

# Insights into the global xenon market

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**Workshop on Xenon Detector  $0\nu\beta\beta$   
Searches: Steps Towards the Kilotonne Scale**

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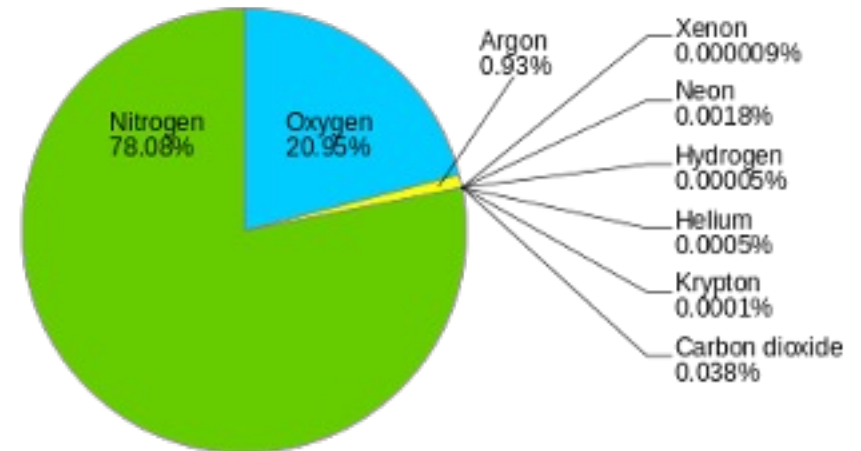
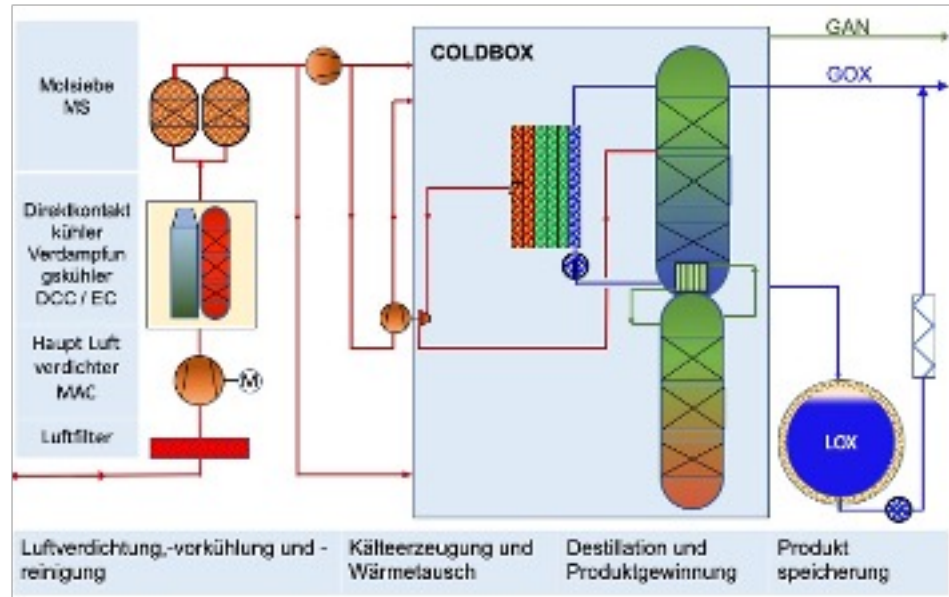
SLAC National Accelerator Laboratory

# Outline

- experience from XENON (co-spokesperson)
    - MPIK: ultra low background physics (GeMPIs, RGMS, ...)
    - bought a large fraction of the Xe inventory of XENONnT (ca. 10t)
      - ➔ & coordinated spot market buying for XENON ↔ LZ
    - talking to producers and other market players
  - discussions about the future of xenon based DM:
    - DARWIN
    - XLZD
- ➔ **insights into the xenon market**
- production
  - consumption
  - market parameters, inter-dependencies, ...
  - comments on alternative ideas, ...

# The traditional xenon market: production

→ xenon is a by-product of air liquification predominantly for steel production



→ cryogenic distillation: liquify & boil-off

LOX: increased fraction of Xe, Kr, ...

