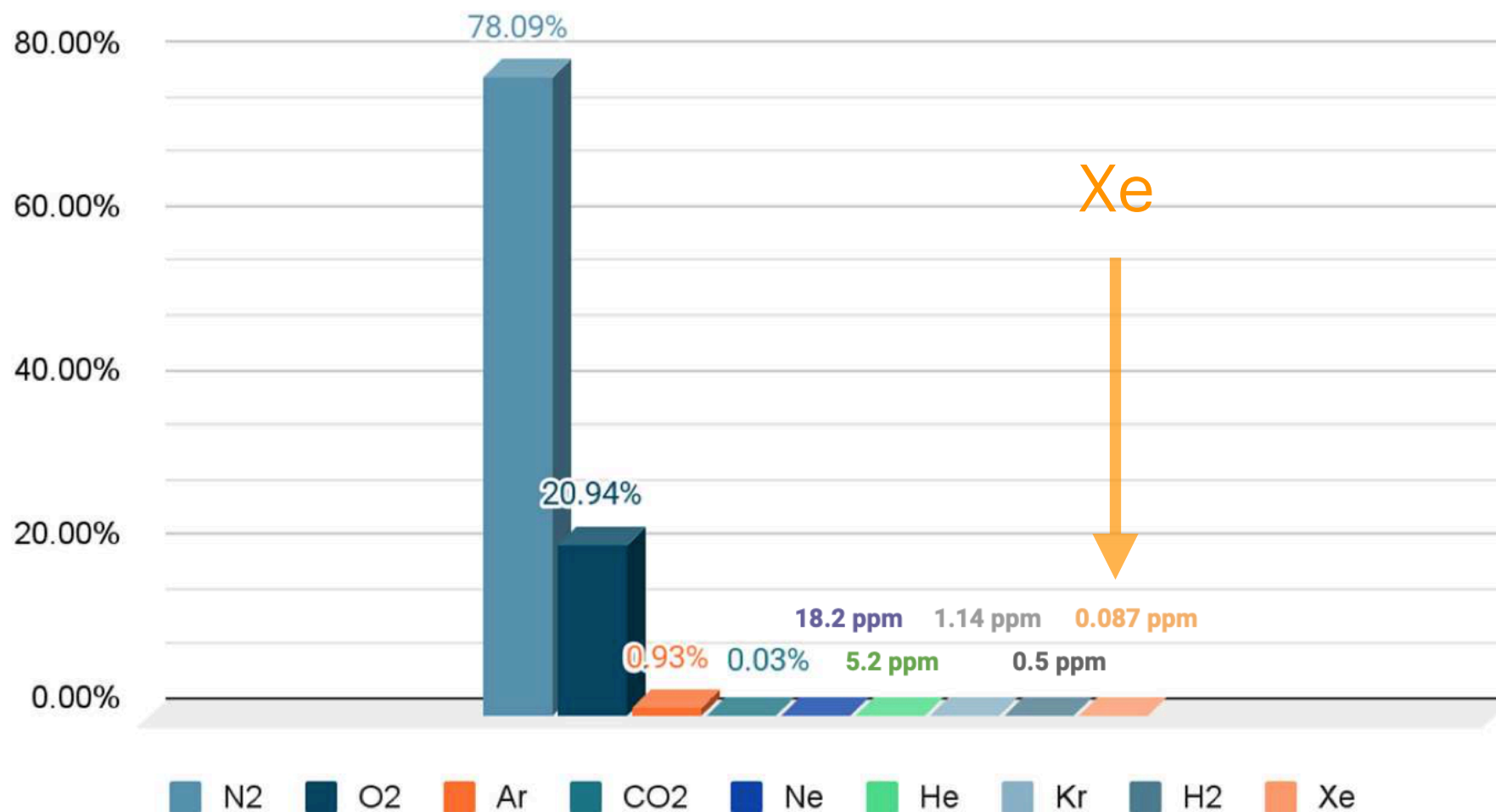
XENONnT: 5.9 (8.6) t



Xenon source

- Present in the atmosphere, at a natural abundance of 87 ppb (per volume)

