PV Recycling: What SPREE Needs to Know

UNSW

2021

Pablo R Dias

W.E.E.E.

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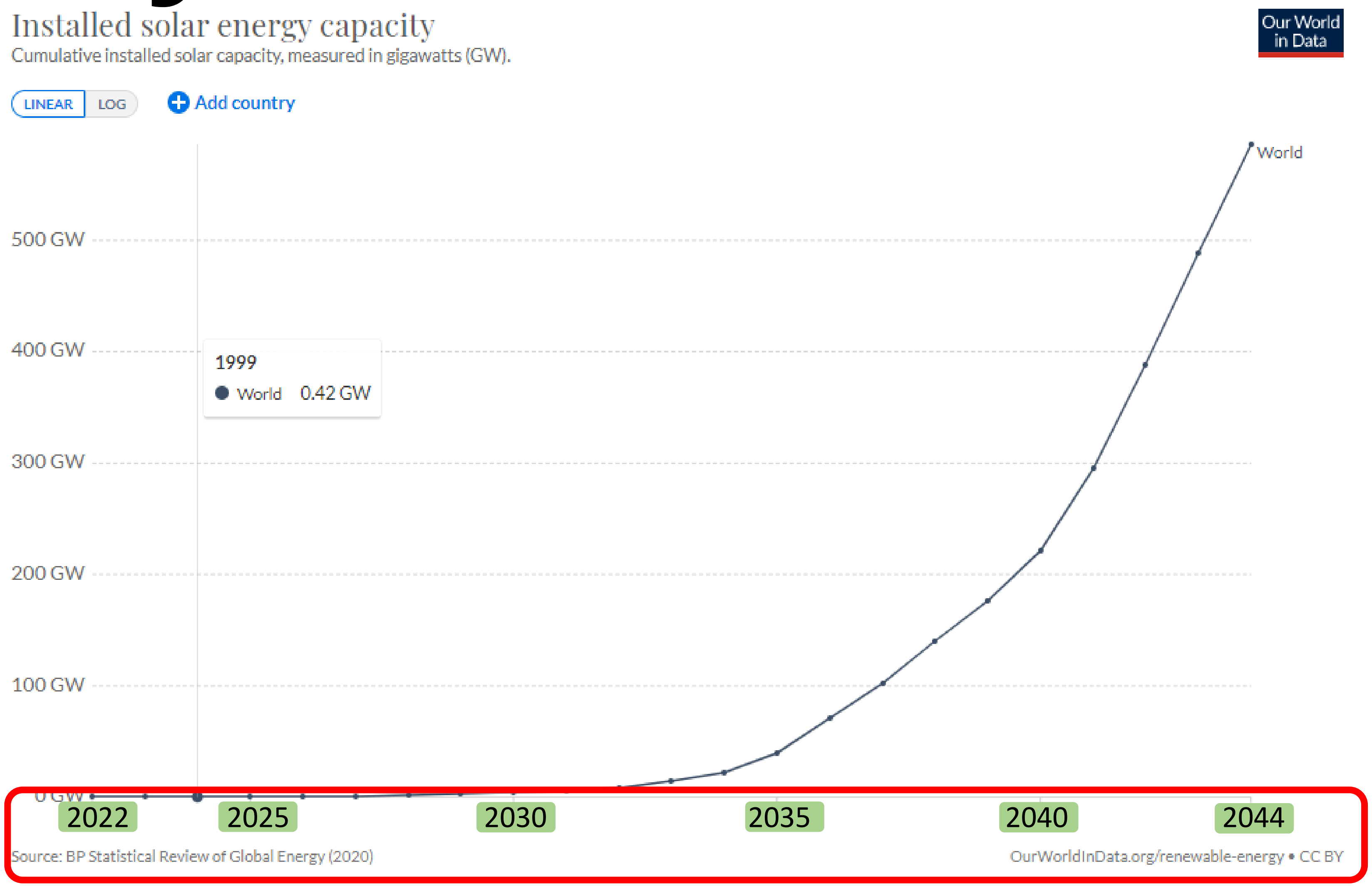
Why? Fast Growing