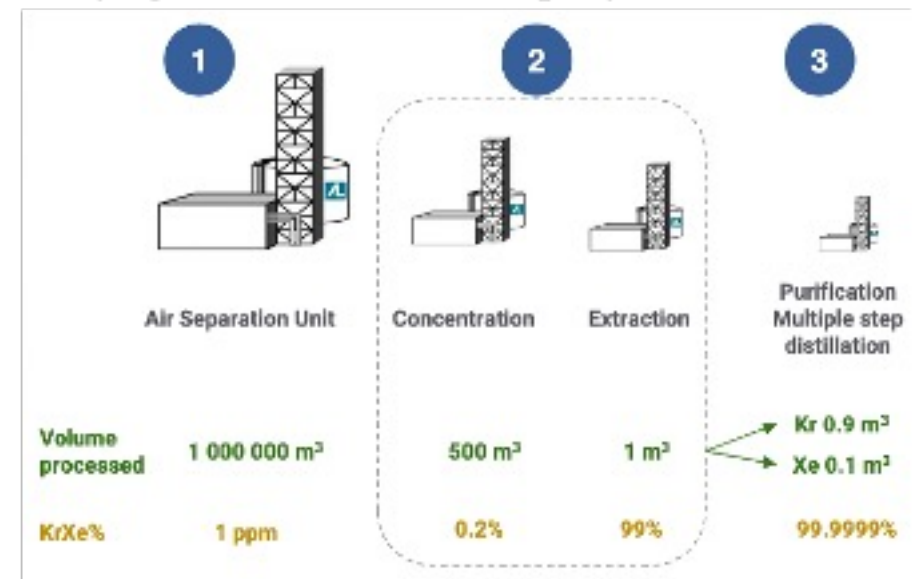
→ second round of distillation

→ further xenon-krypton enhanced 'crude'

→ further distilled to separate Xe and Kr

→ another distillation for highest purity Xe (6.0 or higher)

Nomenclature: 5.0 =  $10^{-5}$  = 99.999 purity



# The main bottleneck: ASU's

There exist  $O(500)$  (sizable) air liquification plants all over the world

Only a small fraction ( $\sim 1/5$ ) is equipped to produce rare gases

- traditionally high fraction in the former Soviet Union = Russia, Ukraine,...
- China growing rapidly...