Gases in Earth's atmosphere



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

Xenon supply

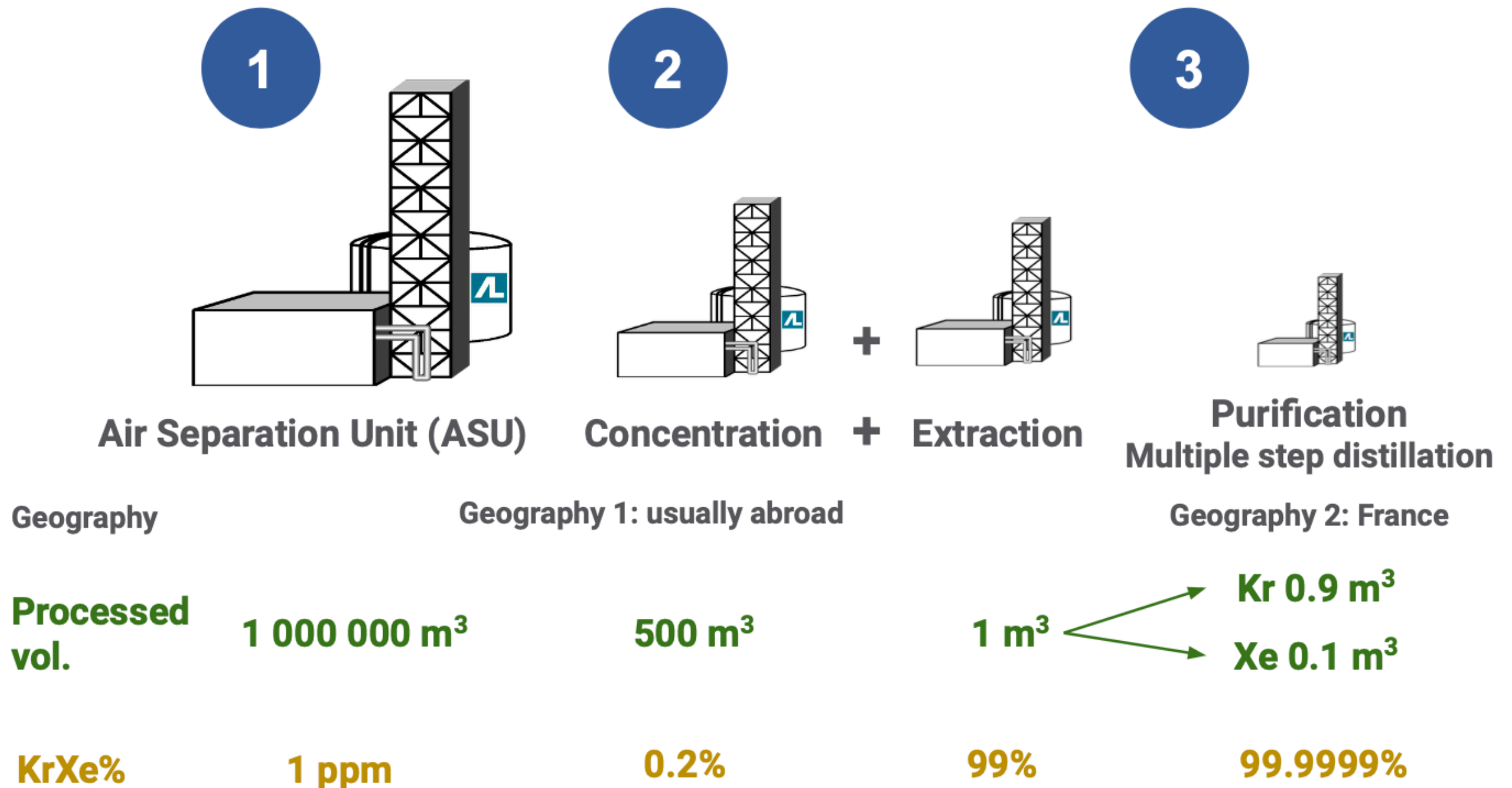
- ◉ Byproduct of liquid oxygen production using Air Separation Units (ASUs), based on cryogenic distillation
- ◉ Xenon usually extracted together with krypton (both high boiling points)
- ◉ Liquid oxygen: by fractional distillation enriched to 0.1-0.2% Kr/Xe mixture (several distillation stages in the oxygen distillation column, Kr and Xe concentrate in the liquid oxygen bath at the bottom)
- ◉ Additional cryogenic distillation columns next to the ASU where Kr and Xe are gradually separated from the liquid oxygen from a few ppm to > 90% Kr + Xe
- ◉ Pre-enriched gas mixture shipped to separation plant to remove residual impurities