ourworldindata.org

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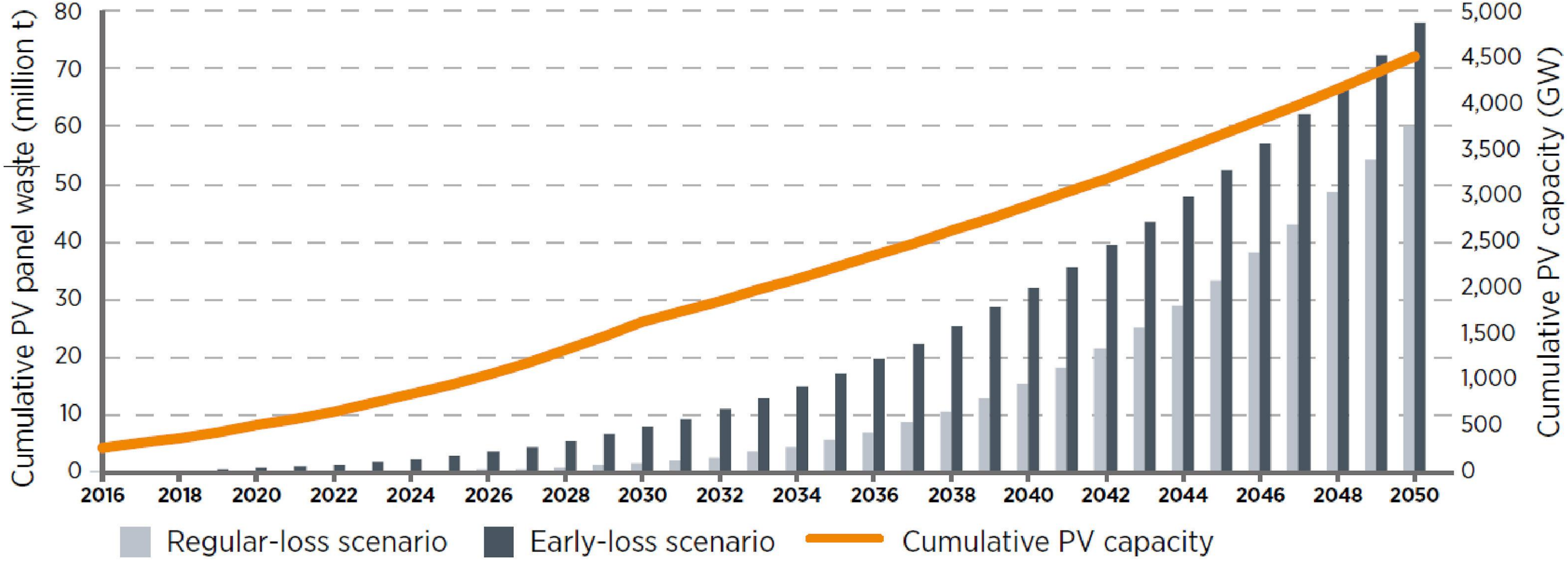
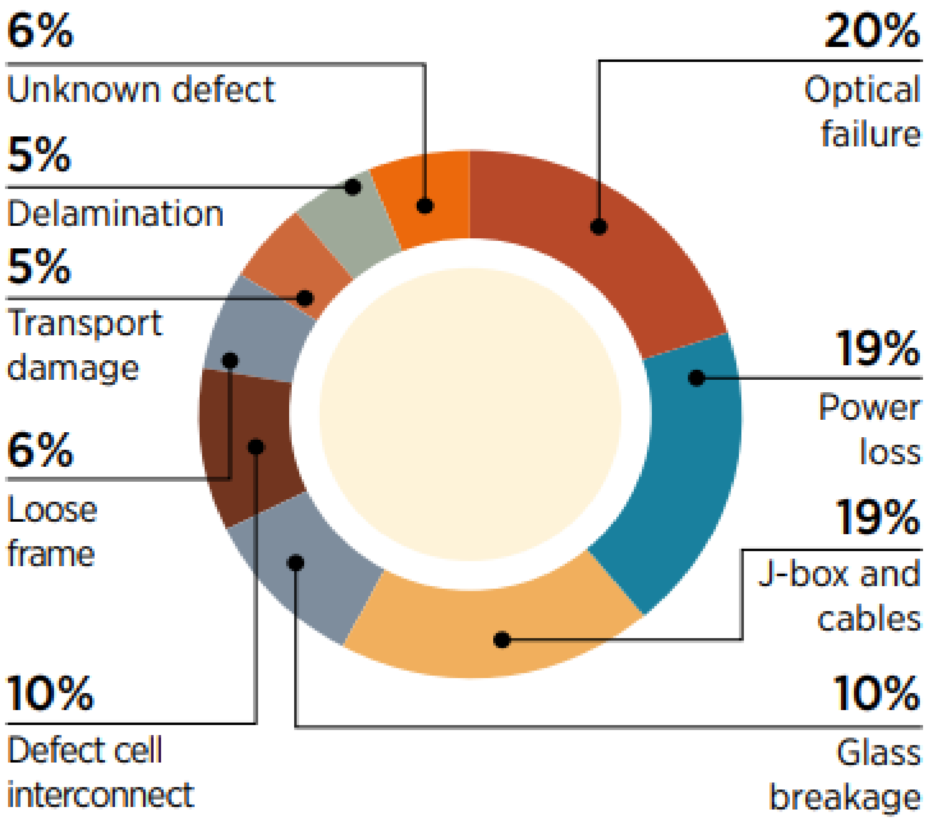
Why? Fast Growing



IRENA & IEA-PVPS, 2016

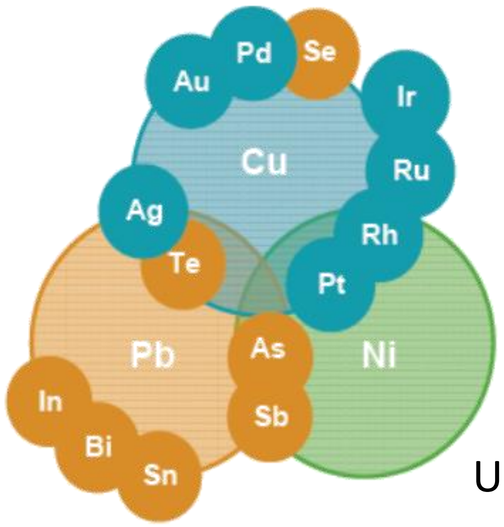


Köntges et al., 2014
IRENA/IEA-PVPS, 2016

Early Loss

Element	Average minimum content in ore (%)	Average content in WEEE* (%)	WEEE ÷ Ore Proportion
Copper (Cu)	0.5	10-20	÷20-40
Iron (Fe)	30	1-5	0.167-0.033
Aluminum (Al)	30	2-6	0.2
Zinc (Zn)	4	0.5-6	1.5
Nickel (Ni)	1	0.1-2.5	2.5
Tin (Sn)	0.5	1.5-8	16
Lead (Pb)	4	0.3-5	1.25
Antimony (Sb)	3	0.2-1.8	0.6
Gold (Au)	0.0001	0.002-0.03	300
Silver (Ag)	0.01	0.03-0.3	30
Palladium (Pd)	0.0001	0.001-0.02	200
Indium (In)	0.001 (in zinc ores)	0.02-0.04*	40

Dias, 2019
Ebin and Isik, 2016



Umicore.com

Why?

