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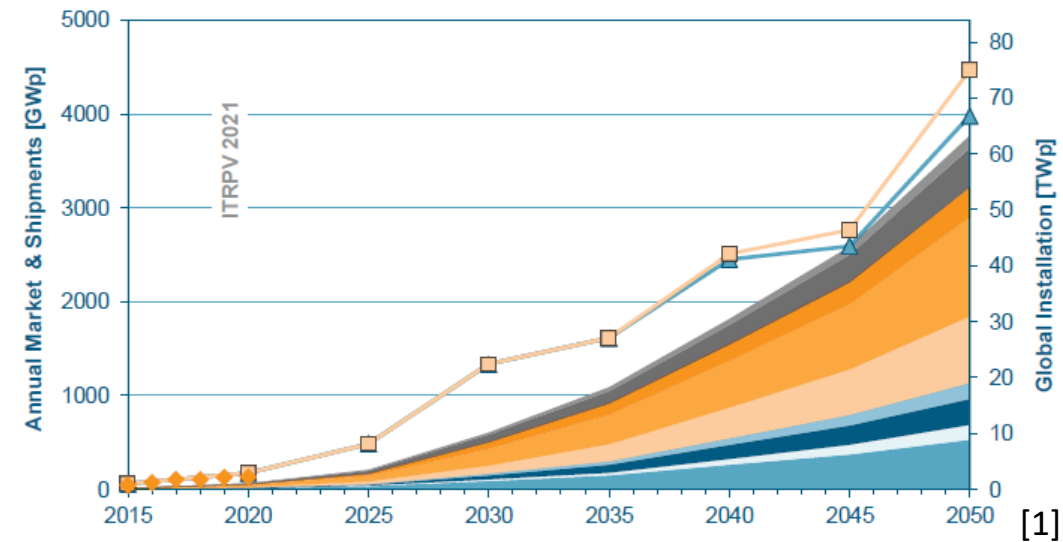
Critical material reduction in PV interconnection

Antoine Perelman, Vincent Barth, Fabien Mandorlo, Eszter Voroshazi



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

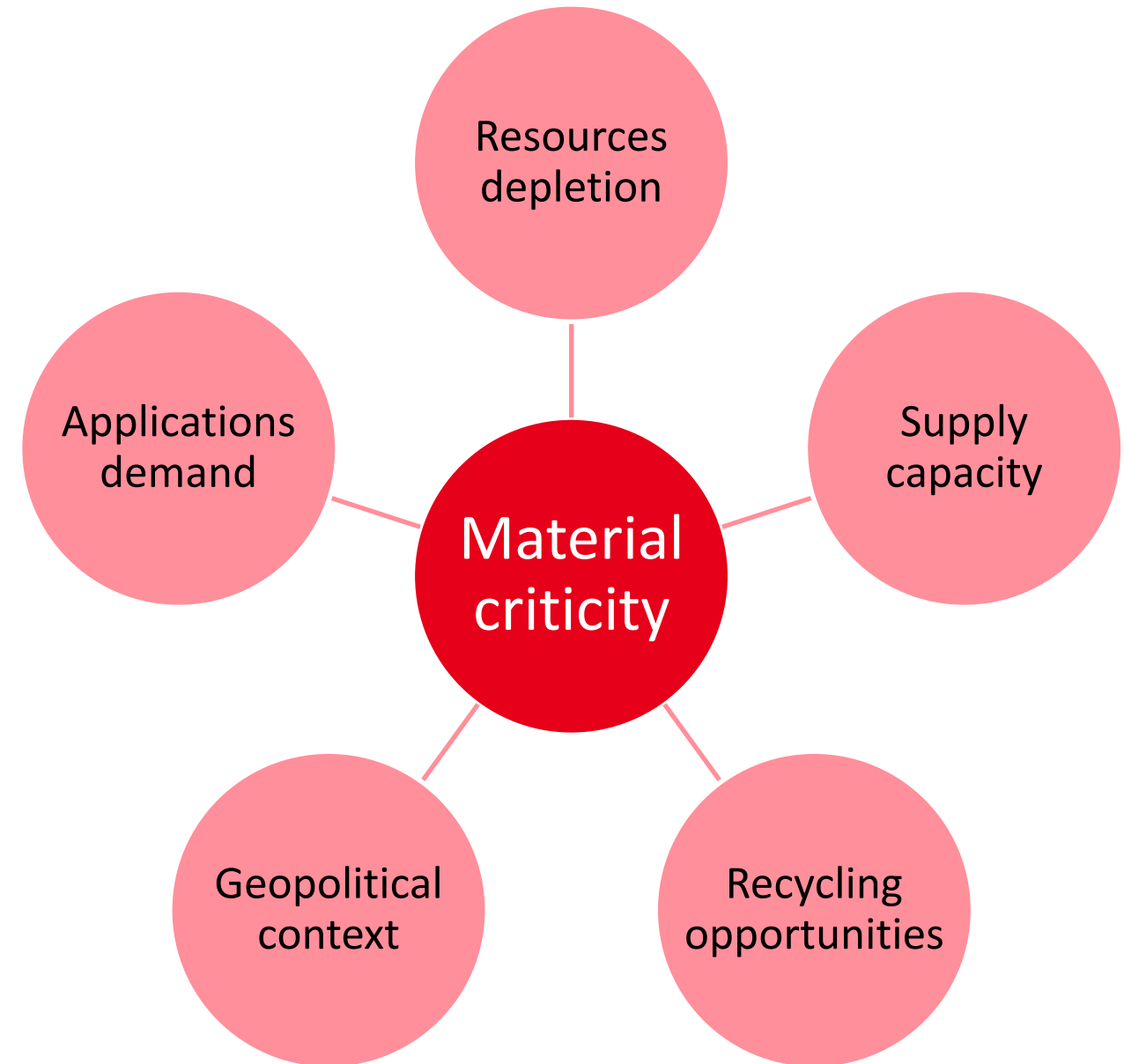


[1] « ITRPV 2021 ».

[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 ..!