Xenon supply

- ◉ Separation of xenon from krypton in subsequent step (additional fractional distillation) + purification, to reach customer specifications
- ◉ Special equipment added to ASUs to extract and purify the xenon
 - ◉ Only a fraction (about 1/5th) of the ~500 ASUs worldwide are equipped to do so
 - ◉ One (large) ASU can produce 0.5 - 1 t/year
 - ◉ 10^6 m^3 of air processed to obtain 0.1 m^3 of Xe (0.58 kg)
- ◉ Annual xenon gas production: 70-100 t (12.2 - 17.4 million gas litres)
 - ◉ Most of it tied in long-term contracts



Xenon supply



Amandine Marc, Air Liquide, public material

ASUs: next to steel and chemical plants (large oxygen consumers)

Xenon supply



AIR SEPARATION UNIT

Oxygen production
Specially designed for KrXe extraction



KRYPTON-XENON EXTRACTION

Removal of oxygen



PURIFICATION PLANT

Separation of Krypton and Xenon

Liquid Oxygen

KrXe mixture

Amandine Marc, Air Liquide, public material

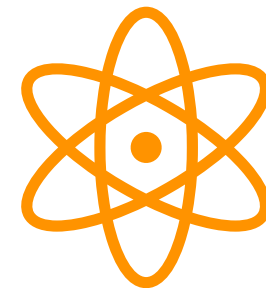
ASUs: it takes 2-3 years to construct new ones that can produce Kr/Xe

Xenon users and main suppliers

- ◉ Semiconductor manufacturing (XeF_2 for dry etching)
- ◉ Spacecraft propulsion
- ◉ Medical applications, lightning (declining)
- ◉ Science (dm , $0\nu\beta\beta$ -decay, $\mu \rightarrow e + \gamma$, etc)



- ◉ Linde, Air Liquide, Messer Group, Taiyo Nippon Sanso
- ◉ Proton gases (India), WISCO (China), Japan Gas
- ◉ Westfalen (Germany, CH), etc



- ◉ **Current price:** (6 - 15) CHF/litre



Requirements for XLZD

- ◉ **Acquire 70-100 tonnes of xenon** (natural abundance) over ~ 10 years
 - ◉ Corresponds to 12.2 - 17.4 million gas litres
- ◉ **Xe quality:** grade 5.0 purity (99.999%), ^{nat}Kr content < 1 ppm
- ◉ **Packaging:** deliver in cylinder packs, custom-developed (see, e.g., LZ model)
- ◉ **We will also need to consider**
 - ◉ Storage
 - ◉ Inventory system
 - ◉ Assay

Component	Xe 5.0
H ₂ O	<1.00 ppm
O ₂	< 1.00 ppm
N ₂	< 2.00 ppm
H ₂	< 0.50 ppm
Ar	< 1.00 ppm
C _n H _m	< 0.50 ppm
CO, CO ₂	< 0.50 ppm
CF ₄ , C ₂ F ₆ , SF ₆	< 0.10 ppm

Example Xe
quality

XLZD acquisition strategy

- ◉ **Discussions with large suppliers** (AL, Linde) started some time ago
- ◉ **Goals**
 - ⦿ Set-up a delivery profile
 - ⦿ Establish long-term contracts, at fixed prizes, with major players (possibly also with emerging ones)
 - ⦿ These long-term contracts should cover > 50% of our Xe needs
 - ⦿ Explore the spot market as well (and the major suppliers could help with this)

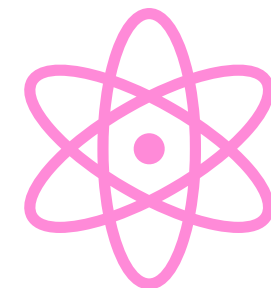


XLZD acquisition strategy

○ Possible delivery profiles

		60-tonne LXe-TPC		80 tonne LXe-TPC	
		tonnes	Σ	tonnes	Σ
Deliver by	Mar 26/27	5	5	5	5
	Mar 27/28	5	10	5	10
	Mar 28/29	5	15	5	15
	Mar 29/30	5	20	5	20
	Mar 30/31	5	25	9	29
	Mar 31/32	5	30	9	38
	Mar 32/33	5	35	9	47
	Mar 33/34	5	40	9	56
	Mar 34/35	5	45	9	65
	Mar 35/36	8	53	10	75
Existing stock			25		25
TOTAL			78		100