Valuable

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Element	Average minimum content in ore (%)	Average content in silicon PV* (%)	WEEE ÷ Ore Proportion
Copper (Cu)	0.5	0.6 – 1	1.2 – 2
Silver (Ag)	0.01	0.006 – 0.06	0.6 – 6
Aluminum (Al)	30	10 – 20	0.33 – 0.67
Tin (Sn)	0.5	0.07 – 0.12	0.14 – 0.24
Lead (Pb)	4	0.05 – 0.08	0.01 – 0.02

Dias and Veit, 2018
Ebin and Isik, 2016
Dias et al., 2021

Why?

Valuable

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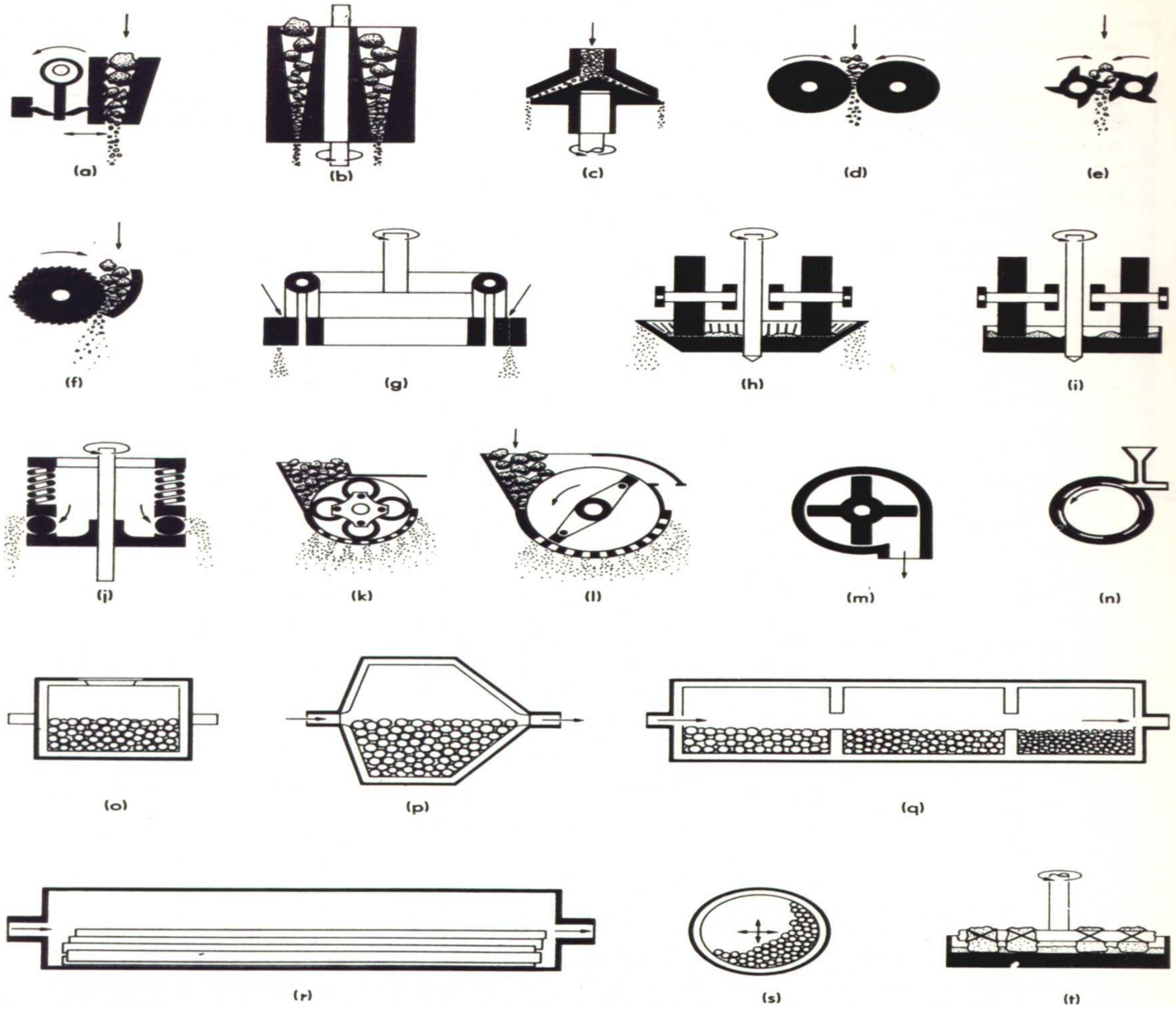
Mining