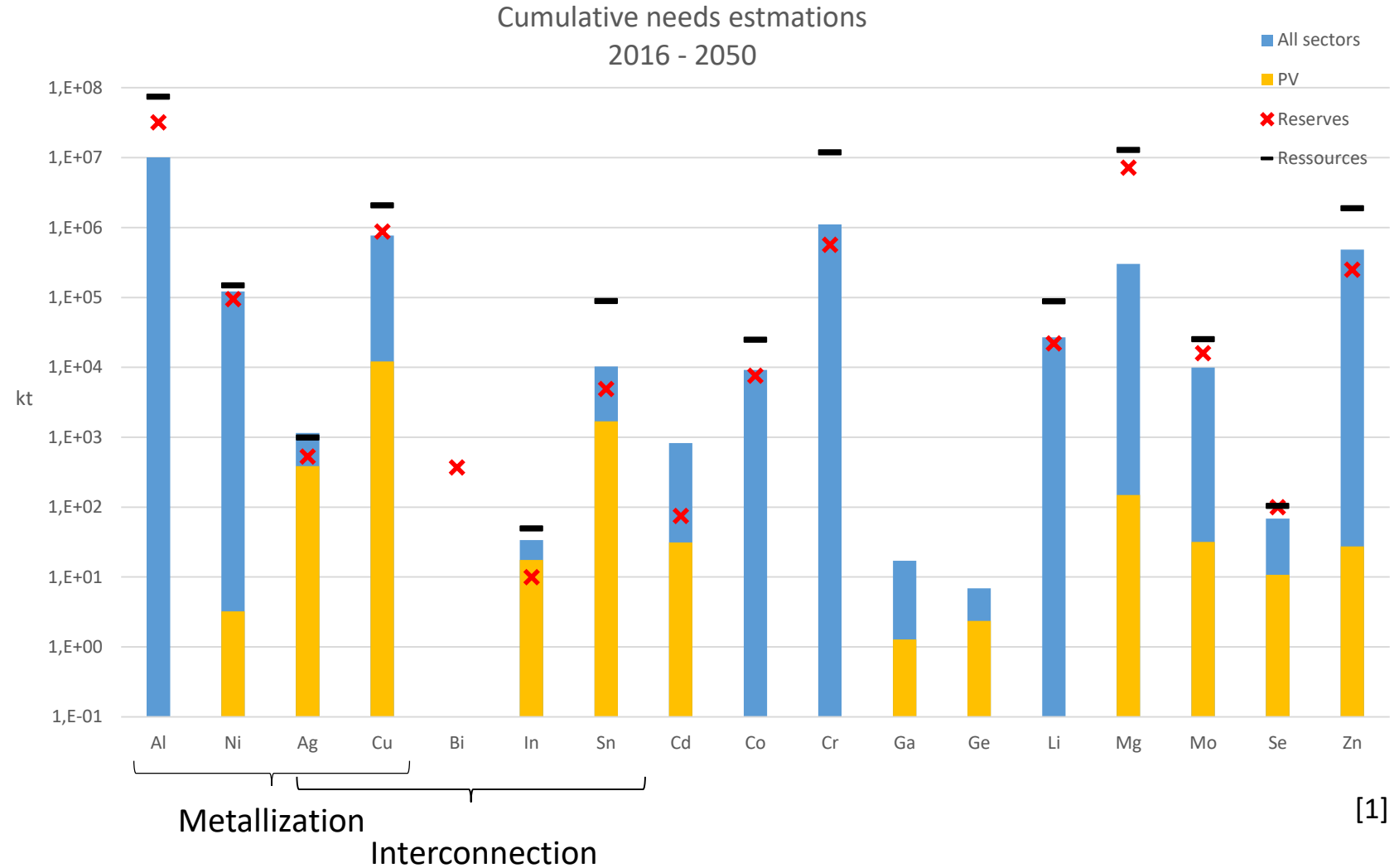


[1] « CE Résilience des matières premières critiques: la voie à suivre pour un renforcement de la sécurité et de la durabilité », Commission Européenne, sept. 2020.

[2] BRGM, mineralinfo.fr

CRITICAL MATERIAL – RESERVES AND RESOURCES DEPLETION

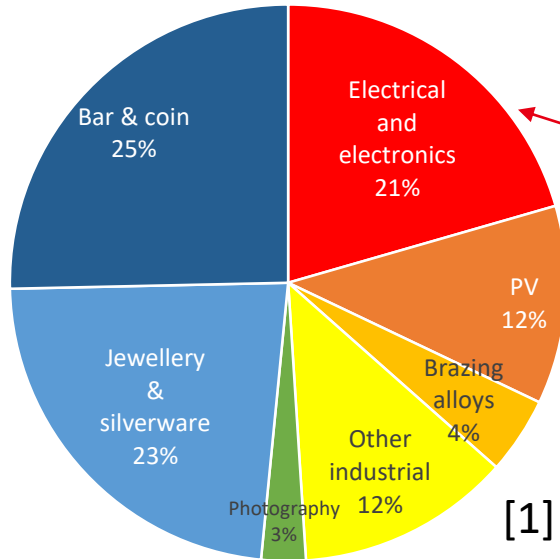
- Focus on strategic and critical resources in the last decade
- On the edge of a mineral rush..!
 - Mineral crisis will happen before end of reserves



[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

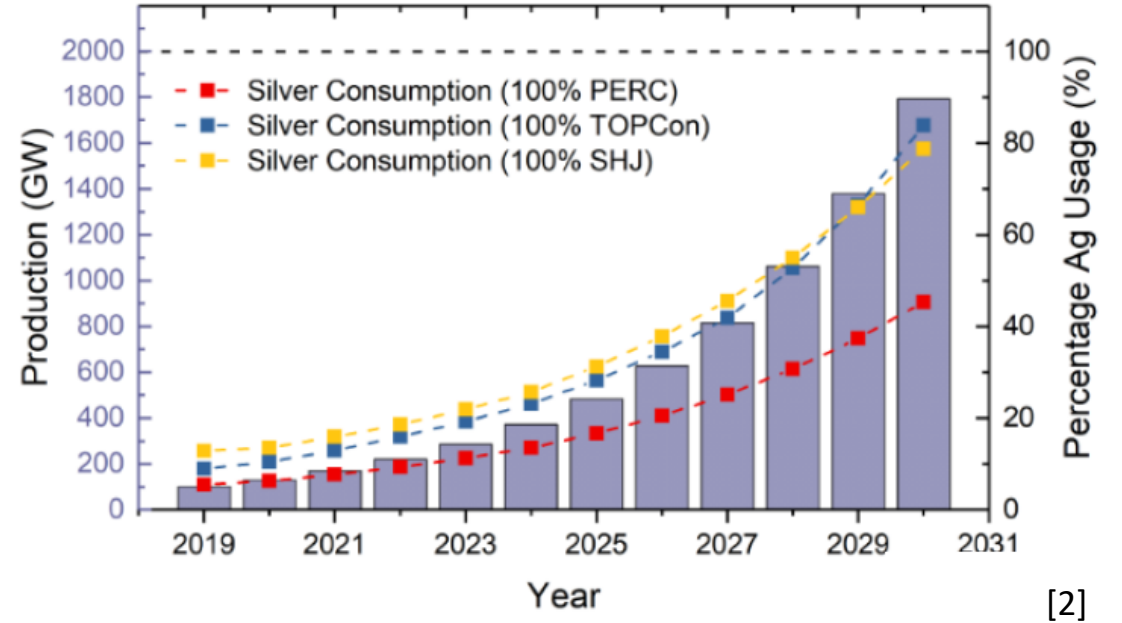


[1]

PV & Electric vehicles ↗↗↗



Easily recyclable applications



[2]

