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Antoine Perelman, Vincent Barth, Fabien Mandorlo, Eszter Voroshazi

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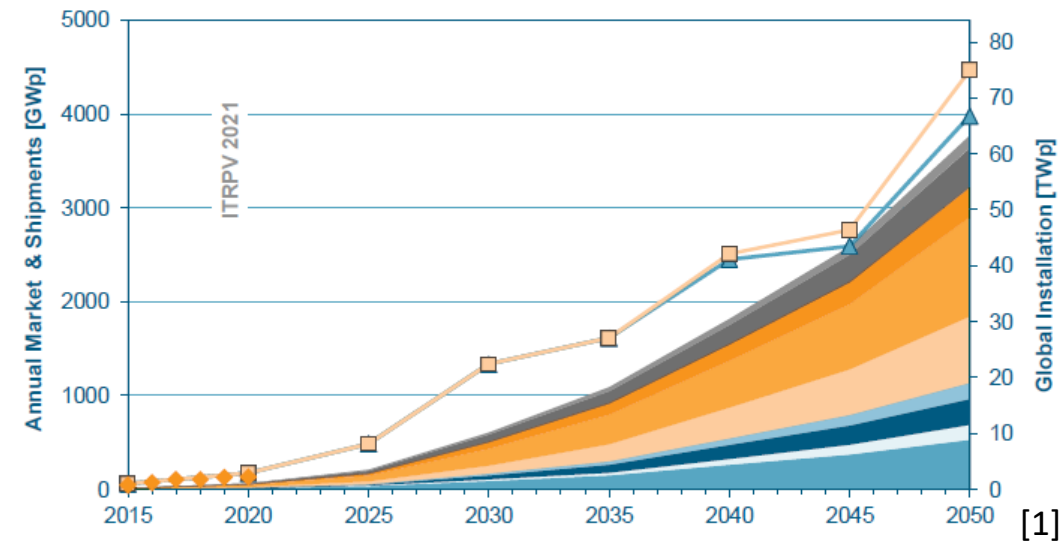
## Critical material reduction in PV interconnection

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## CONTEXT – ENERGY TRANSITION

- **From fossil fuels to renewable energy**
  - Metals demand booming
  - Ensure raw materials supply
- **PV sector is scaling up...**
  - TW annual capacity production before 2030 !
- **... but is getting close to glass ceilings on Silver [2]**
  - Rising and volatile prices
  - Scarcity

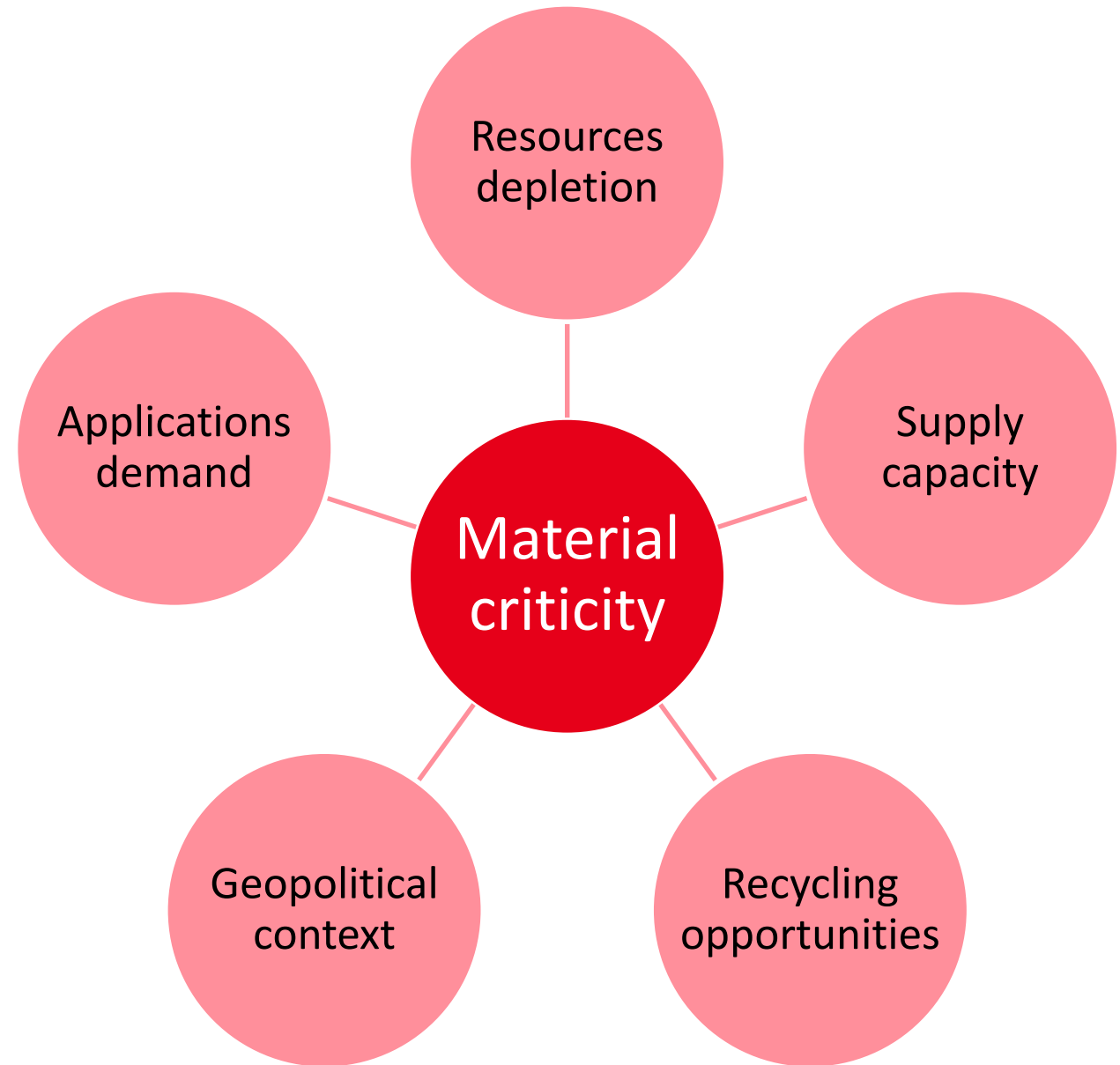


[1] « ITRPV 2021 ».

[2] Zhang et al., « Design Considerations for Multi-Terawatt Scale Manufacturing of Existing and Future Photovoltaic Technologies ».

## CRITICAL MATERIAL – A DEFINITION ?

- **Critical material = hazardous supply material**
  - « materials that are the most important on economic level and present a high supply shortage hazard are called *critical raw materials* » [1]
  - « Critical metal : remarkable properties metal that can trigger great industrial or economical negative impacts linked to difficult supply, prone to risks » [2]
- **≠ sets of criteria in littérature**
  - ≠ conclusions ..!