Veit, H. 2020

Glass & Silver

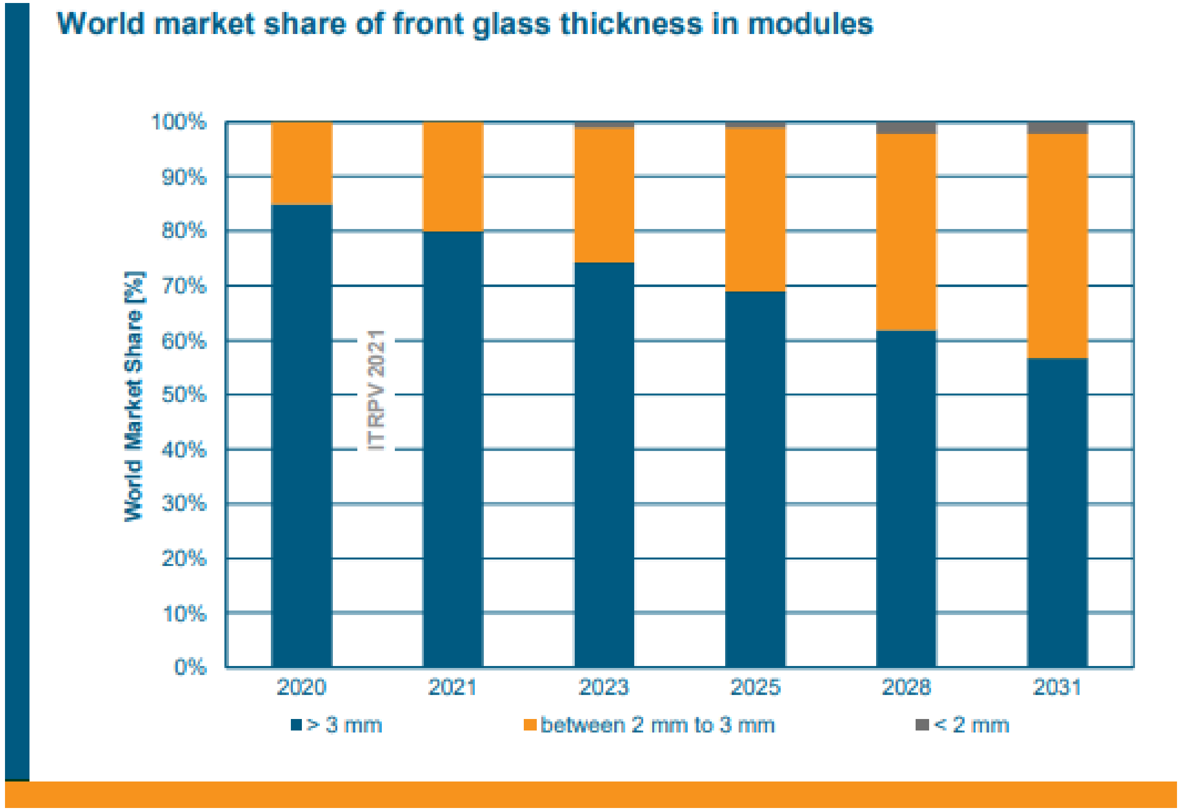


Fig. 38: Expected trend of front glass thickness in c-Si modules.

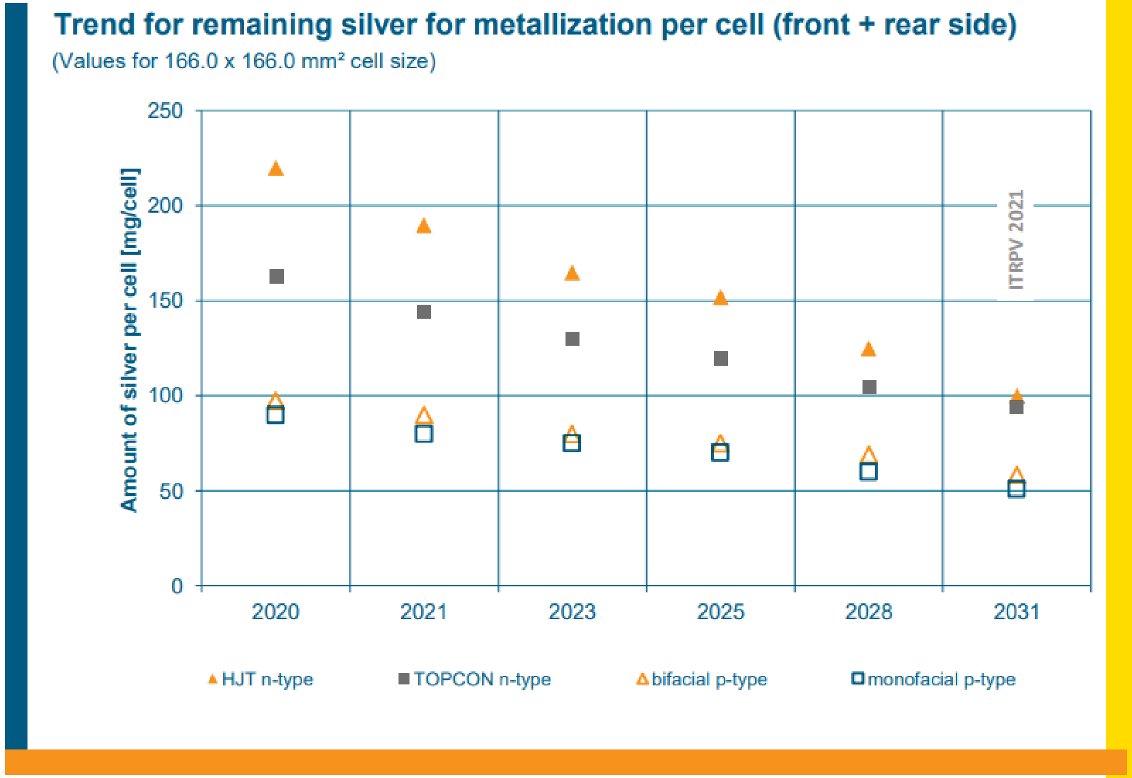
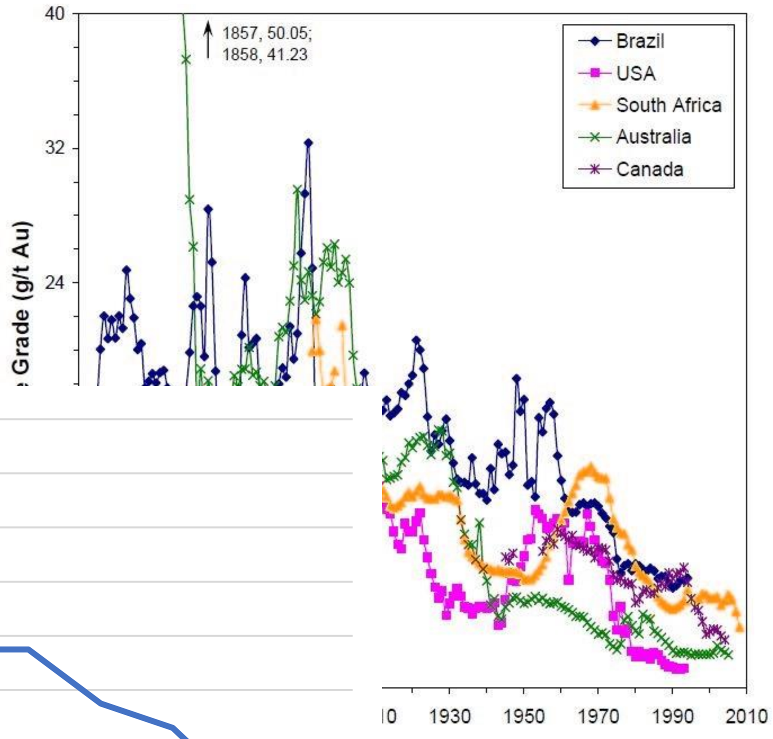
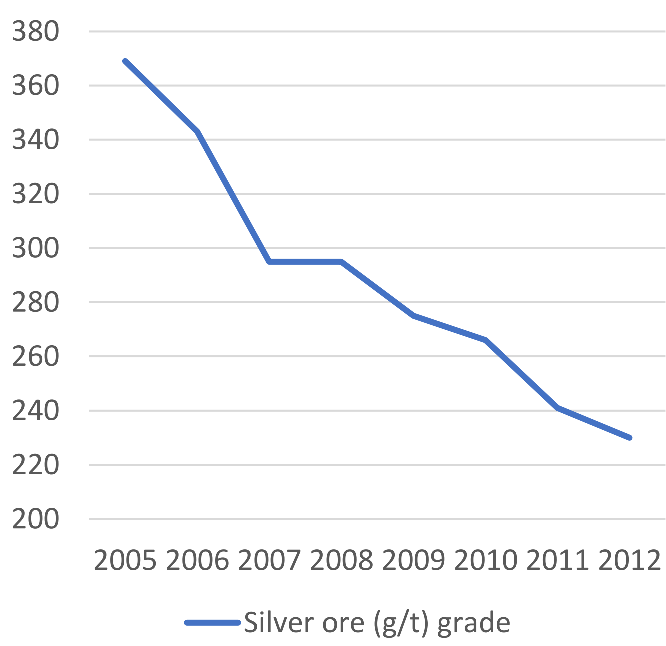