➤ **Prioritization**

[1] Silver Institute

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

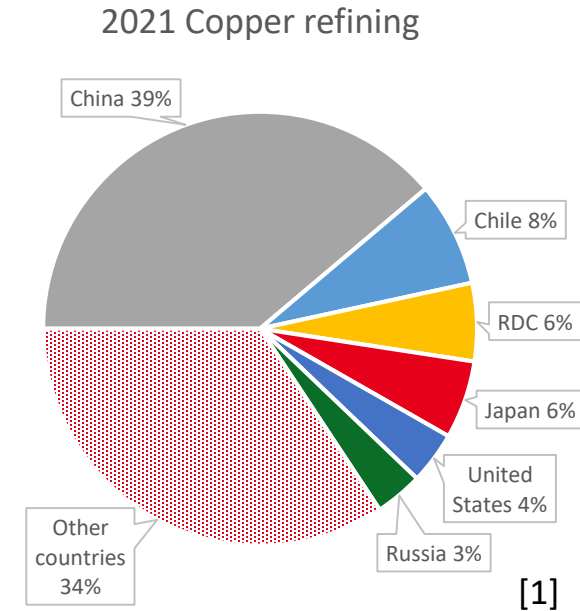
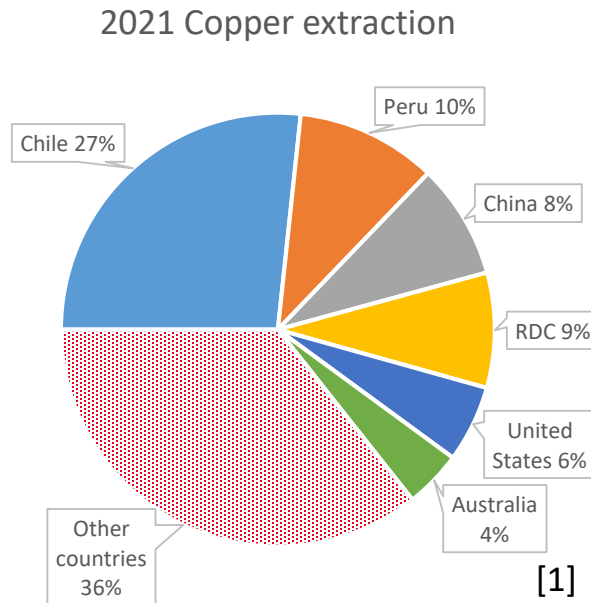
CRITICAL MATERIAL – GEOPOLITICAL CONTEXT

- **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
 - 1st waste producing sector in the world (As, Sb, Hg, Cr...)
 - 8 to 10 % of global energy consumption [2]



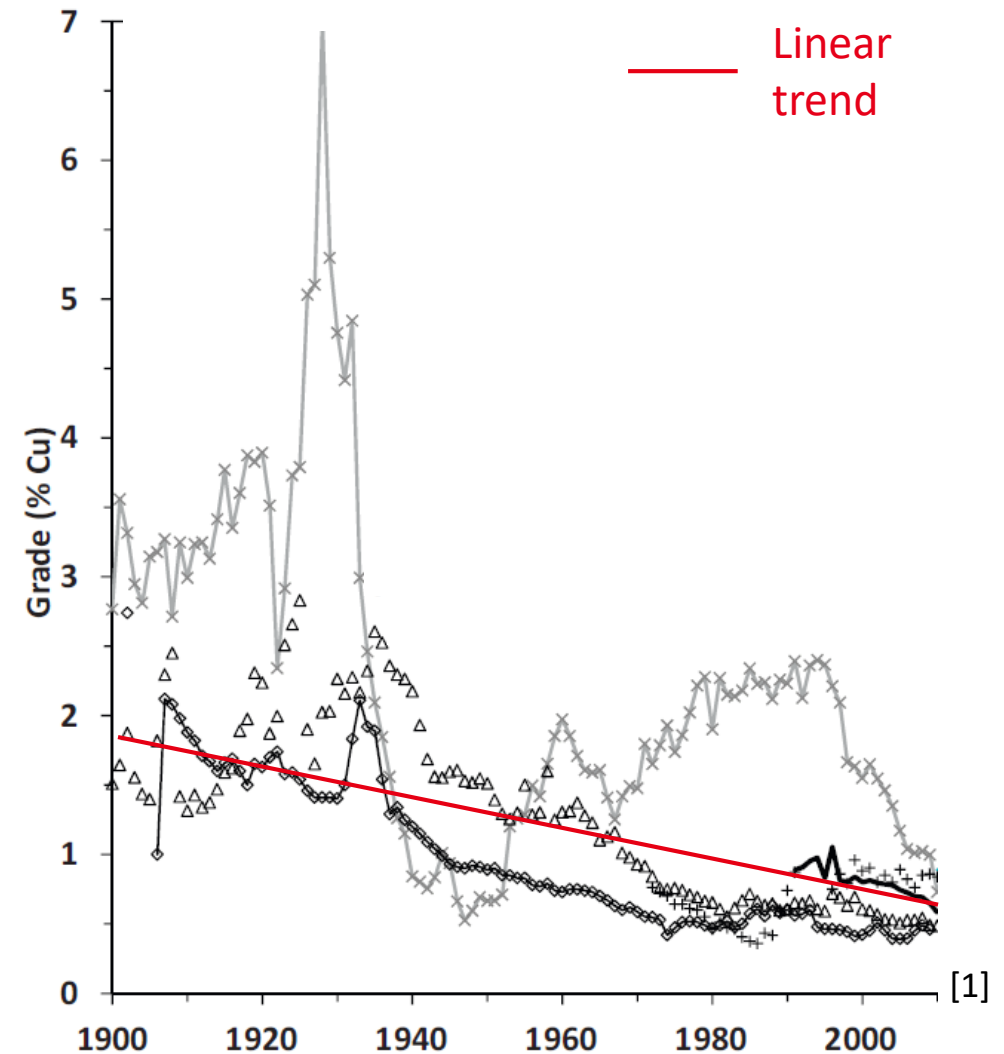
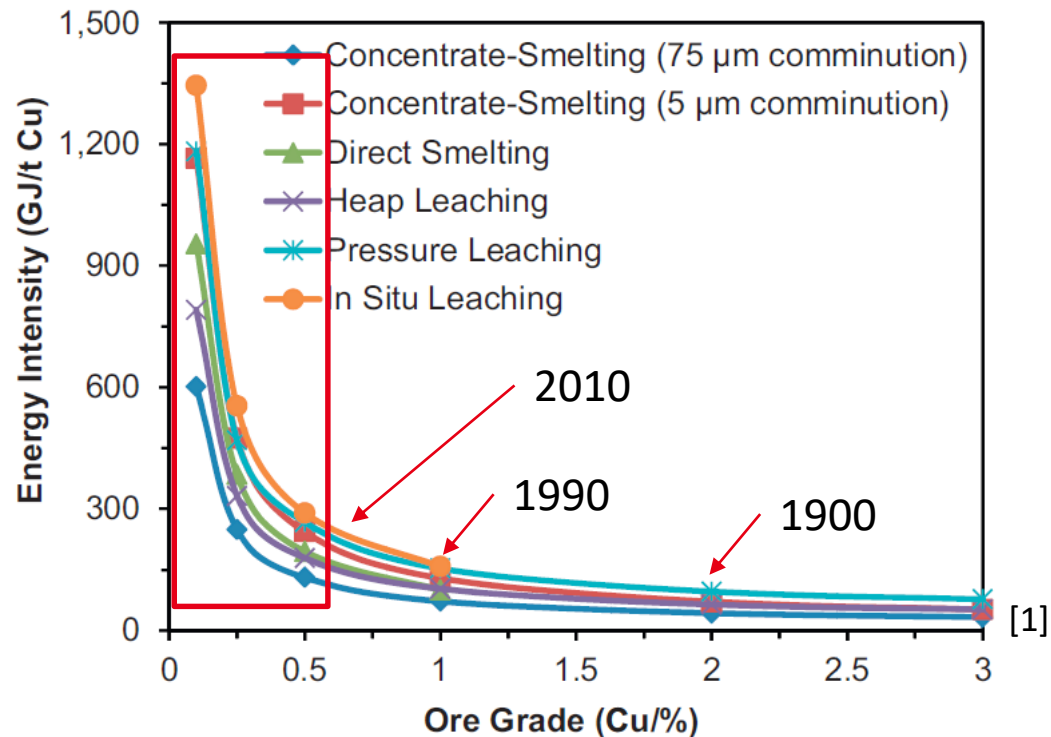
[1] © Alex Kokcharov · Twitter