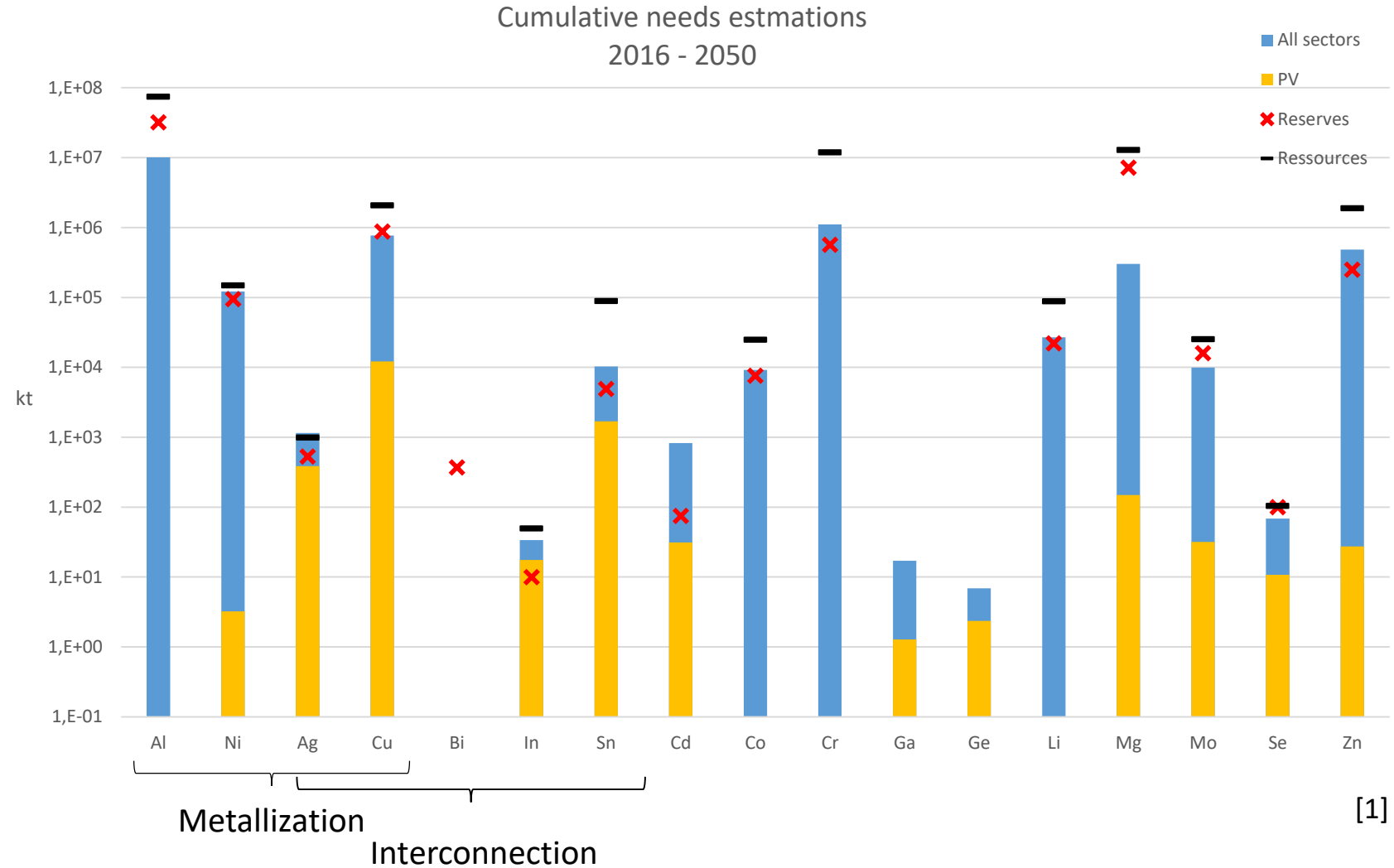


[1] « CE Résilience des matières premières critiques: la voie à suivre pour un renforcement de la sécurité et de la durabilité », Commission Européenne, sept. 2020.

[2] BRGM, mineralinfo.fr

# CRITICAL MATERIAL – RESERVES AND RESOURCES DEPLETION

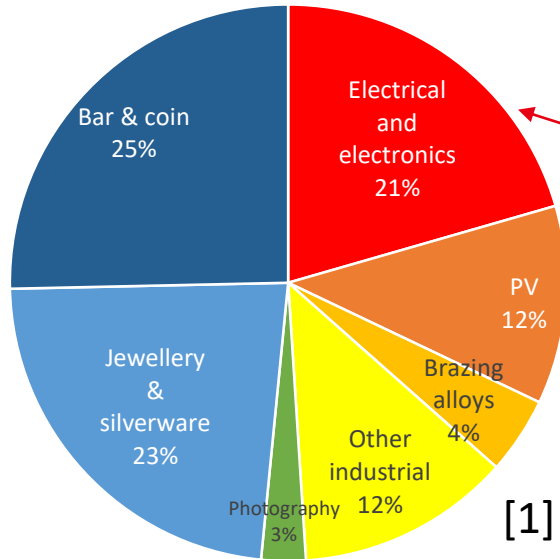
- Focus on strategic and critical resources in the last decade
- On the edge of a mineral rush..!
  - Mineral crisis will happen before end of reserves



[1] From A. Valero, A. Valero, G. Calvo, et A. Ortego, « Material bottlenecks in the future development of green technologies », *Renewable and Sustainable Energy Reviews*, oct. 2018 and USGS Mineral Commodity Summary 2022

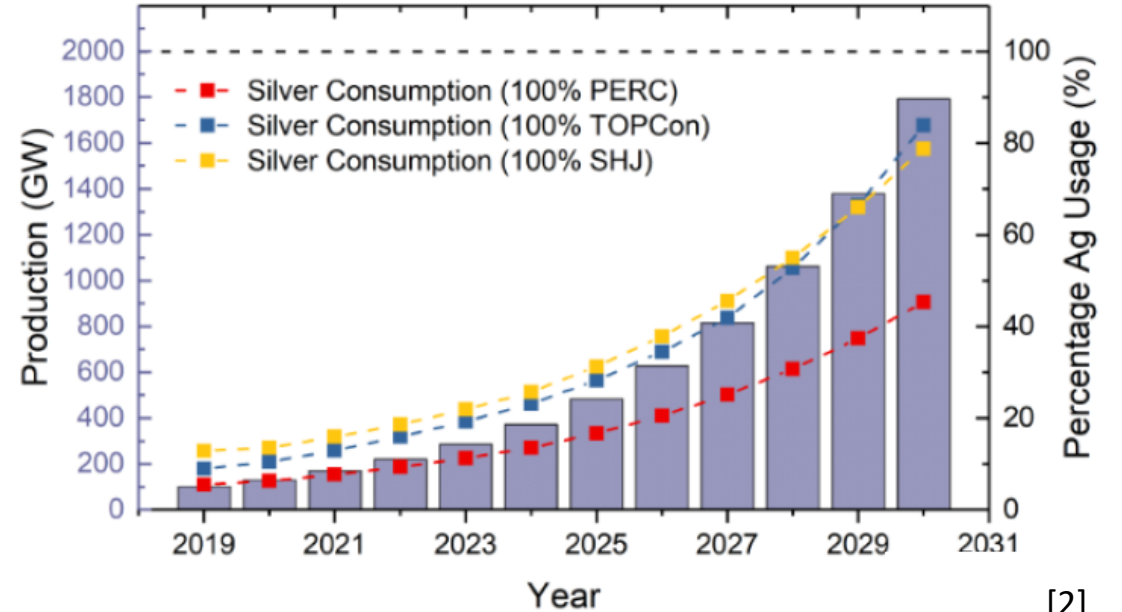
# CRITICAL MATERIAL – APPLICATIONS COMPETITION

2021 Silver demand



[1]

PV & Electric vehicles ↗↗↗



[2]

➤ **Prioritization**

[1] Silver Institute

[2] Zhang et al., « Design Considerations for Multi-Terawatt Scale Manufacturing of Existing and Future Photovoltaic Technologies ».