Crude Xe/Kr production and Xe/Kr purification often in different countries

**Adding Xe/Kr production requires to specially equip ASU's:**

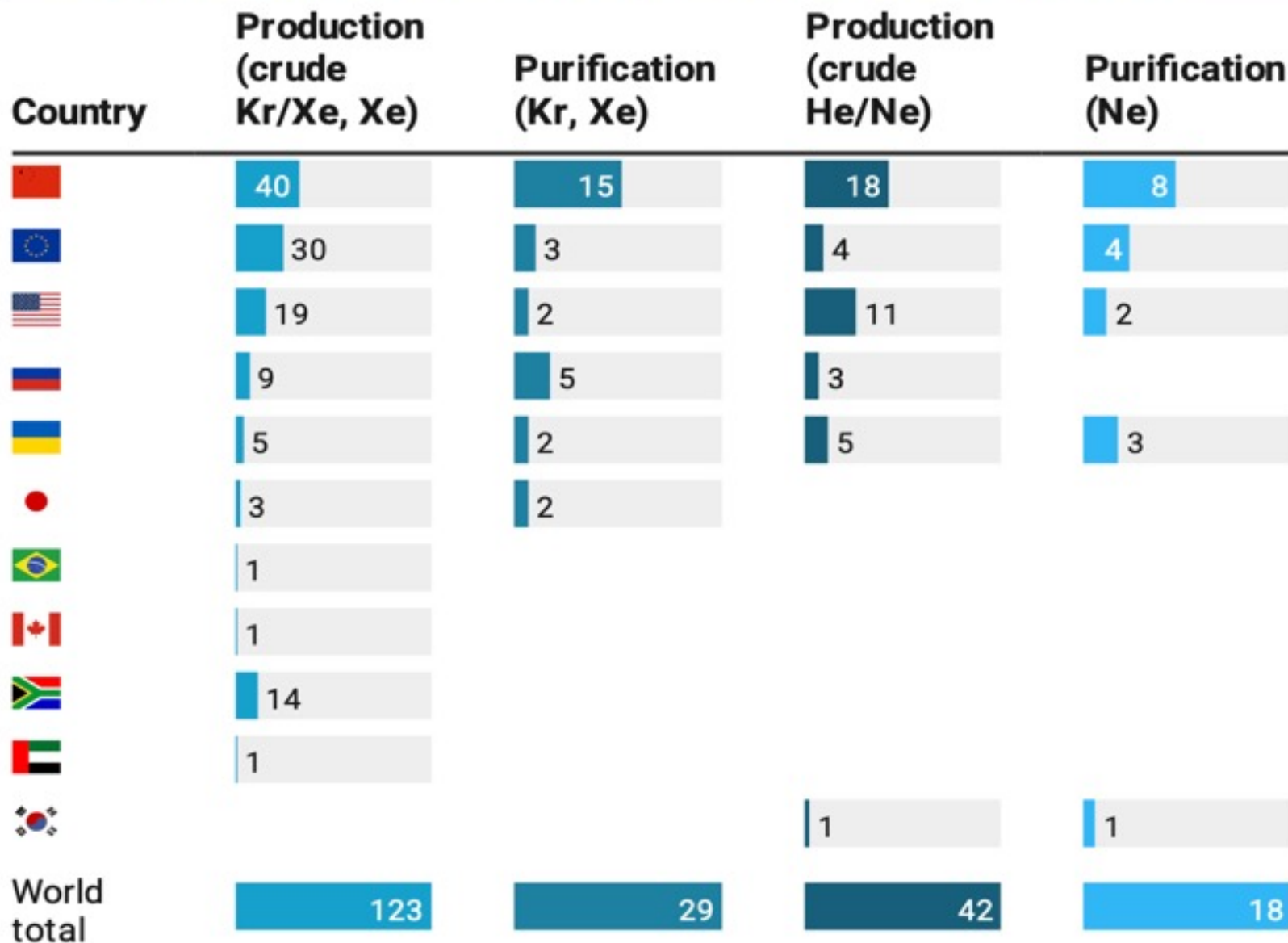
- financially not worth while to modify existing plants (cost/efficiency)
- financial threshold:  $O(80M€)$
- newly built ASU's or added upon replacement of existing ASU's
  - if prices are expected high enough for long enough  $\longleftrightarrow$  return of invest

**Overall world-wide xenon production (before Ukraine war):**

$\sim$  linearly growing. Now ca. 65 t / year; growth ca. 2t/year

$\sim$  ca. 90% are fixed term contracts with industry  $\rightarrow$  small spot market few t/year