[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
Sn						
Bi						
In	TCO					
Ag						
Cu	Cables					
Ni						
Al	Frame					

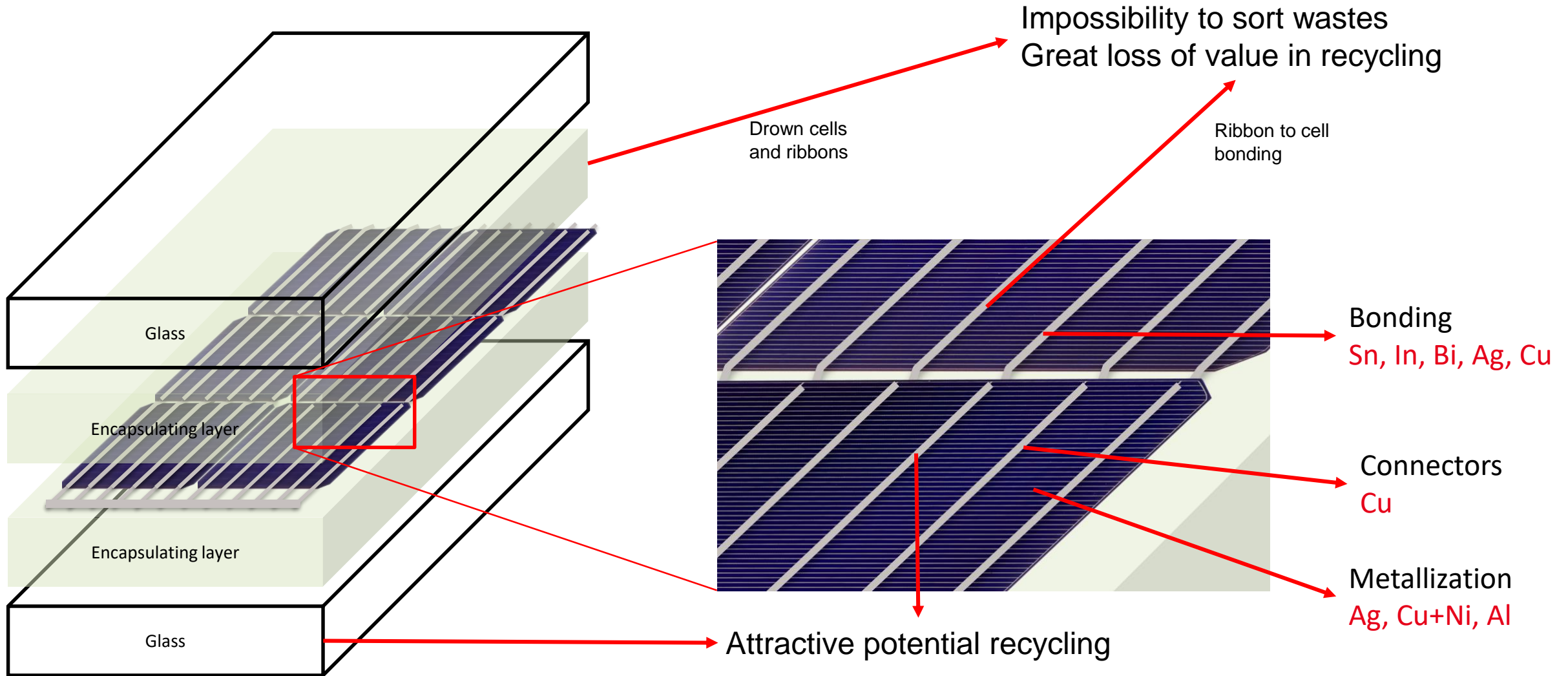
Bonding

- 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



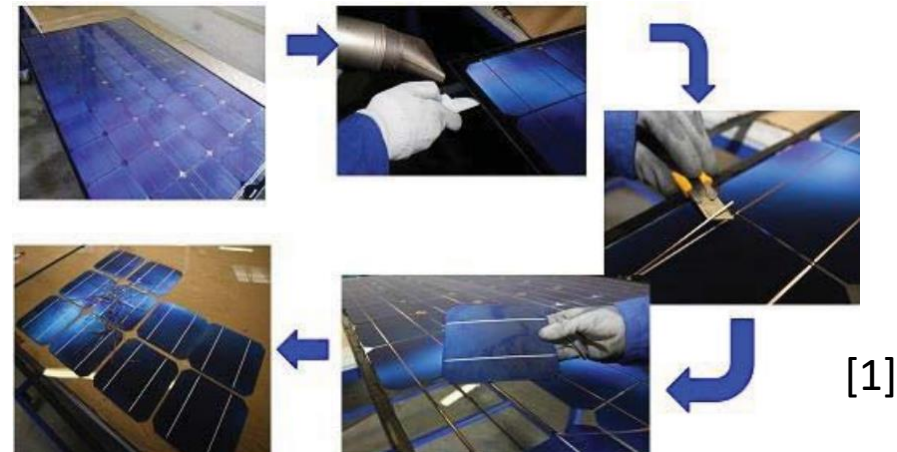
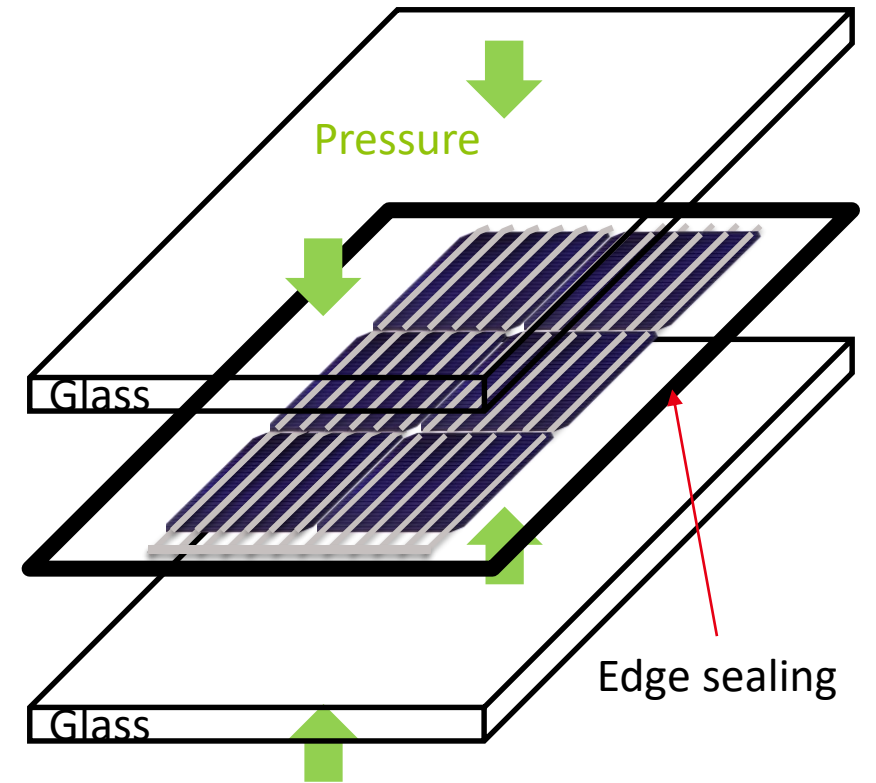
[1] R. J. Garcier et F. Verrax, « Critiques mais non recyclées : expliquer les