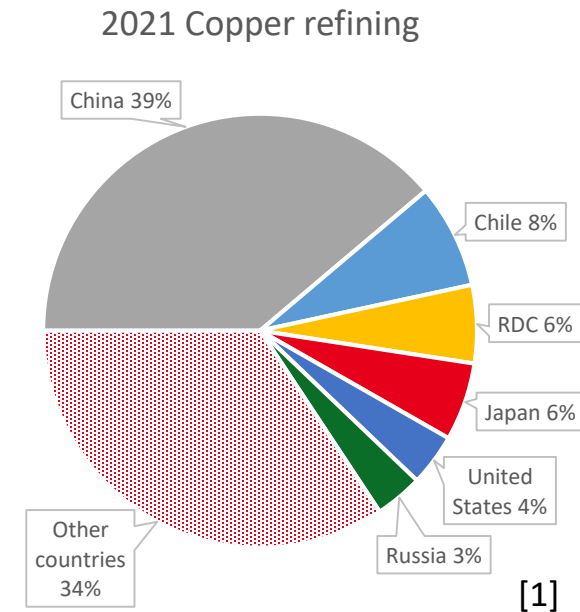
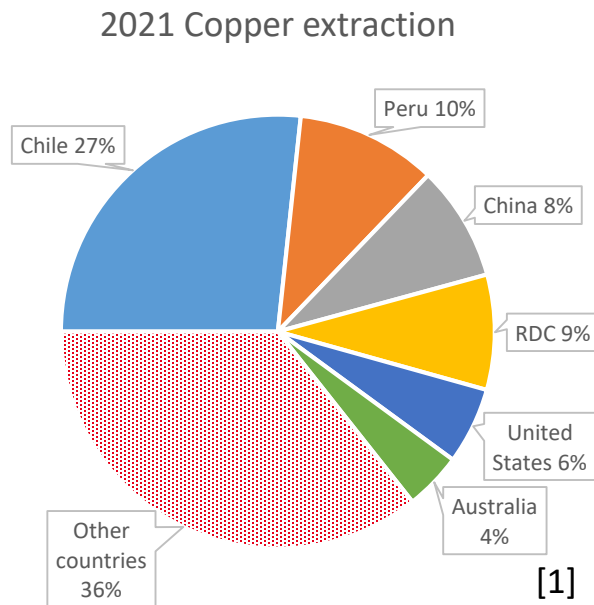
## CRITICAL MATERIAL – GEOPOLITICAL CONTEXT

- **High concentration of material extracting and refining**

- Copper: 8 countries ≈ 65 % of global extracting and refining
- Hazards of monopolistic behaviors

- **Critical material supply as a leverage**

- Chinese embargo on Rare earth's against Japan in 2010 [2]
- Indonesian embargo on Nickel for protectionism in 2011 and 2022 [3]



[1] « Mineral Commodity Summaries 2022 », United States Geological Survey, 2022.

[2] B. Pedroletti, « En Indonésie, ruée vers le nickel, or noir du futur », Le Monde, 11 novembre 2022.

[3] A. Valero, A. Valero, et G. Calvo, « Resumen y análisis crítico del informe especial de la Agencia Internacional de la Energía: El Rol de los minerales críticos en la transición hacia energías limpias », Revista de Metalurgia, juill. 2021

## MINING, EXTRACTING AND REFINING IMPACTS

- Mining, extracting and refining activities are dangerous...
  - Huge consumption of water, chemicals and energy
  - Long-term air and ground pollution
  - 1<sup>st</sup> waste producing sector in the world (As, Sb, Hg, Cr...)
  - 8 to 10 % of global energy consumption [2]



[1] © Alex Kokcharov · Twitter

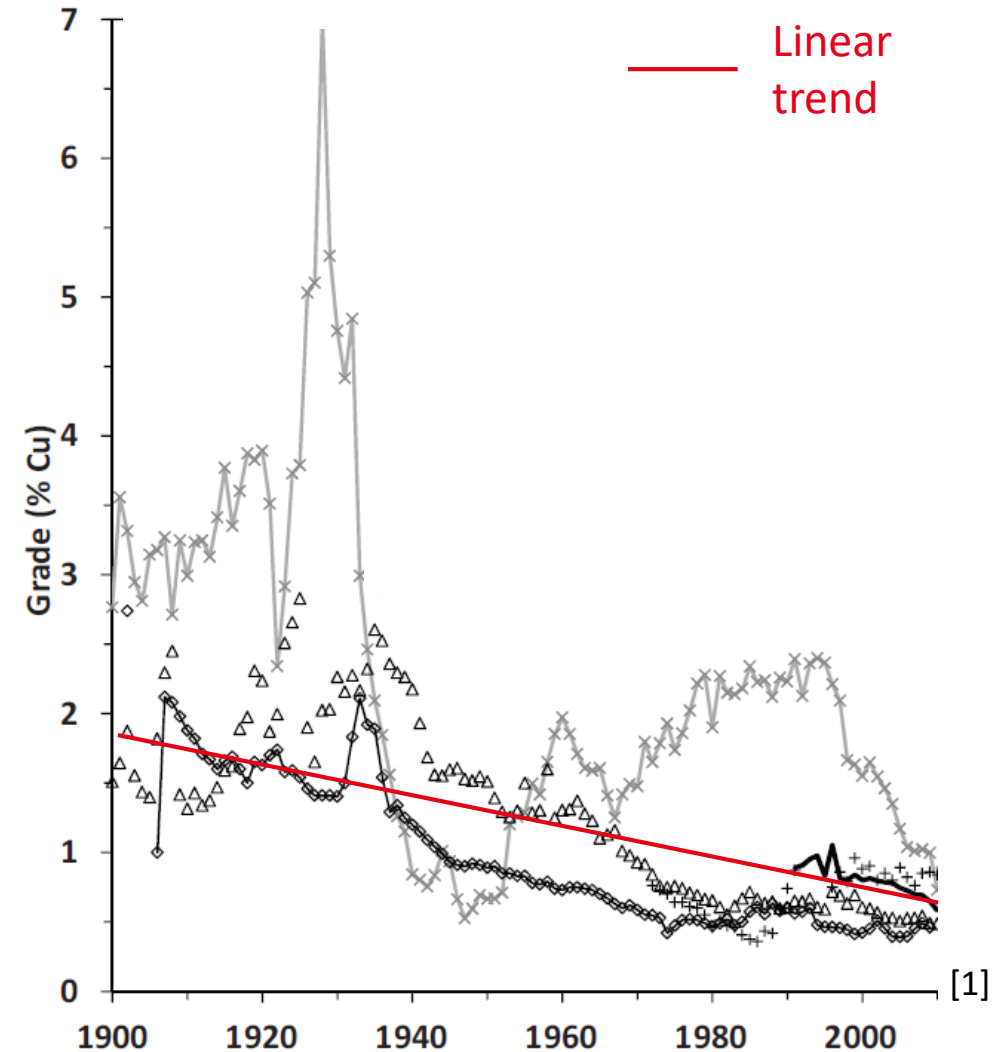
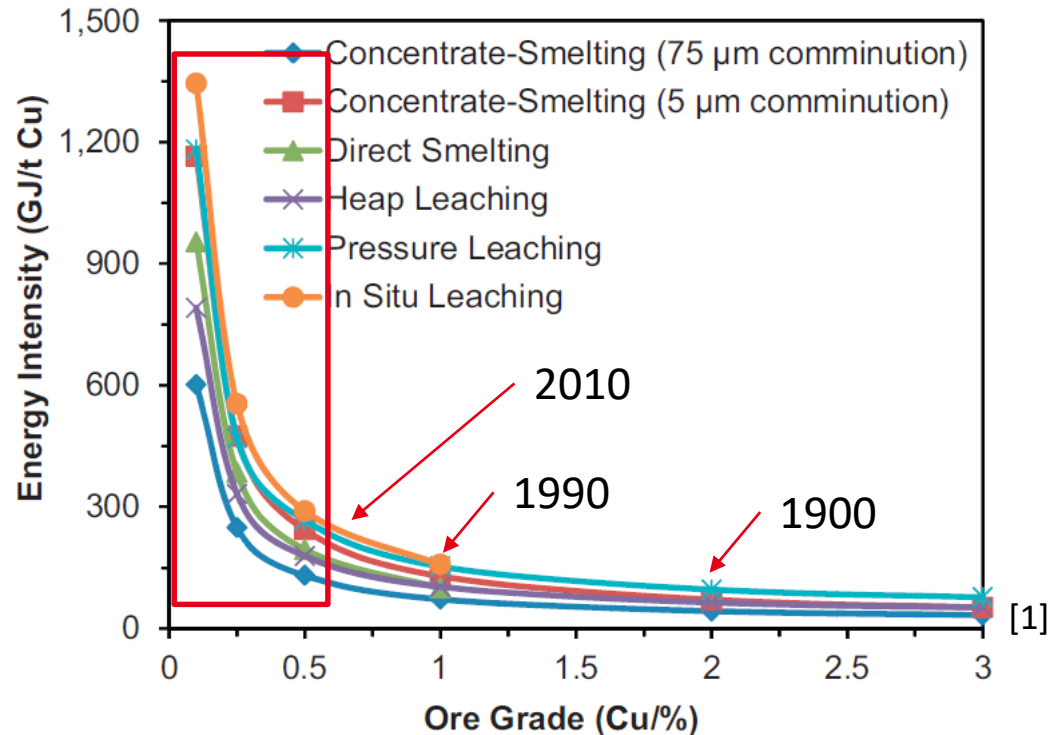
[2] IEA