# Number of ASU's by location



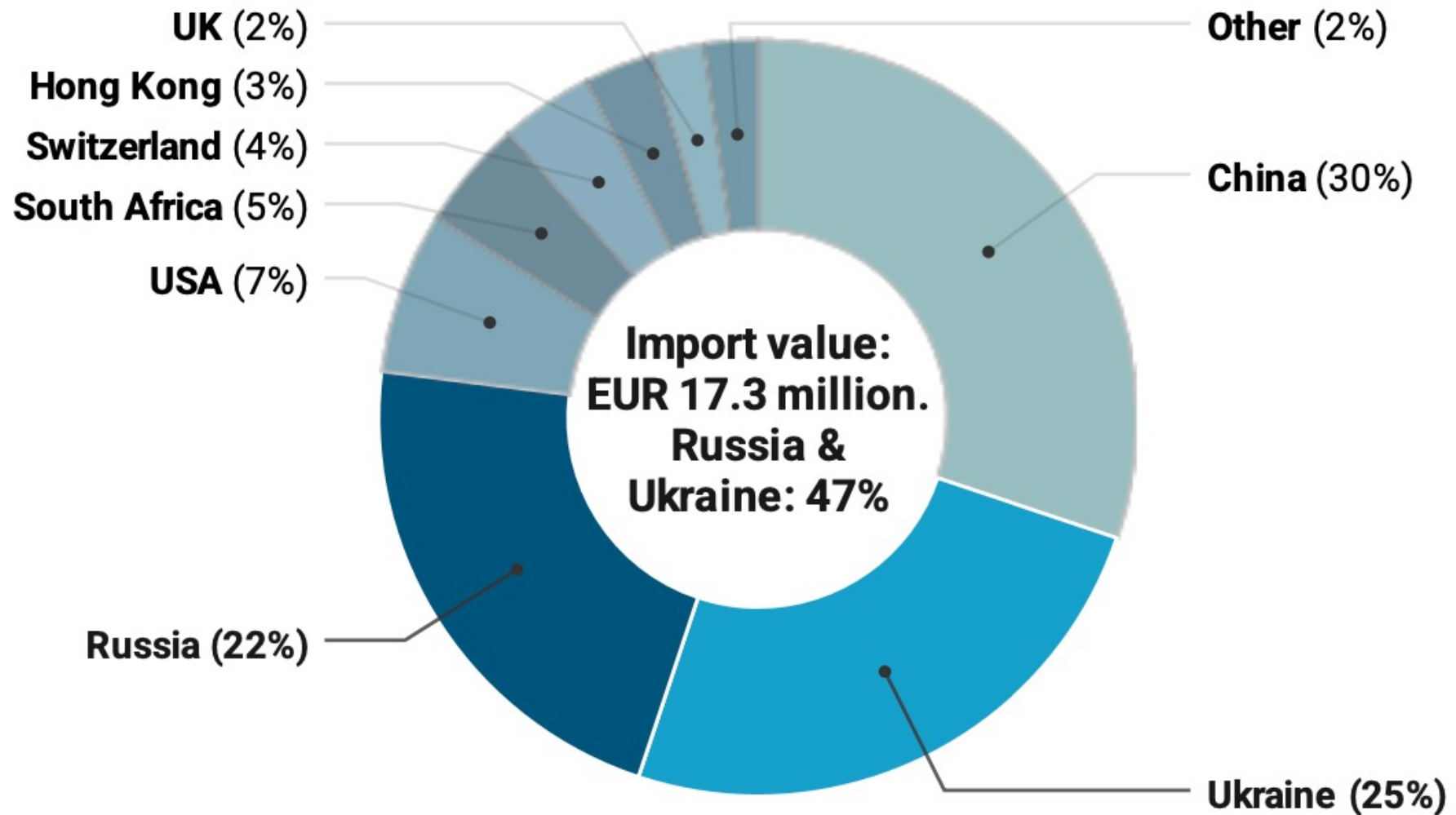
Source: Data from Elsner (2018) (except for South Korea<sup>8</sup>)



➔ strong perturbations from war in Ukraine and embargo regulations on Russia



## EU import value of rare gases<sup>16</sup> by origin, in 2021



Source: Eurostat Comext (2022).

# Commercial boundary conditions

- Xe/Kr is a by-product of steel production – otherwise extremely expensive  
←→ connected to the steel market ←→ overall economic development
- Who pays for Kr/Xe separation  
←→ Kr and Xe markets: demand ←→ uses
- The Krypton market:  
Insulation windows ←→ energy costs for heating  
lighting ←→ transition to LED's  
propellant for thrusters ←→ Xe price
- Typical Xe price range: 5-20\$ /liter ↔ threshold for investing into new ASU's
- Past price excursions due to unexpected events:
  - Iridium satellite plans
  - plasma displays
  - now: Ukraine war...