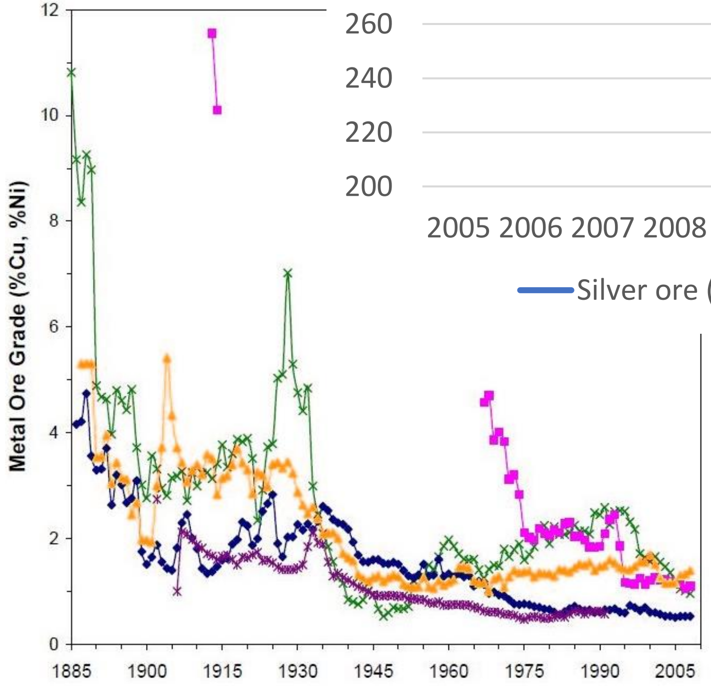
Fig. 15: Trend for remaining silver per cell for different cell concepts in M6 wafer format (166.0 x 166.0 mm²).

ITRPV, VDMA, 2021

Mining







Giurco, 2010

Dias, 2015

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Why?

Hazardous

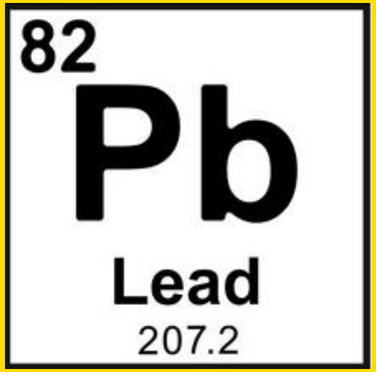
GENERAL SOLID WASTE | **RESTRICTED SOLID WASTE** | **HAZARDOUS WASTE**

	Unit	Maximum TCLP (Restricted solid waste)	Experimental Result
Lead (Pb)	mg/L	20	5 – 22
Silver (Ag)	mg/L	20	< 0.015
Fluoride	mg F^- /L	600	0.07