[3] © Dillon Marsh (top picture) - « Controverses minières - Pour en finir avec certaines contrevérités sur la mine et les filières minérales - Volet 1 », SystExt, nov. 2021 (bottom picture)



## MINING, EXTRACTING AND REFINING IMPACTS

- Mining, extracting and refining activities are dangerous...
- ... and it is to worsen :  $\searrow$  ore grade =  $\frac{\text{Quantity of metal}}{\text{Quantity of extracted rock}}$ 
  - ↗↗↗ energy, water and material intensive processes
  - ↗↗↗ wastes production



[1] S. Northey, S. Mohr, G. Mudd, Z. Weng, et D. Giurco, « Modelling future copper ore grade decline based on a detailed assessment of copper resources and mining », *Resources, Conservation and Recycling*, oct. 2013

## CRITICAL MATERIALS IN PV INTERCONNECTION

Element	Involved in other parts	Ressources depletion	Supply capacity	Recycling	Applications competition	Geopolitical context
<b>Sn</b>						
<b>Bi</b>						
<b>In</b>	TCO					
<b>Ag</b>						
<b>Cu</b>	Cables					
<b>Ni</b>						
<b>Al</b>	Frame					

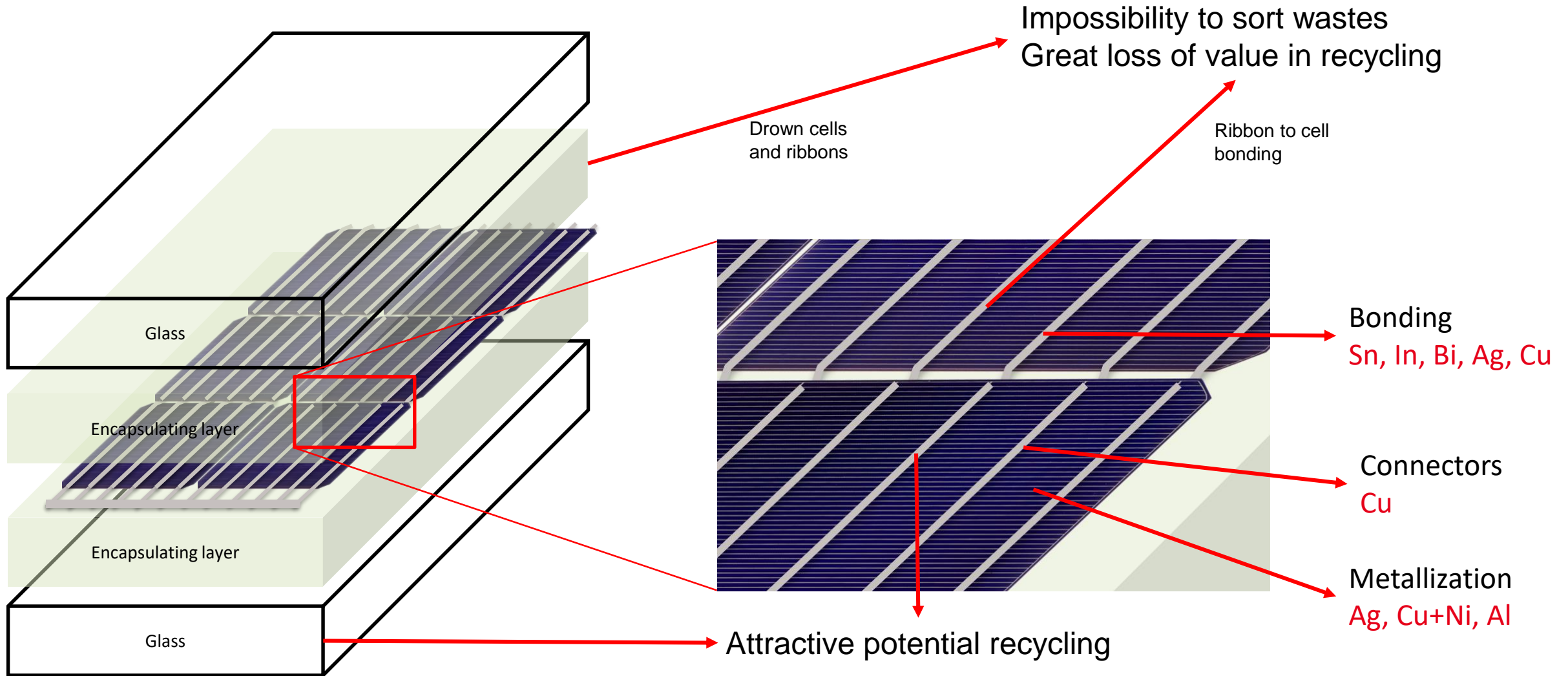
Bonding

- Soldering
- ECA

Metallization

- Printing
- Plating

# LIMITS OF STANDARD MODULE ARCHITECTURE



## RECYCLING : WHICH TARGET ?

High value recycling	Low value recycling
↘ energy/material intensive	Lower-than-predicted rates
Can improve waste sorting	Impossible on integrated devices
Needs care from conception	Needs waste management chains [1]
Additional constraint	Easy to apply

- **Ecoconception**

- Include end-of-life in conception
- Build a device **ONLY** when you know how to treat it once it's broken

- **In PV**

- X Bonding (soldering or ECA)
- X Adhesion between encapsulating layers and cells strings