limites au recyclage des terres rares en Europe », *Flux*, juin 2017.

[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



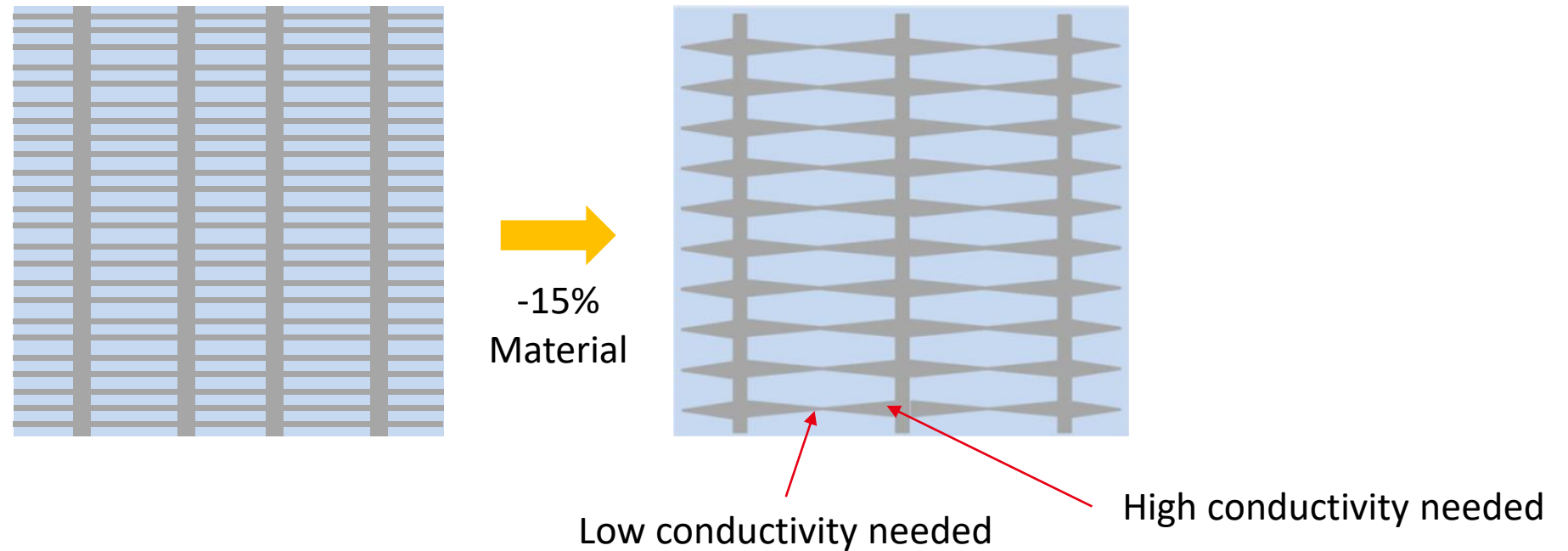
[1]

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]

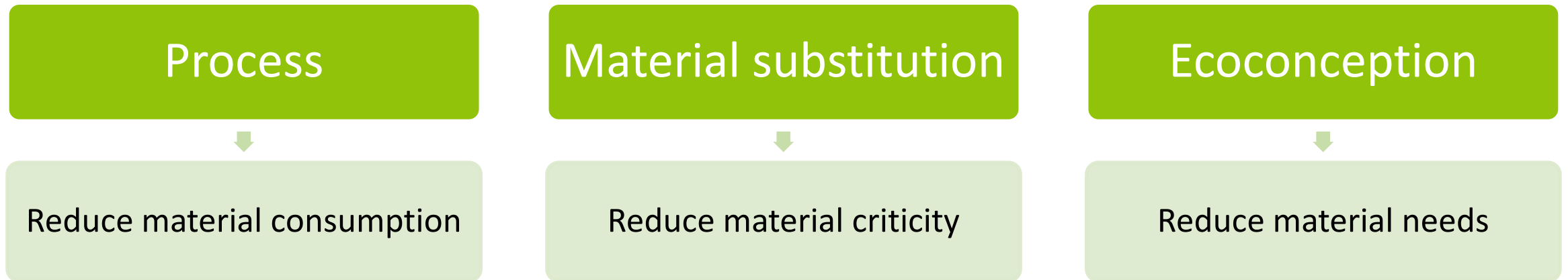
- Relevant geometry to reduce resistive losses in fingers while reducing material
- Ability to relax geometrical constraints