Early science could
start ~ 2032
(50 t total)



What happened so far

◉ Air Liquide

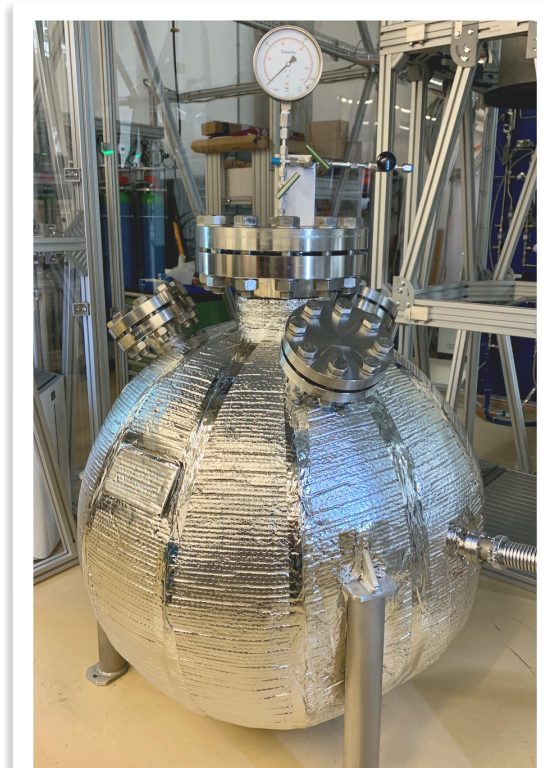
- ◉ Visit of AL purification plant, March 2023
- ◉ Meeting between AL, ICL, UZH in Zurich, March 2024
- ◉ NDA for Rough Order Magnitude study with Air Liquide (ICL, UZH; 15 kUSD)
 - ◉ **ROM study to include:** technological background, design cases for Xe production, economical ROM assessment, suggestion for sourcing strategy

◉ Linde

- ◉ Online meetings with directors (global) rare gases, Linde
- ◉ NDA with Linde (STFC, U Freiburg, SLAC, UCSD, UZH, KIT)
- ◉ In-person meeting at LNGS (today ;)