- **Where is the added value in a device ?**

- PV cells > rest of PV module



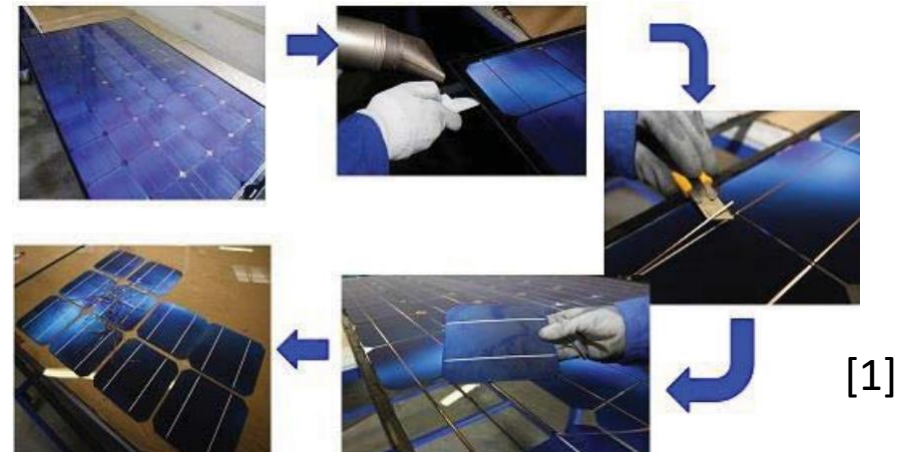
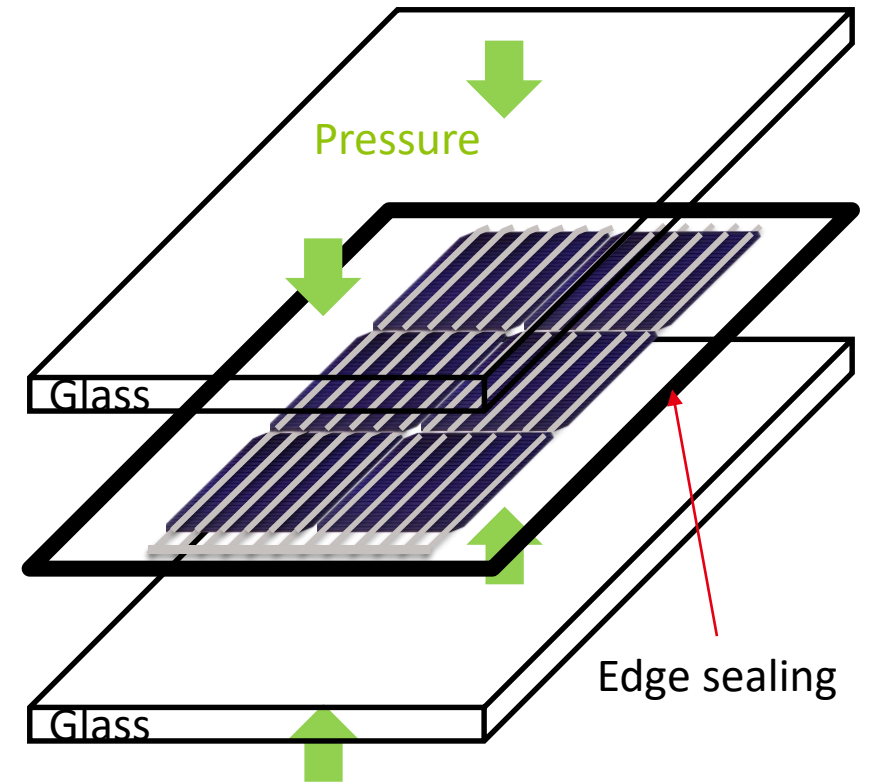
[1] R. J. Garcier et F. Verrax, « Critiques mais non recyclées : expliquer les limites au recyclage des terres rares en Europe », *Flux*, juin 2017.

[2] NREL, <https://www.nrel.gov/news/program/2021/to-toss-repair-or-recycle-how-human-behavior-affects-the-fate-of-aging-solar-panels.html>

# RECYCLABILITY AIMED ARCHITECTURE

## NICE CONCEPT [1]

- X Encapsulating layer
- X Bonding ribbon to cell
- Edge sealing
- Underpressure in the module to keep ribbons on the cell



[1]

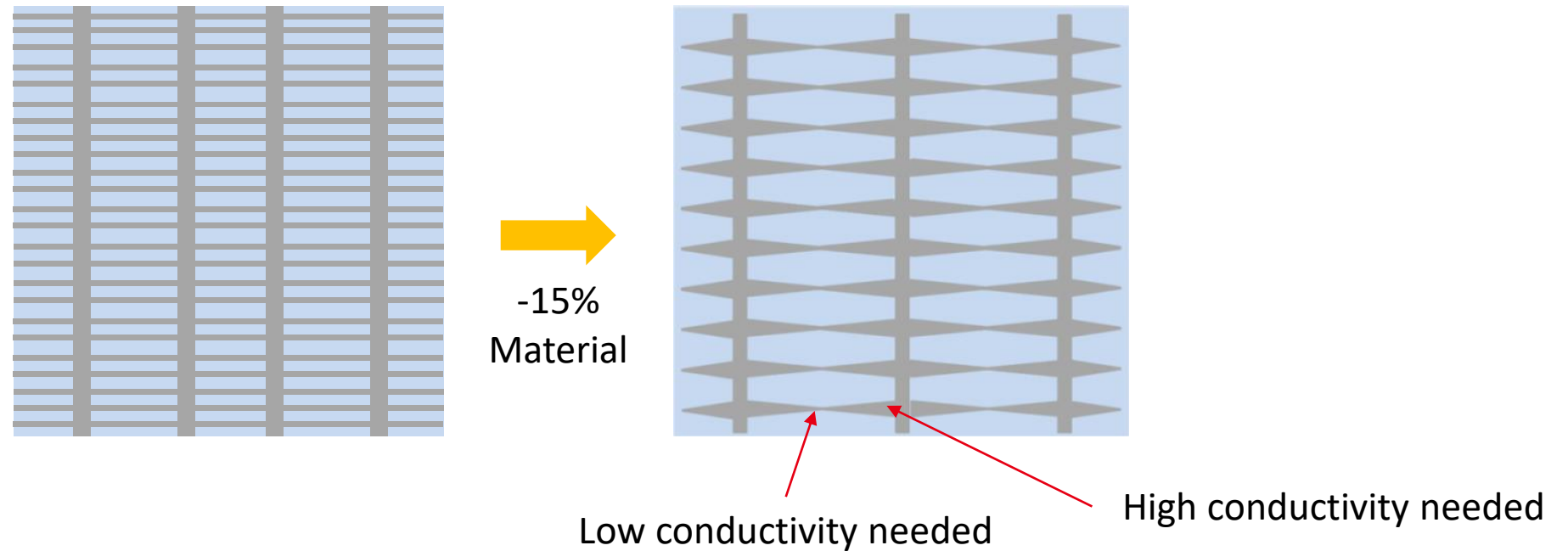
NICE	Standard
≠ optical indices glass/air/cell	Optimization of optical indices progression
Components separability	Harsh to recover components

[1] R. Einhaus et al., « Recycling and Reuse potential of NICE PV-Modules », in 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC), juin 2018

# MATERIAL CONSUMPTION REDUCTION ARCHITECTURE

## NON UNIFORM METALLIZATION [1]

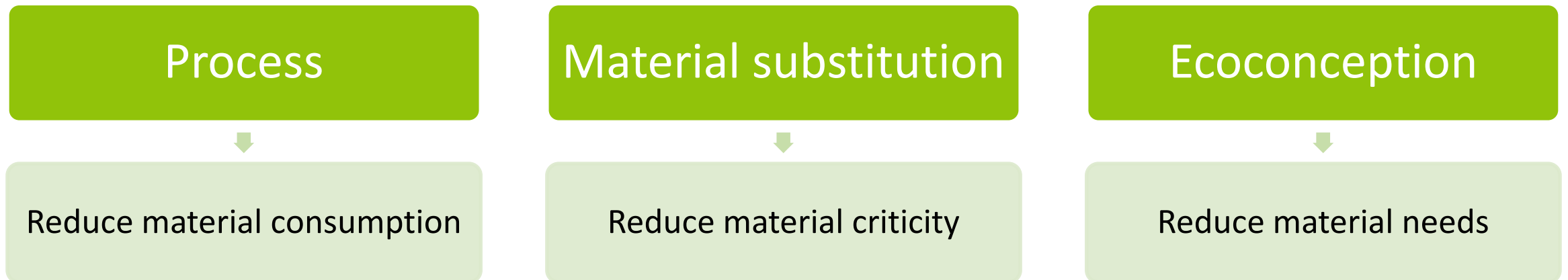
- Relevant geometry to reduce resistive losses in fingers while reducing material
- Ability to relax geometrical constraints