[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 :**



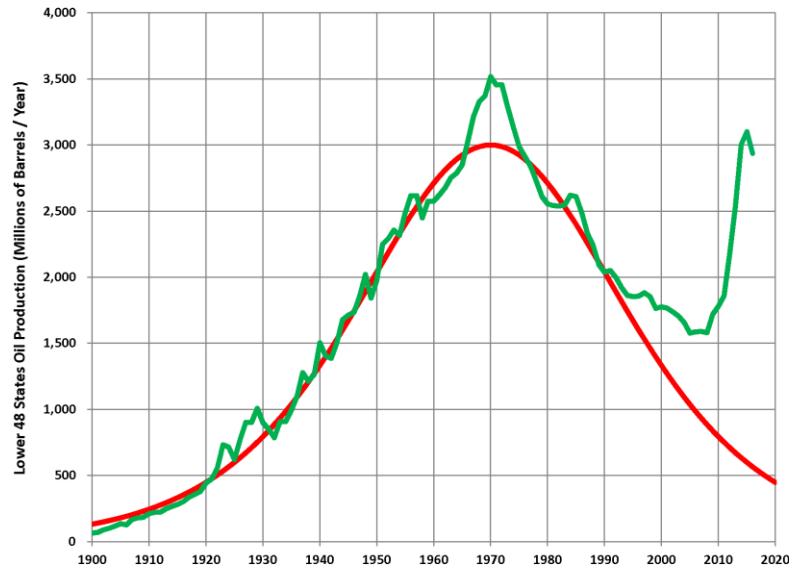


Thanks to
Interconnection team
and Metallization team
in INES for discussion



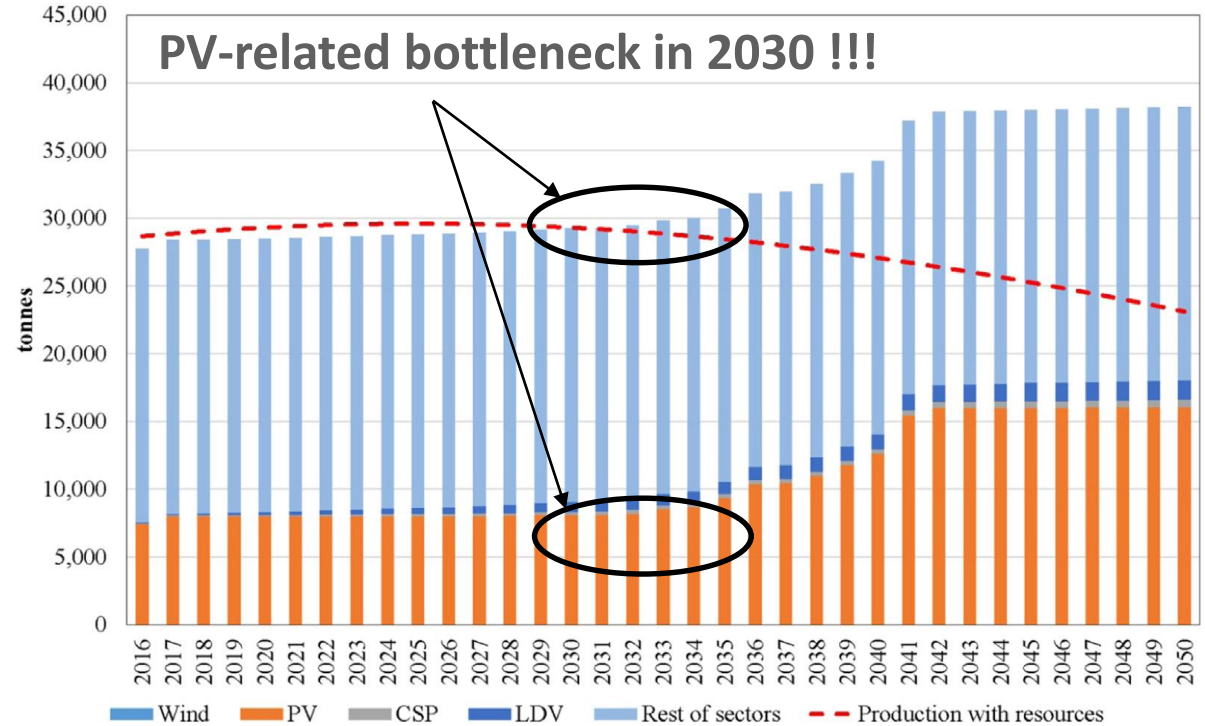
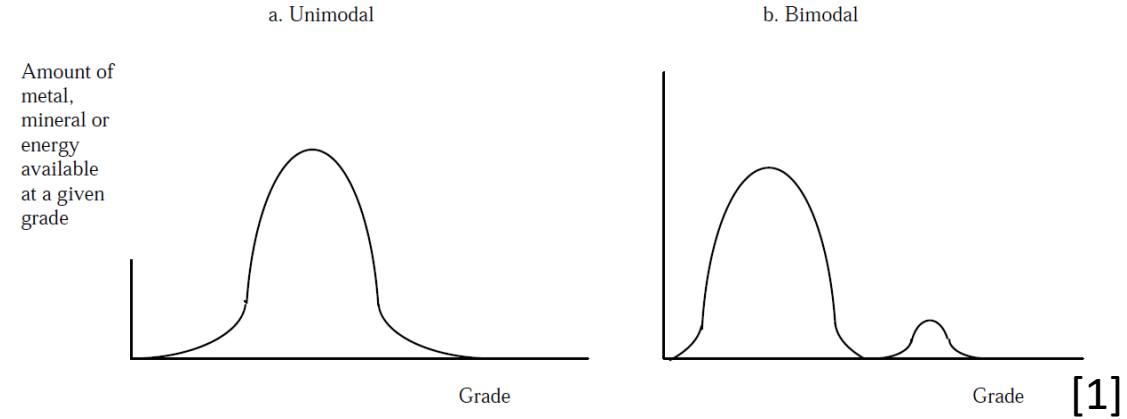
CRITICAL MATERIAL – SUPPLY CAPACITY