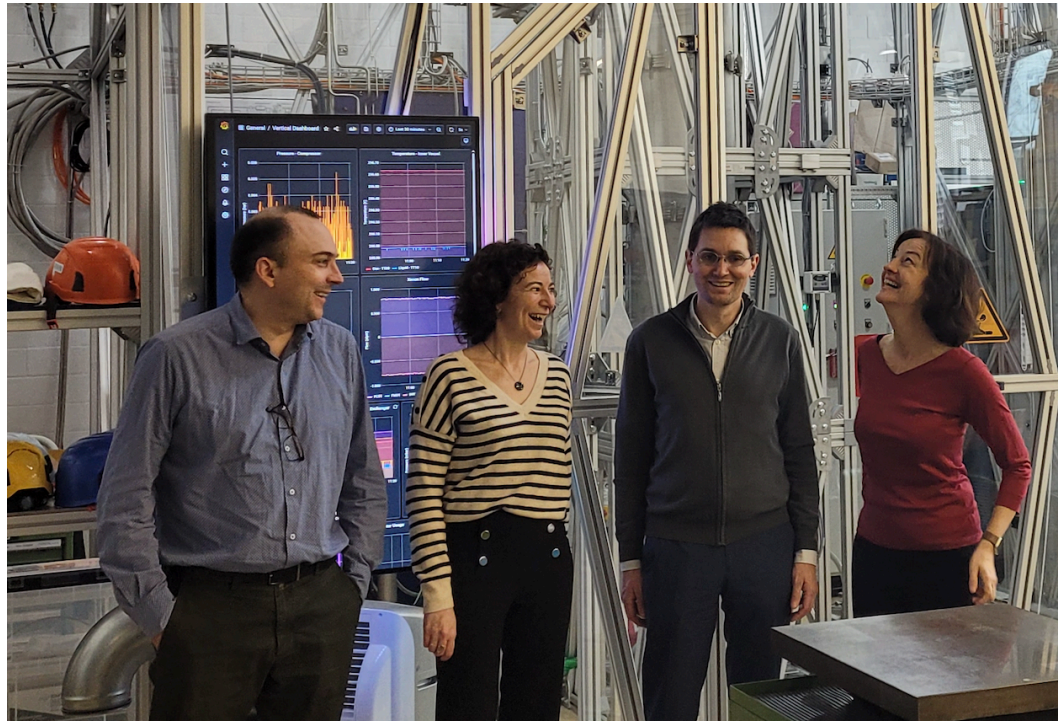
What next

- ◉ **XLZD formal working group**
 - ◉ Work out an acquisition strategy with the majors suppliers
 - ◉ Establish the type of contracts with the suppliers
 - ◉ Coordinate between the different countries
 - ◉ Coordinate with the funding agencies
 - ◉ Establish procurement processes
 - ◉ Think about long-term storage systems
 - ◉ Think about feed and recovery systems
 - ◉ ...



Questions?

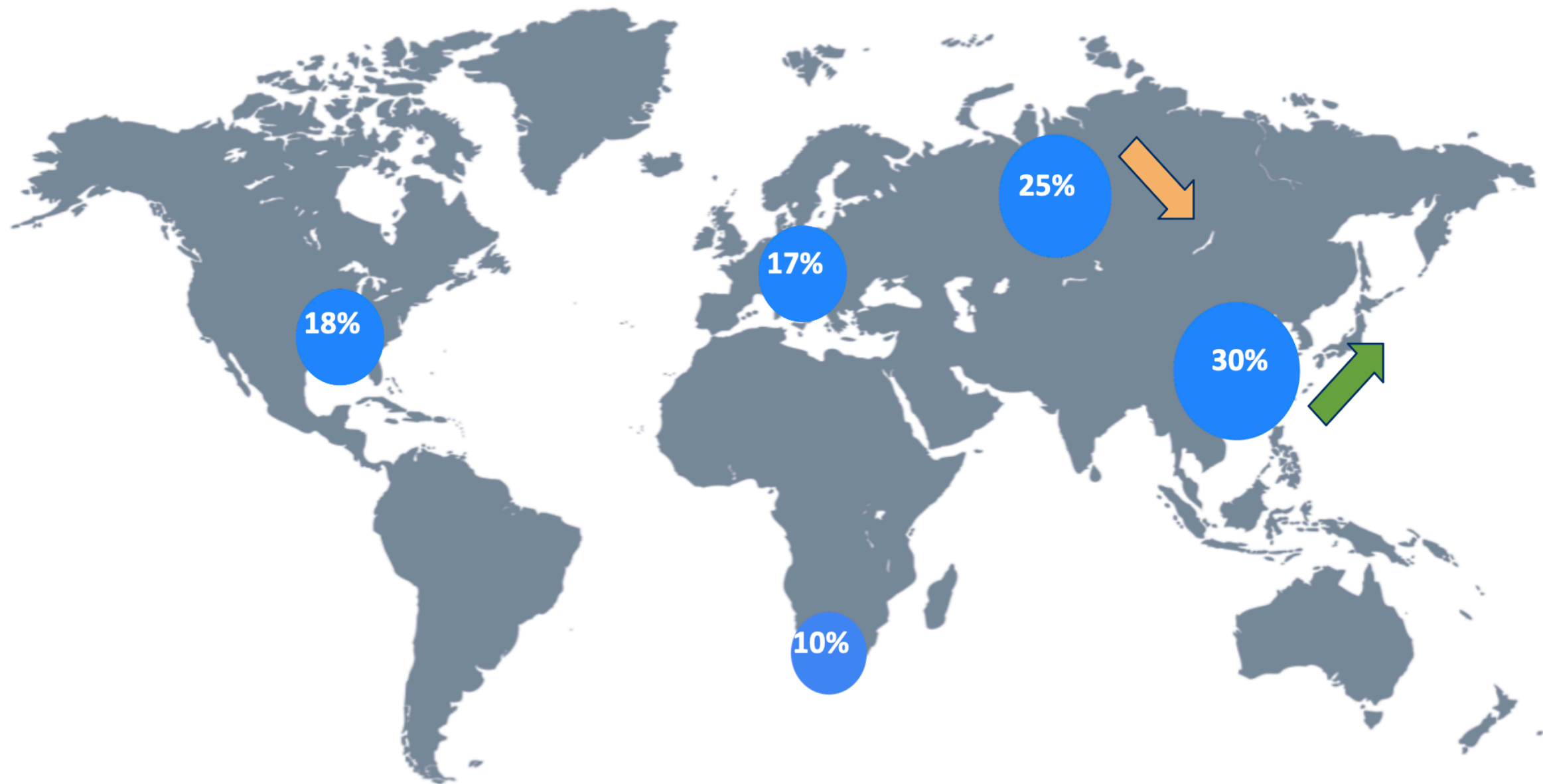
AL visits impressions ;)