[1] M. Galiazzo *et al.*, « Fine Line Double Printing and Advanced Process Control for Cell Manufacturing », *Energy Procedia*, avr. 2015

## CONCLUSIONS & PERSPECTIVES

- **Raw materials supply will face various hazards**
  - Geological availability
  - Logistical capacity
  - Recycling challenge
  - Geopolitical tensions
  - Markets trends
- **PV sector has to adress challenges to ↘ dependance to raw materials supplies...**
  - Go on ↘ material consumption
  - ↗ recycling requirement
- **... but has different leverages at disposal :**





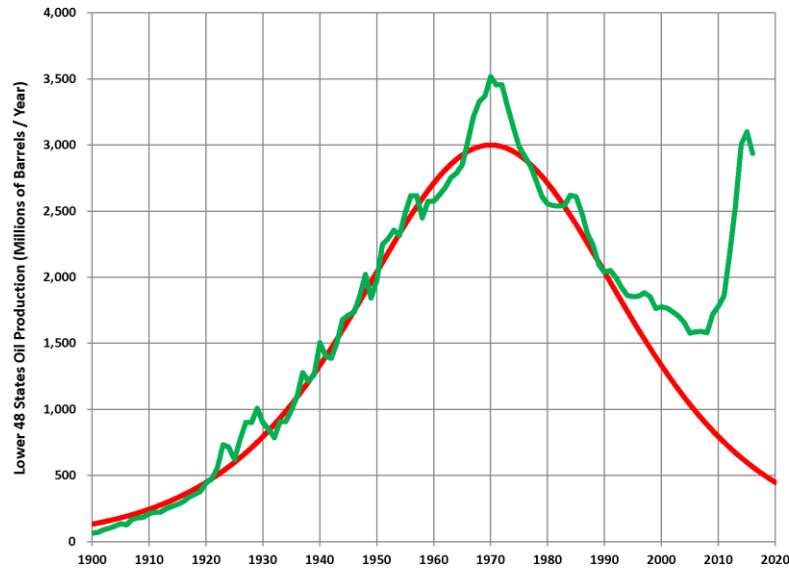
Thanks to  
Interconnection team  
and Metallization team  
in INES for discussion





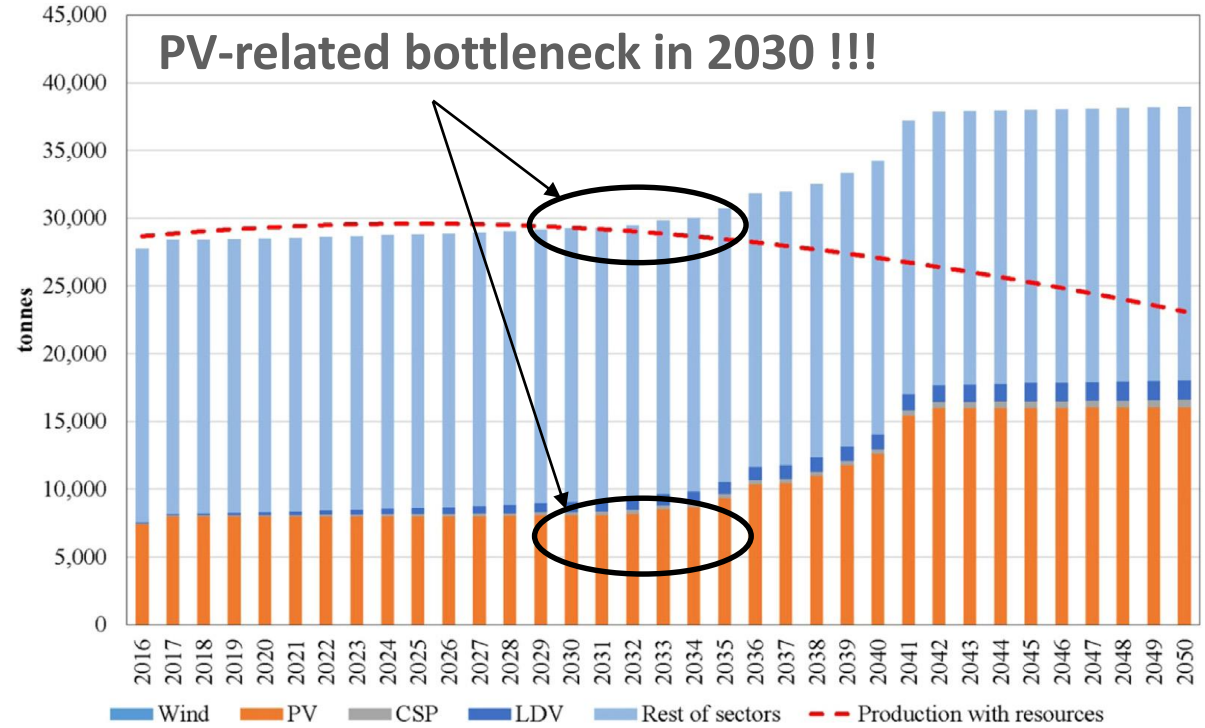
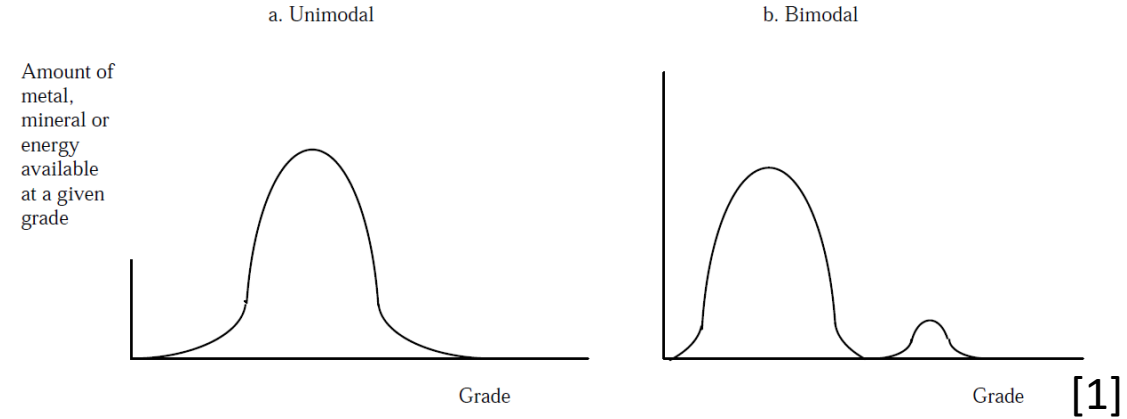
# CRITICAL MATERIAL – SUPPLY CAPACITY

- Ability to constantly satisfy material demand
- Logistical criteria
- Major issue : bottlenecks
- Sensitive to new major application → Electric vehicles
- Bismuth: high dispersion in Earth’s crust



[1]