## Recent developments during due to Ukraine war:

- a large fraction of the Ukrainian production is missing
- embargo policies  $\leftrightarrow$  Russian suppliers

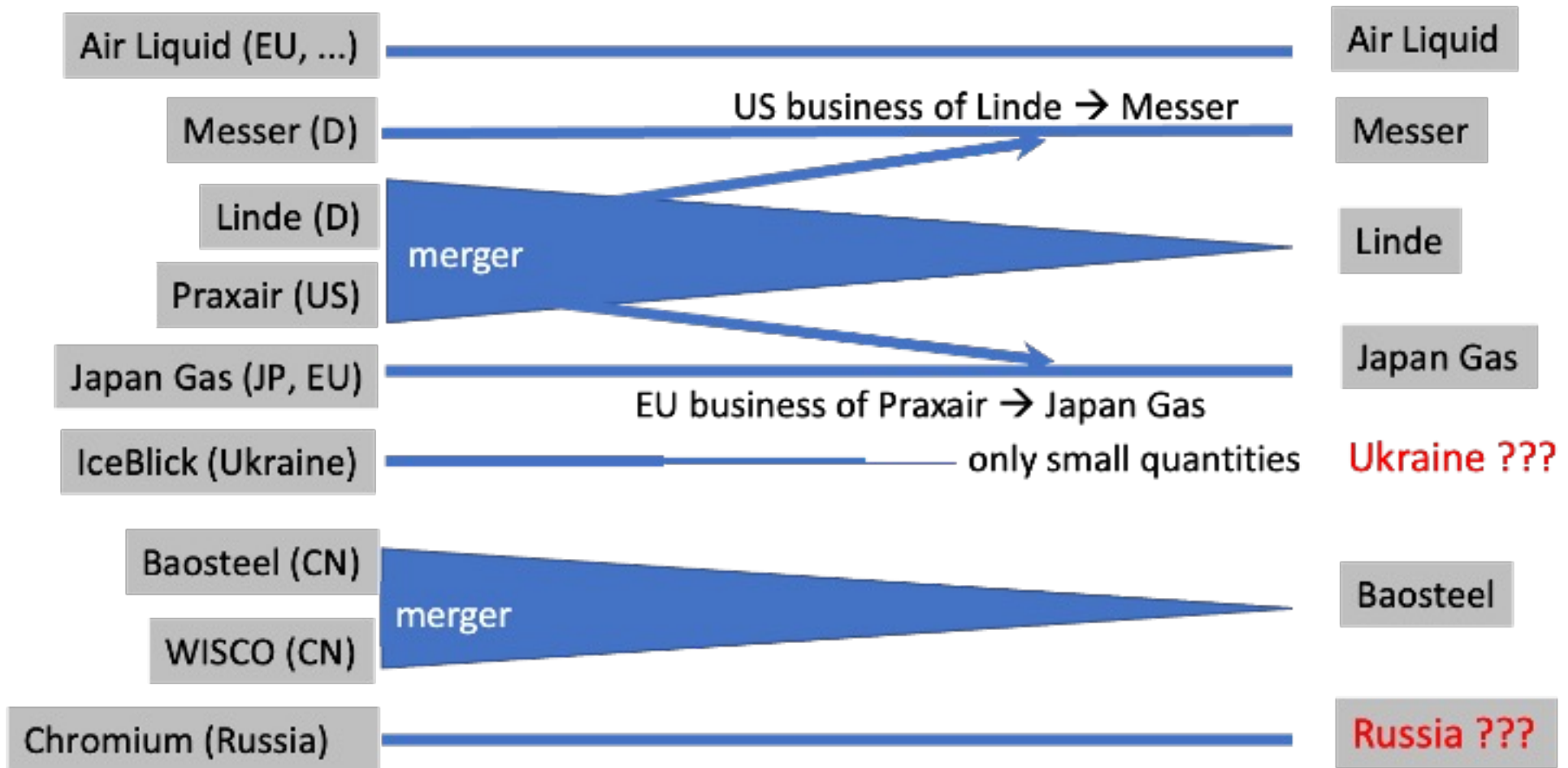
## Consequences:

- very volatile market
- consumers moving to alternative solutions:
  - e.g. Starlink → argon (lifetime of thrusters  $\leftrightarrow$  cost of replacement)
  - ...
- in addition: general market trends
- prices went very high even beyond 1000\$/liter

## Changes:

- A) gas companies think about new ASU's in other countries
  - time scales?
  - is on-going...
- B) embargo by-passing: xenon from Kasachstan? ...more from China?, ...
  - prices have significantly dropped, even \$10/L , market still volatile...