- 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

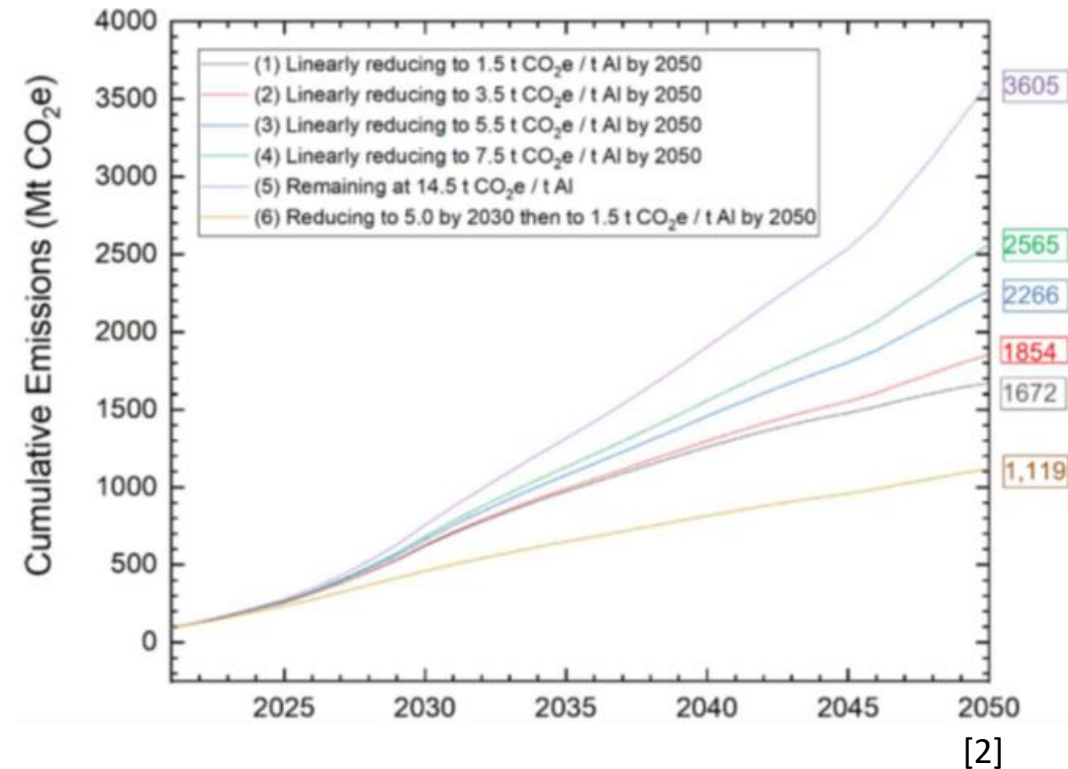


[2]

[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

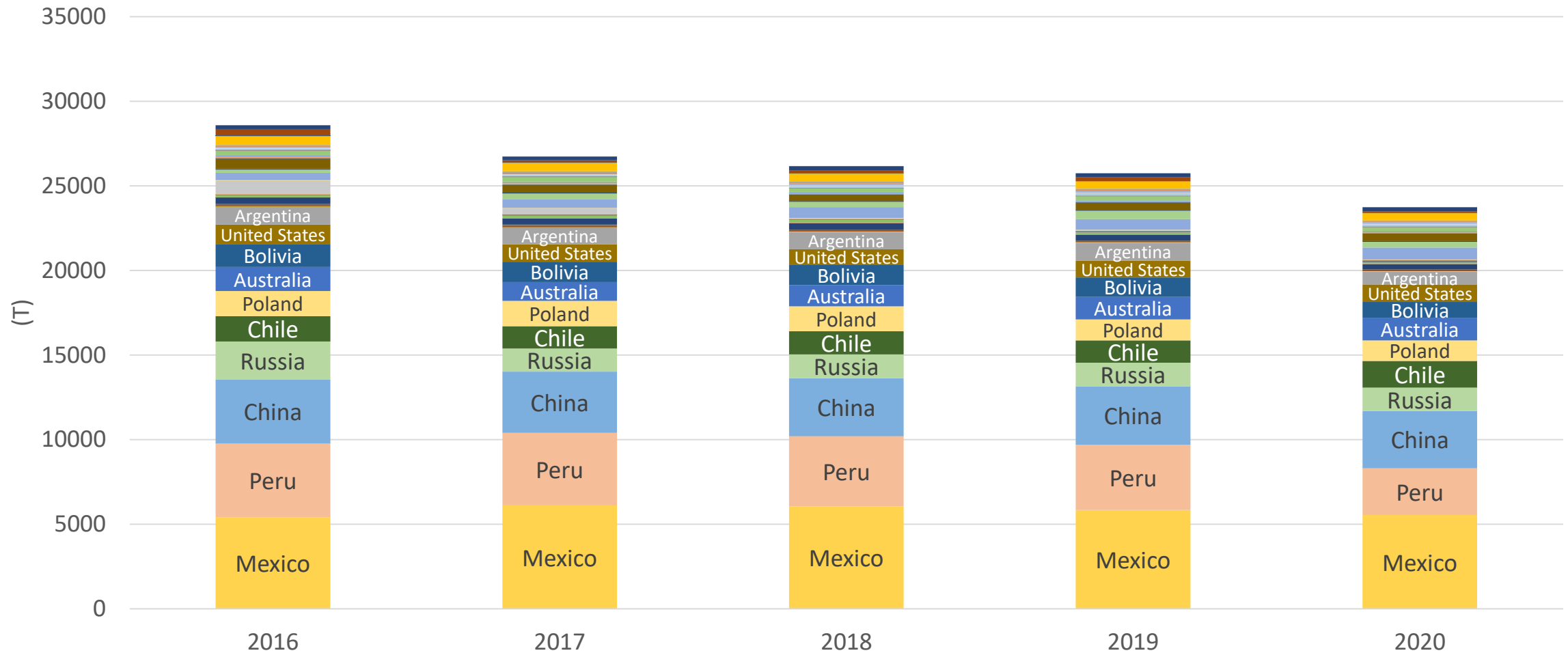


[1] Y. Zhang, M. Kim, L. Wang, P. Verlinden, et B. Hallam, « Design considerations for multi-terawatt scale manufacturing of existing and future photovoltaic technologies: challenges and opportunities related to silver, indium and bismuth consumption », 2021