[1] B. J. Skinner, « A second iron age ahead? », 1976

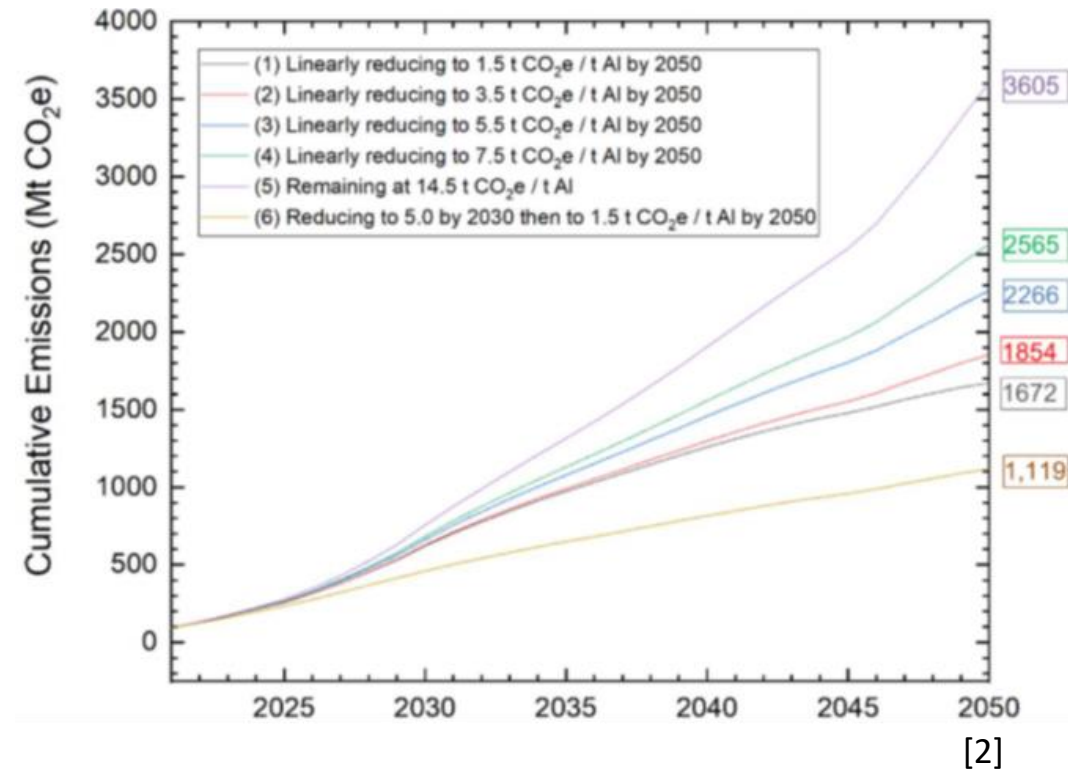


[2]

[2] A. Valero, A. Valero, G. Calvo, et A. Ortego, « Material bottlenecks in the future development of green technologies », *Renewable and Sustainable Energy Reviews*, oct. 2018

## CRITICAL MATERIAL EXCEPT PV INTERCONNECTION

- **Copper for the cables**
  - PV plants = long cables to connect few production sites to multiple consumption sites
  - System level power transmission = almost all Copper demand in PV [1]
  - Thinking PV plants as nuclear, hydro or coal plants is not relevant
- **Aluminum for the frames and glass for the protective plate**
  - High energy consumption → GHG budget

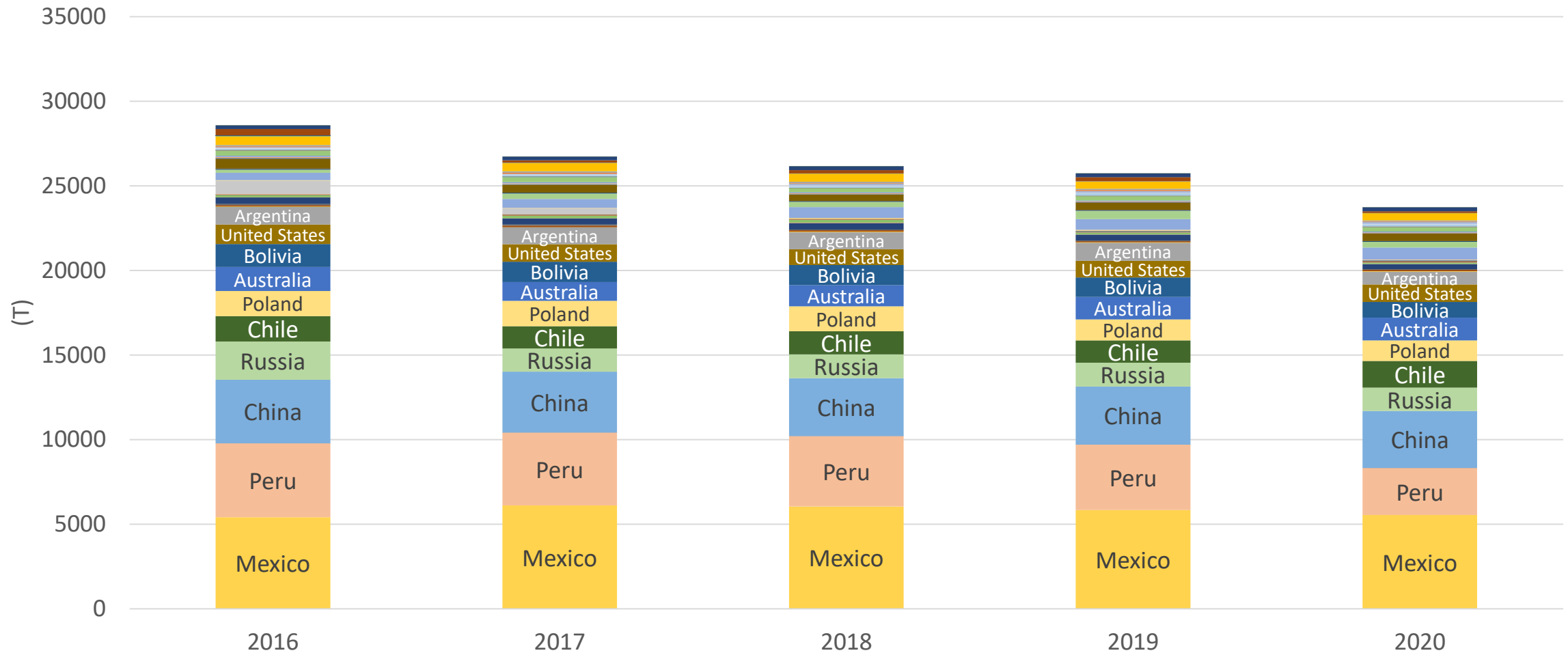


[1] Y. Zhang, M. Kim, L. Wang, P. Verlinden, et B. Hallam, « Design considerations for multi-terawatt scale manufacturing of existing and future photovoltaic technologies: challenges and opportunities related to silver, indium and bismuth consumption », 2021

[2] A. Lennon, M. Lunardi, B. Hallam, et P. Dias, « The Aluminium Demand Risk of Terawatt Photovoltaics for Net Zero Emissions by 2050 », preprint, sept. 2021