# Evolution of major xenon producers

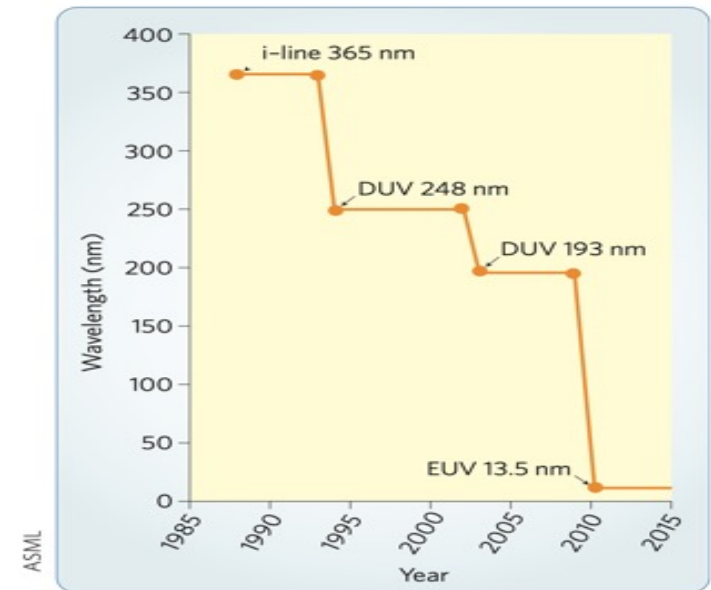


- Additional companies: Airgas, Air Water, American Gas, BASF, Core Gas, Matheson Tri-Gas, Proton Gas, ... ~ **only small quantities**
- Ukraine/Russia: expect new ASU's in other countries  $\leftrightarrow$  high prices/investments
- China: Growing

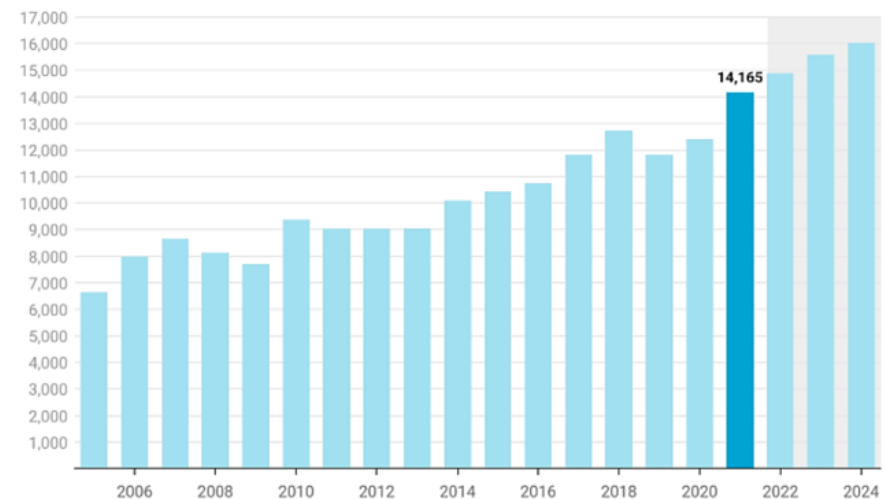
# Xenon consumers

## Electronics industry chip production

- EUV lithography → smaller structures
- for years: xenon @ EUV systems (ASML)
- moving to tin (metal...) → **less xenon**
- 3D NAND storage chips → **growing**
- sensor chips (Xe etching) → **growing**



Shipments of silicon materials<sup>6</sup> globally (2005-2021) and shipments forecast (2022-2024), in millions of square inches (MSI)



Source: Background data from SEMI (2021), SEMI (2022)

**net effect:  
growing demand**

## **Aerospace: Thrusters for space missions**

- traditional agencies (NASA, ESA, ...)
- new commercial players (SpaceX, ...)
- military...

momentum transfer and lifetime of thrusters:

- better for xenon → deep space, long term missions
- replacements: krypton, argon, ...