[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

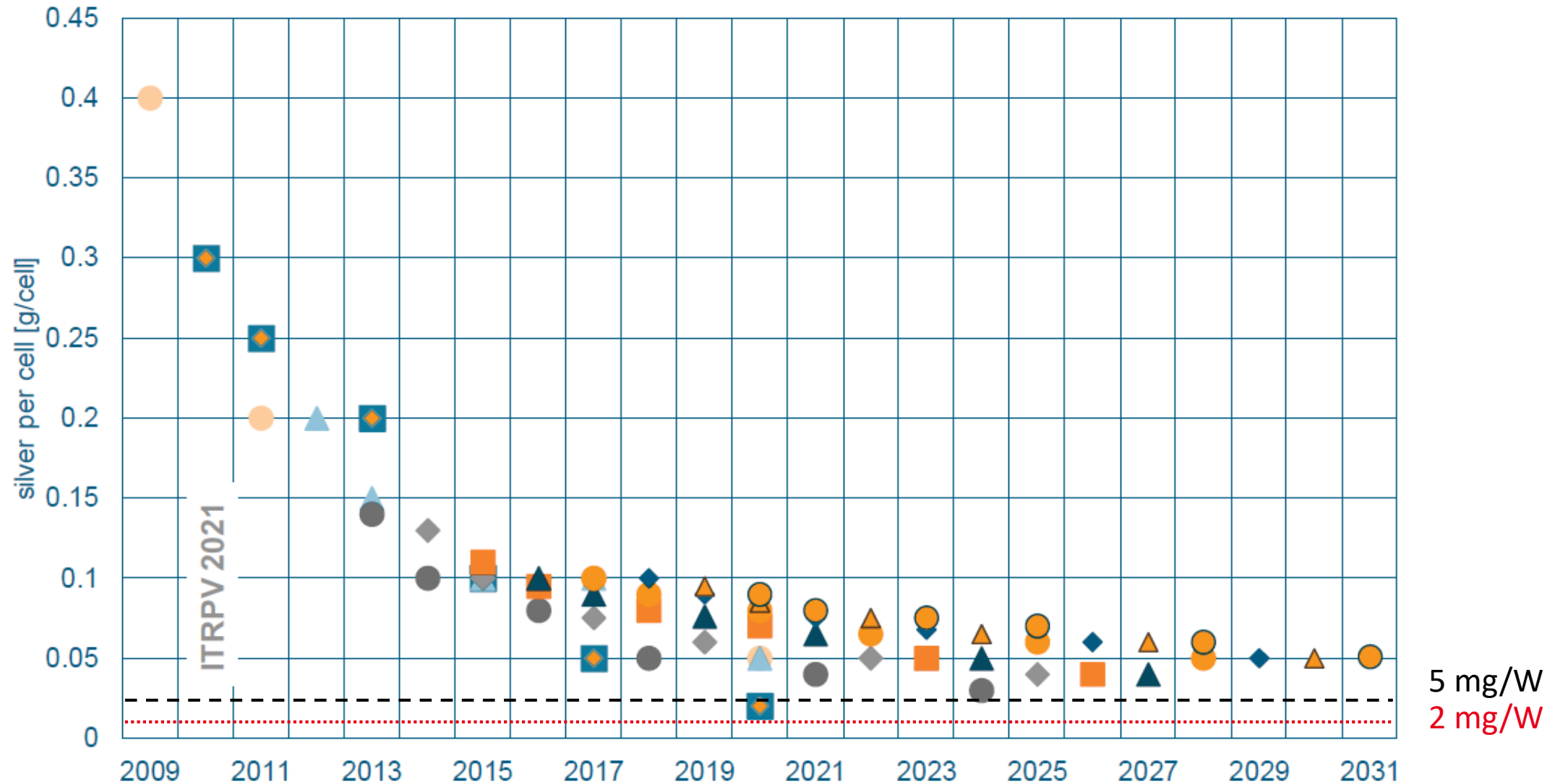
CRITICAL MATERIAL – SUPPLY CAPACITY

Silver production 2016-2020



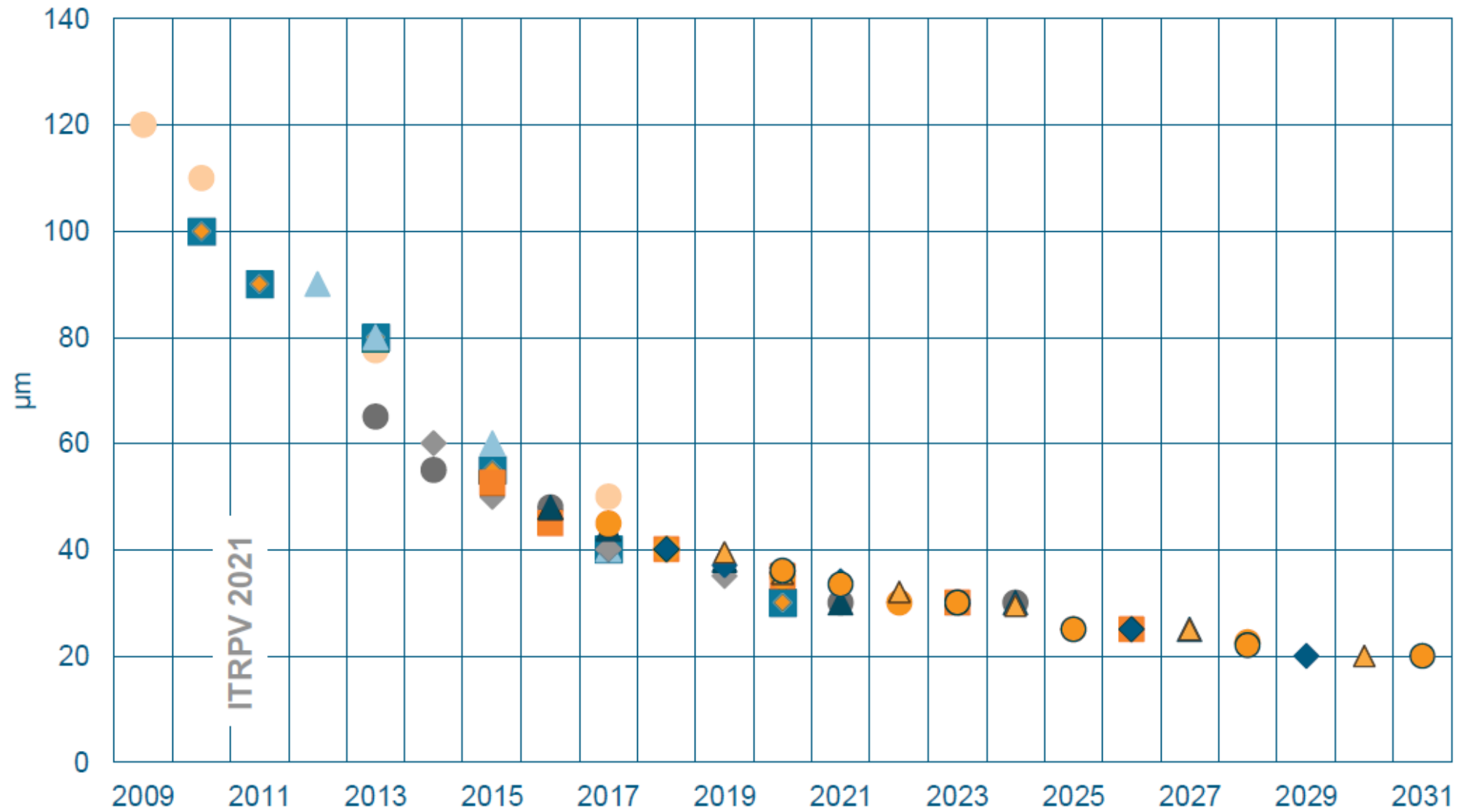
[1] J. E. Athey et M. B. Werdon, « Mineral Yearbook Silver 2020 », Alaska Division of Geological & Geophysical Surveys

SILVER METALLIZATION CONSUMPTION PER CELL



[1] ITRPV 2021, VDMA

FINGER WIDTH



[1] ITRPV 2021, VDMA