Amandine Marc, AL, Sales manager
Florent Chafotte, AL, General manager, Global Rare Gases

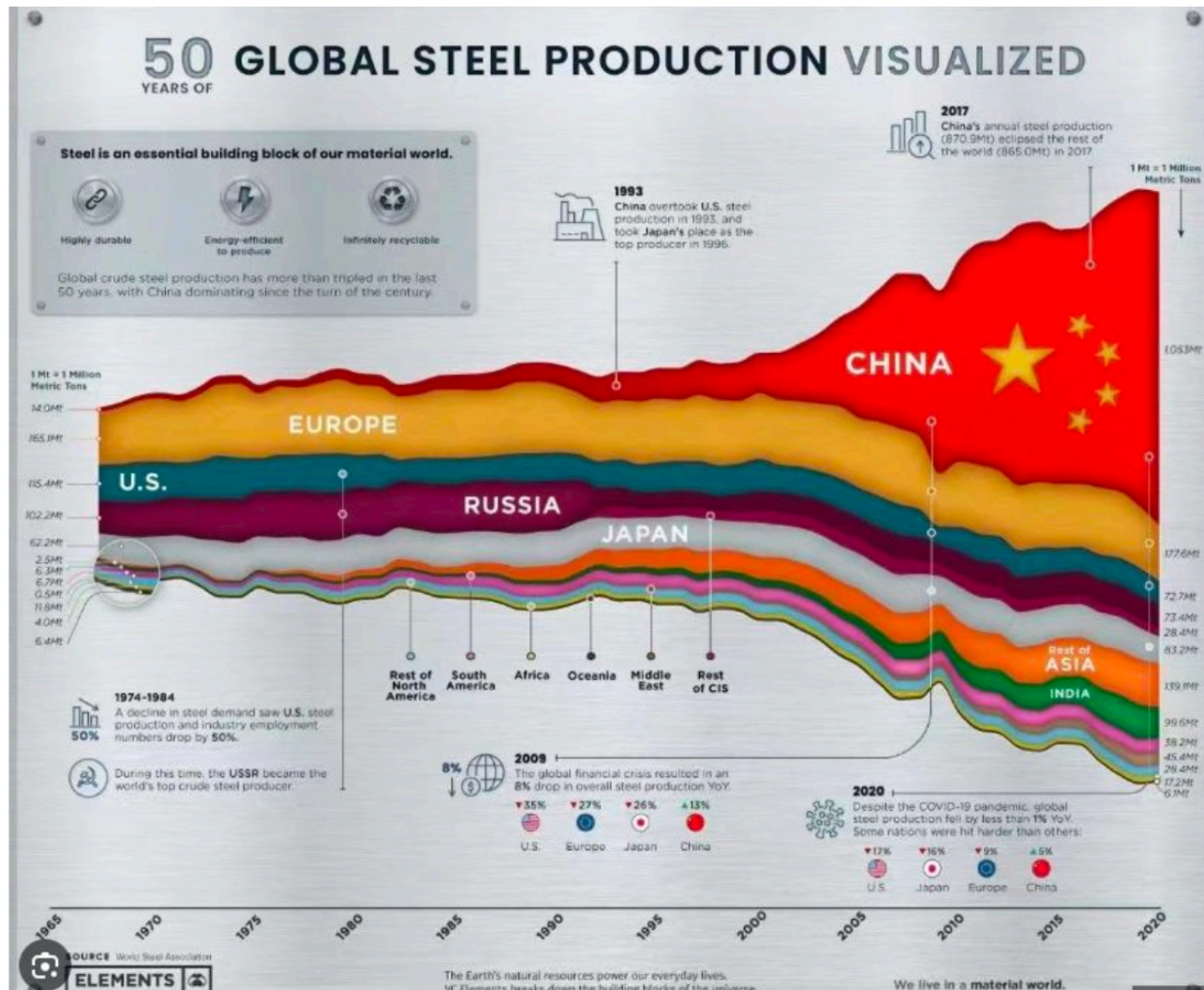


Global production



Amandine Marc, Air Liquide, public material

Global 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".