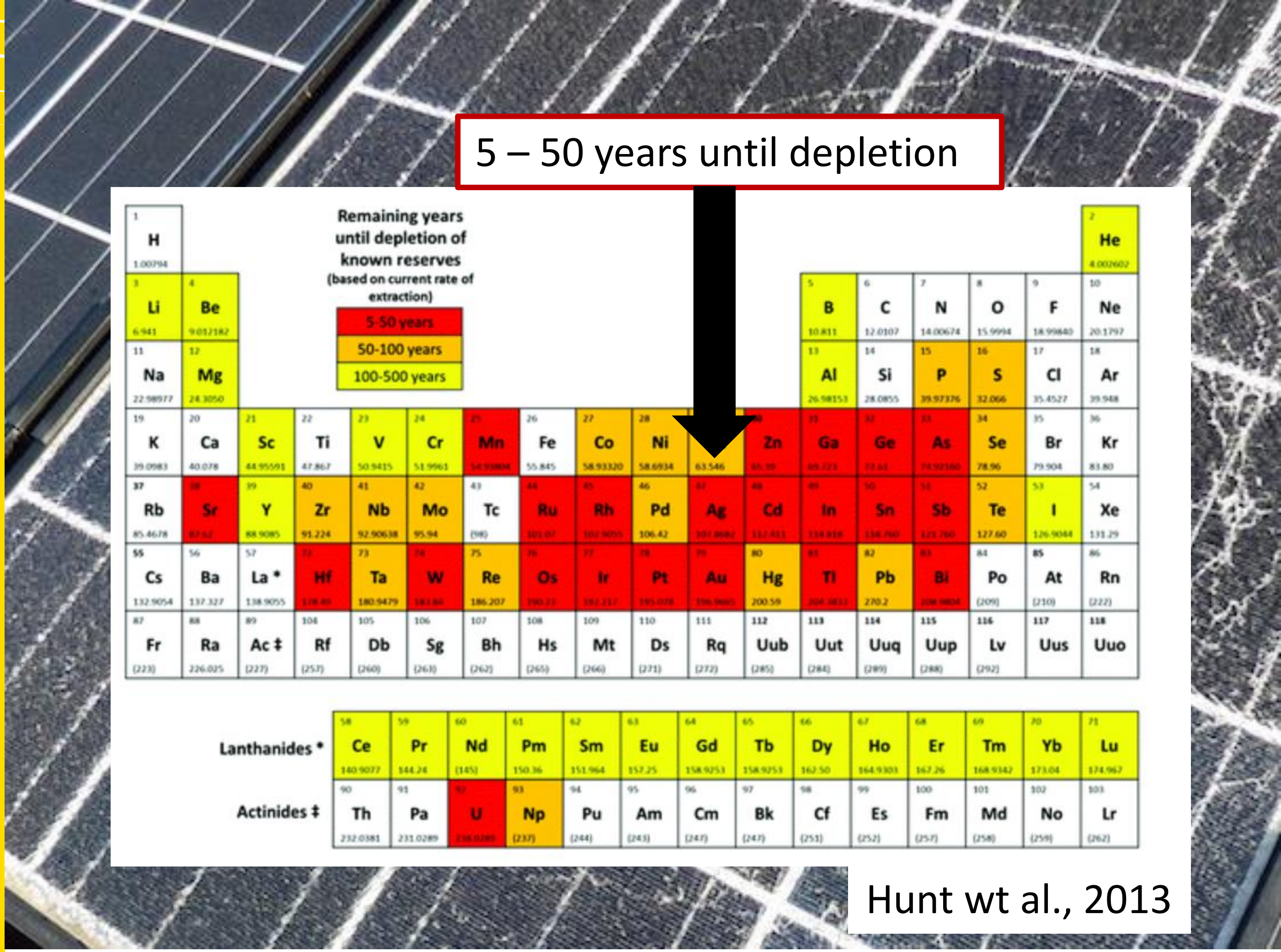
NSW EPA, 2014 | Dias, 2015

Why?

Hazardous



Why PV



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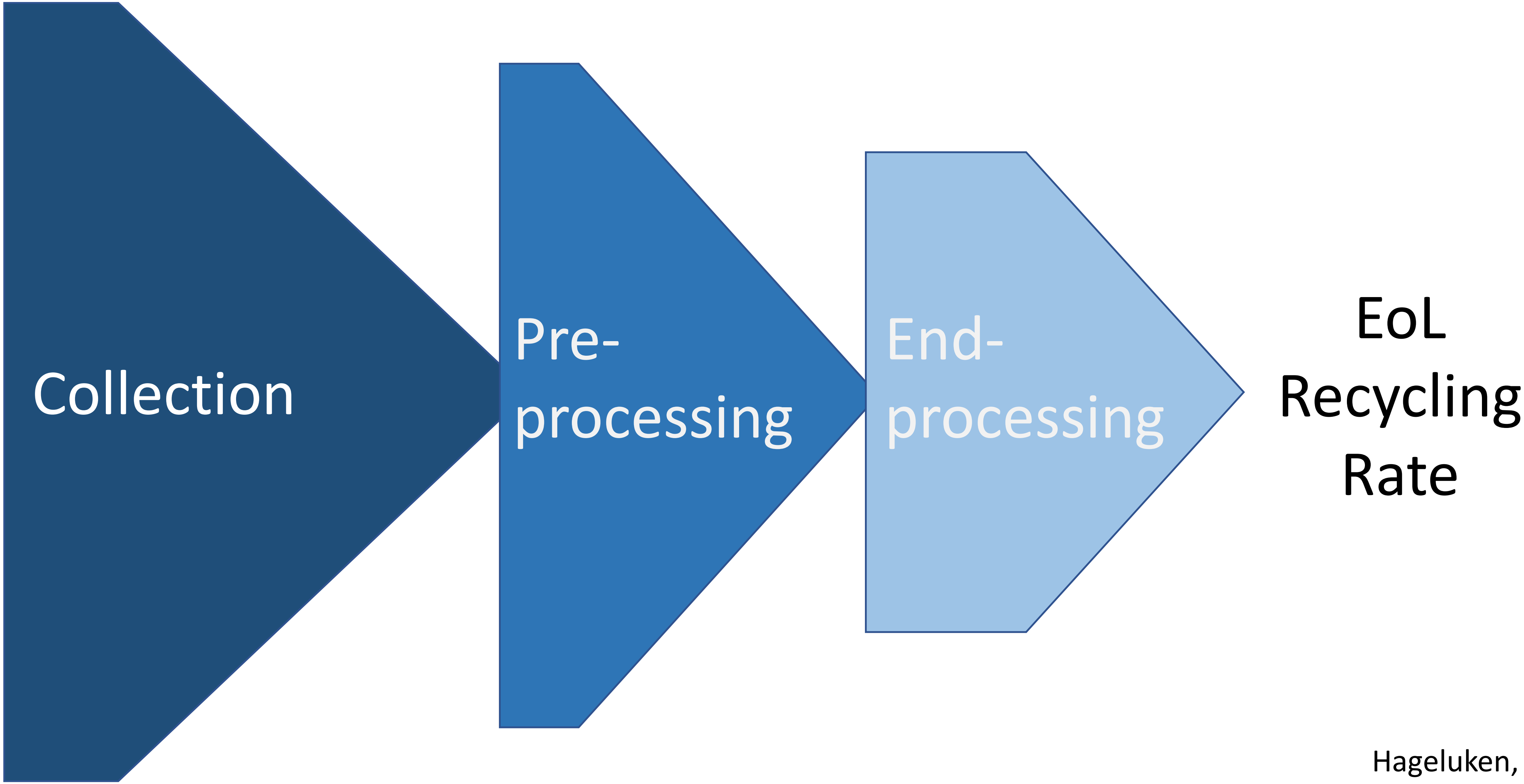
Waste Management