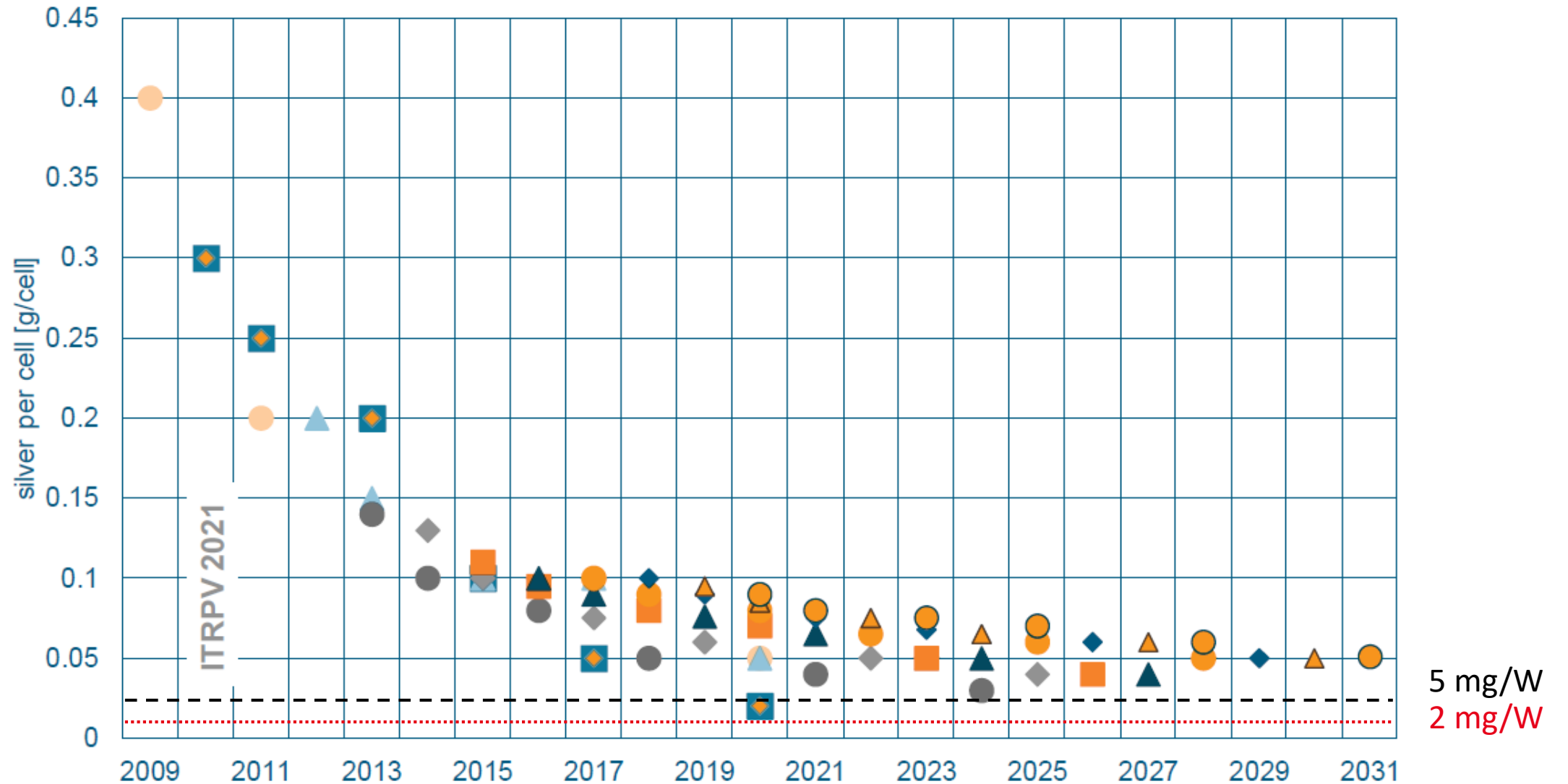
## CRITICAL MATERIAL – SUPPLY CAPACITY

Silver production 2016-2020



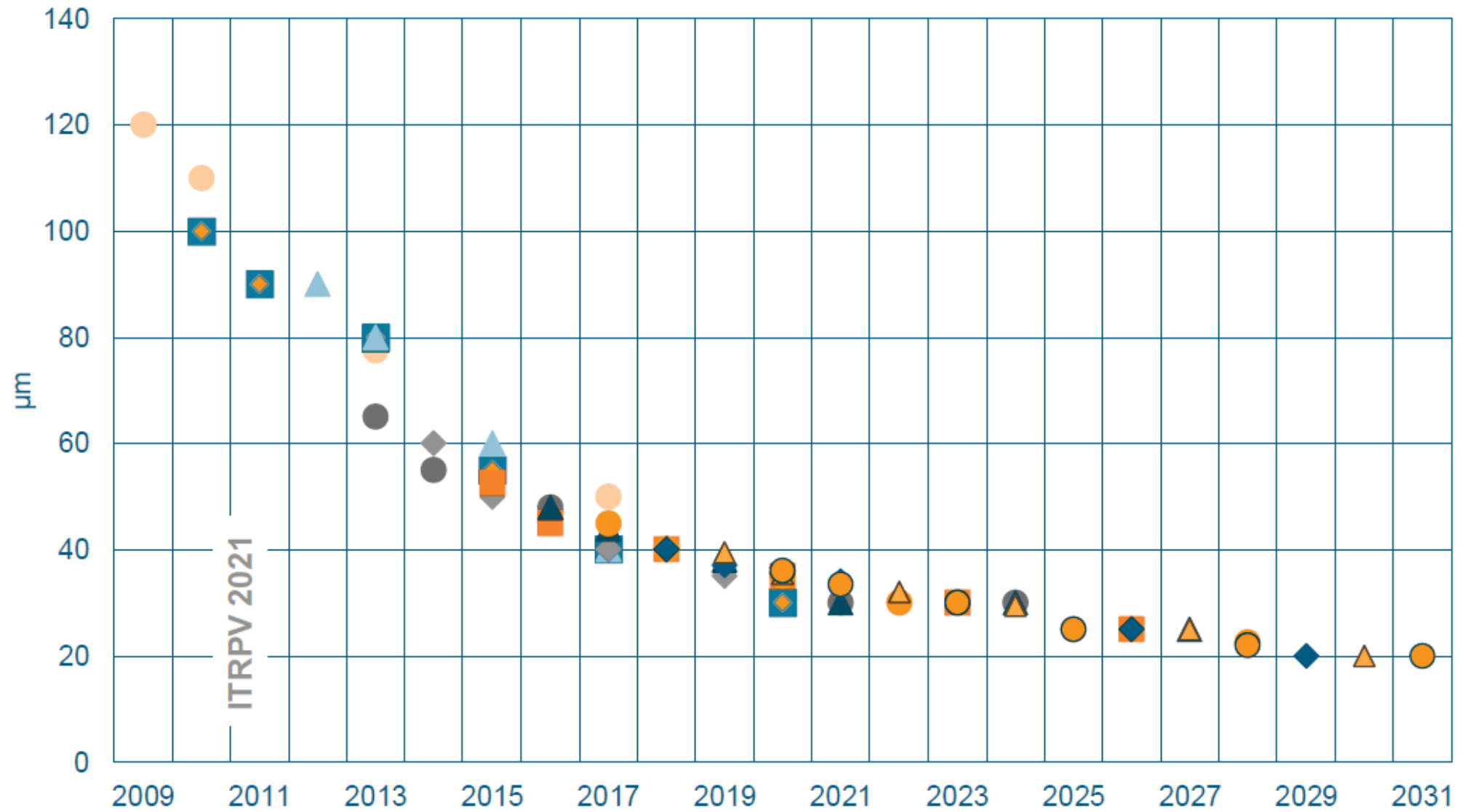
[1] J. E. Athey et M. B. Werdon, « Mineral Yearbook Silver 2020 », Alaska Division of Geological & Geophysical Surveys

# SILVER METALLIZATION CONSUMPTION PER CELL



[1] ITRPV 2021, VDMA

# FINGER WIDTH



[1] ITRPV 2021, VDMA