## **Lighting industry:**

- Xe lamps for cars, cinematography, ...
- declining demand ↔ LED's - some applications will remain

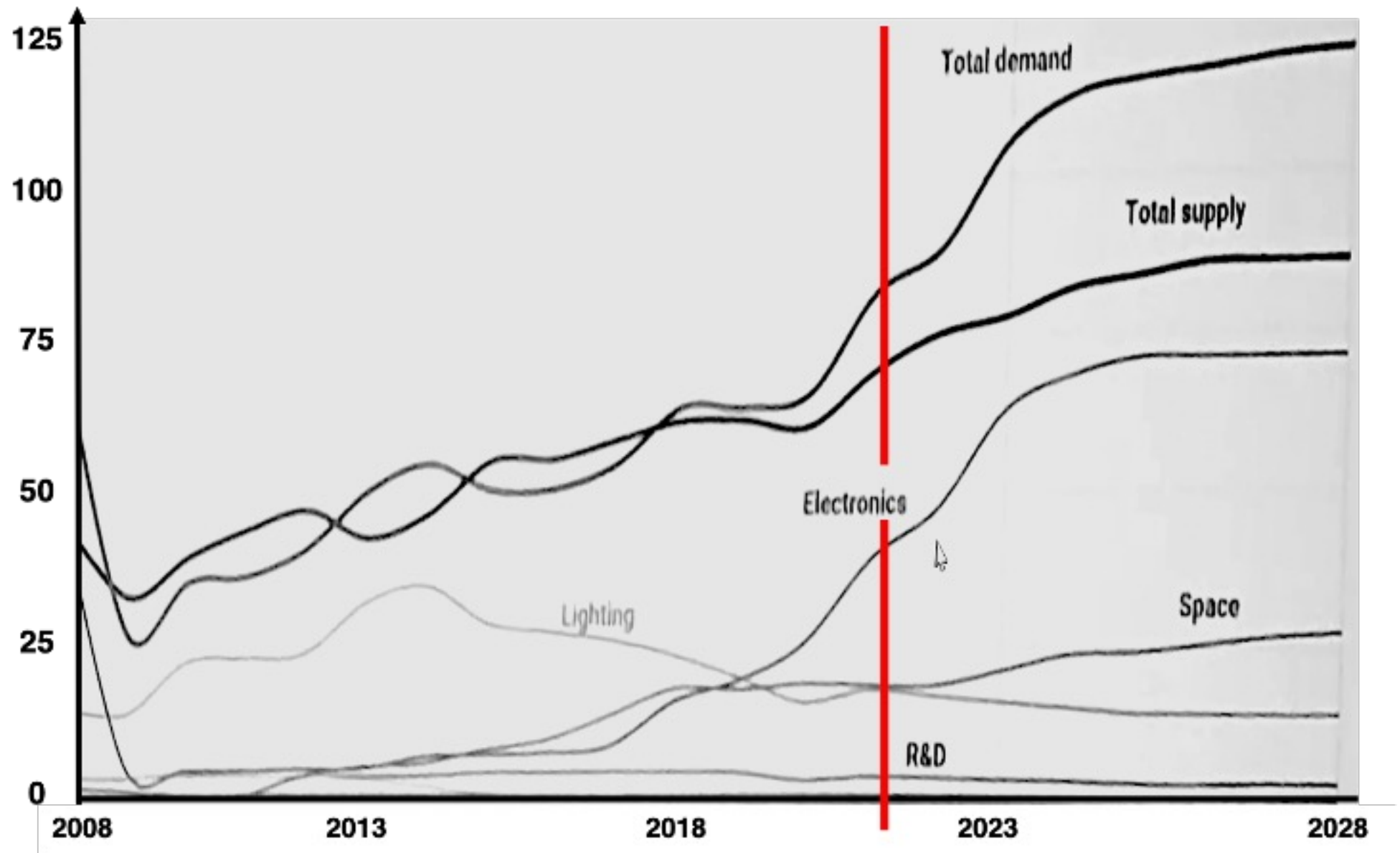
**Medical:** anesthetics, CT scan, ... → small fraction