Hageluken, 2012

Insights from France

Pvcycle.org

ASSOCIATION PV CYCLE

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Insights from France

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Insights from France

Collection of used PV modules by canoe on the Maroni river in French Guyana (2020)

Pvcycle.org

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Australia

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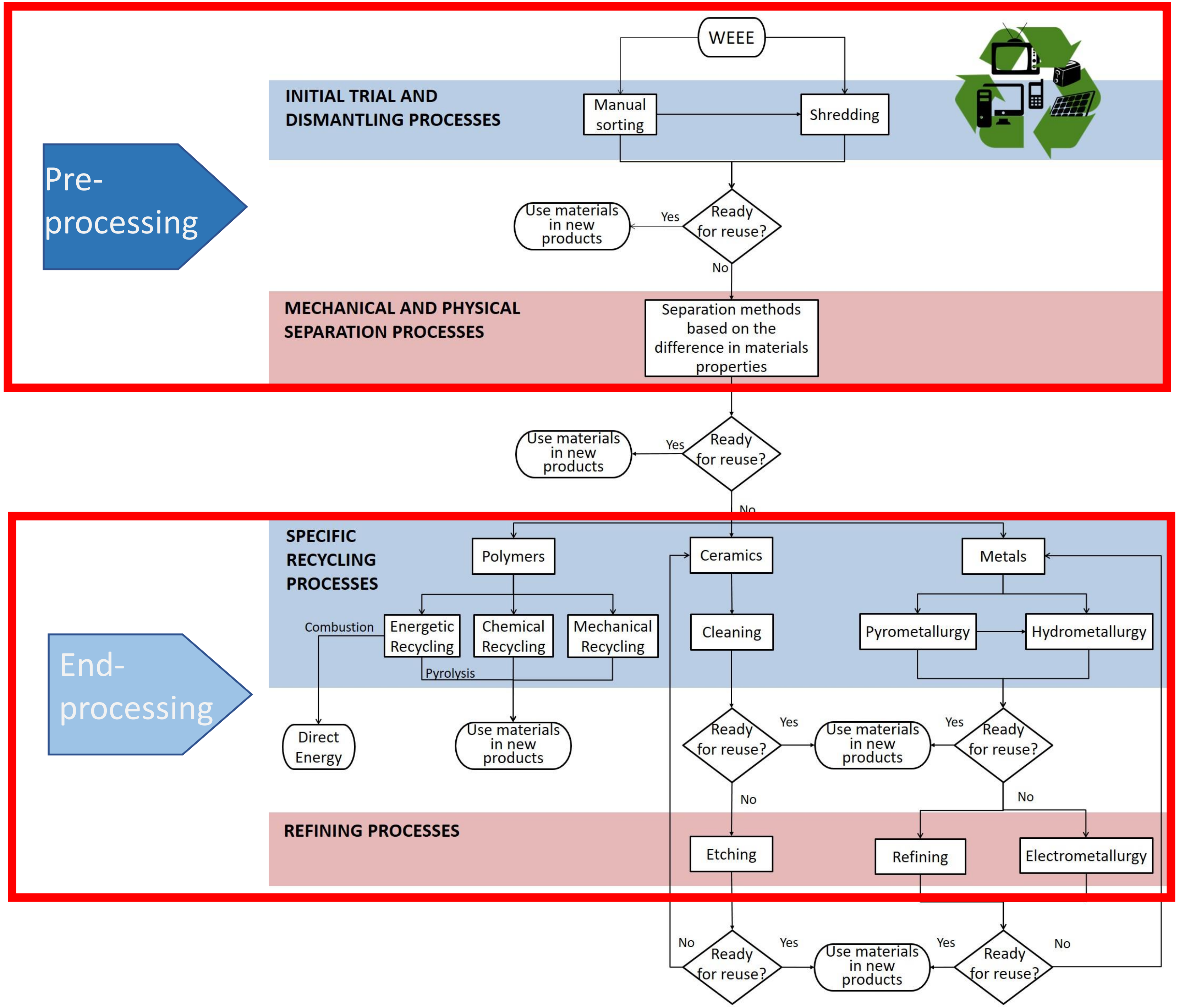
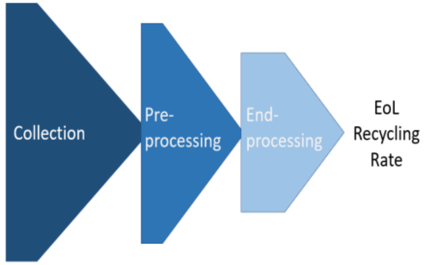
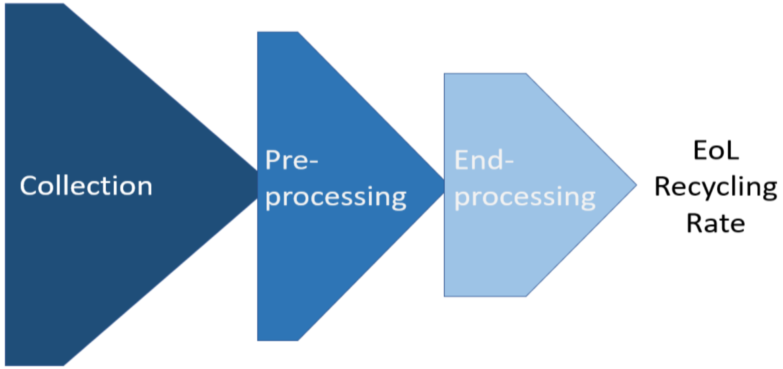
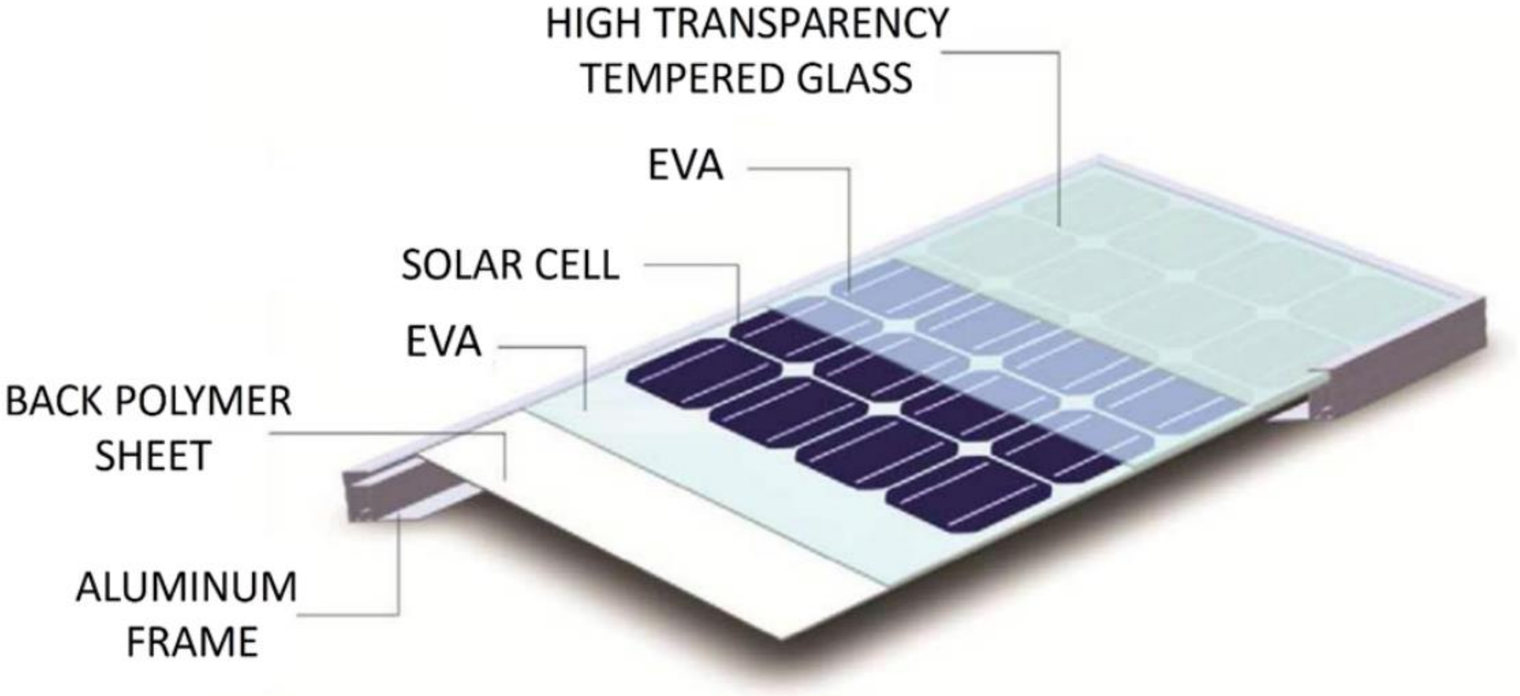