**Psychopharmaca:** antidepressant- and anxiolytic-like effects

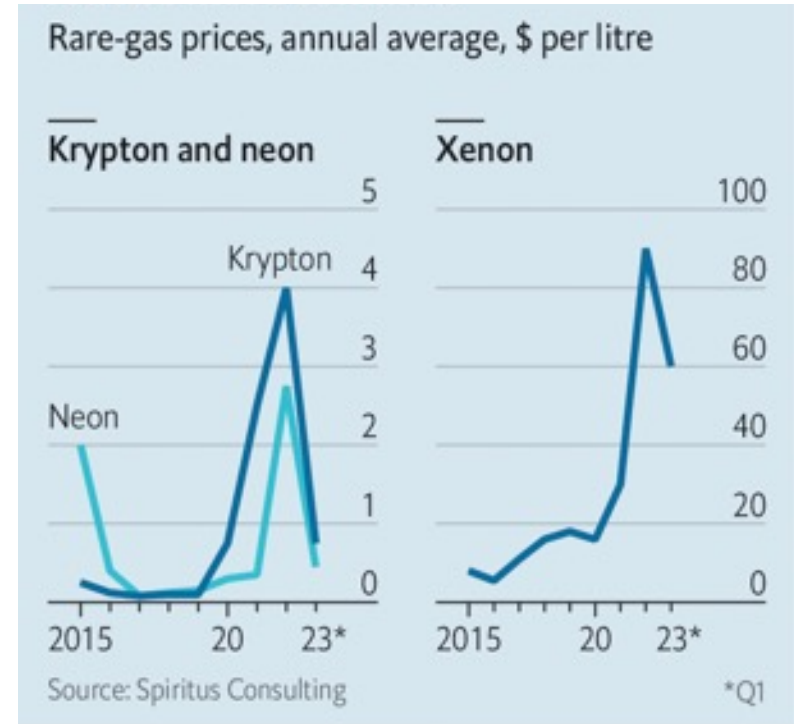
**Doping:** ...

**Science:** dark matter,  $0\nu\beta\beta$ , other → growing

# Supply versus demand (t/y)



# Price Dervevelopment (\$/L)



The Economist

# Other remarks

- **Enrichment:** → centrifuges → Russia (Krasnoyarsk, ...) ↔ access/embargo?
  - other countries with smaller capacities → no problem for small quantities
  - bigger quantities:
    - build-up of new facilities?, embargo bypassing?, new ideas
    - big enriched quantities have a restricted market ↔ price, perturbations
- **Alternative production ideas:**
  - important R&D – may change everything (see talk by S. Sangiorgio)
  - not easy to beat ASUs where energy costs are paid by others (steel industry)
  - investment costs compared to ASU?
  - ASUs: cost of crude production shared between Xe and Kr
  - adsorption of noble gasses varies tremendously → make use of it
  - thruput of many tons of air...
  - keep R&D going, but don't rely on it if you plan now



# Summary

- many aspects of xenon production and consumption  $\leftrightarrow$  many market factors
  - growing xenon market  $\leftrightarrow$  increasing demand
  - return of invest  $\leftrightarrow$  typical price range \$5-\$20
  - market perturbations  $\rightarrow$  relaxation:
    - Ukraine  $\leftrightarrow$  no quick return to market, but new ASUs elsewhere
    - Russia: embargo bypassing
- $\rightarrow$  questions / speculations
- how much for science per year? my guess for so far: 5t/y = 1 ML  $\rightarrow$ ???
  - if all ASUs in the world were equipped  $\rightarrow$   $\sim$ x5  $\rightarrow$  ca. 350 t/y
  - BUT: return of invest would require a constant demand from other consumers
    - $\rightarrow$  not soon...
  - xenon stockpile of experiments is a commodity
    - $\rightarrow$  what if big quantities come back to the market?
    - $\rightarrow$  big market perturbations which are in nobody's interest!
    - $\rightarrow$  big quantities of depleted xenon & restricted market usage