Dias et al., 2018a

Recycling



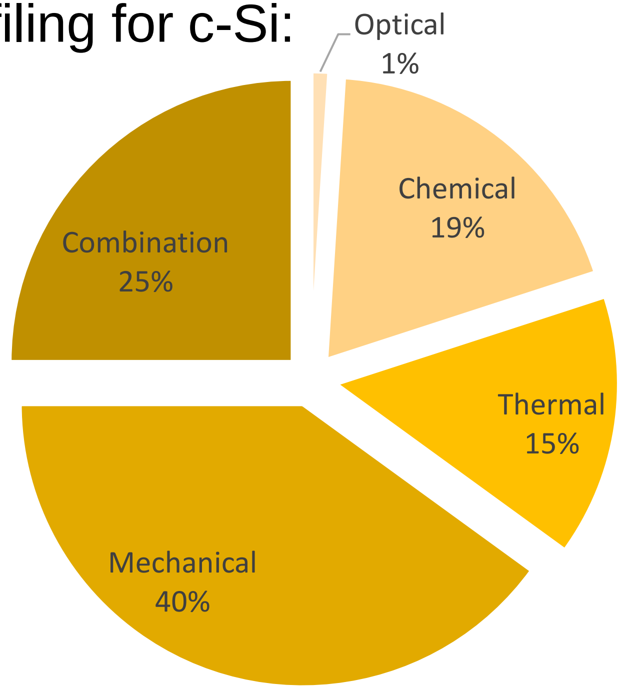


Pinho & Galdino, 2014

PV Recycling

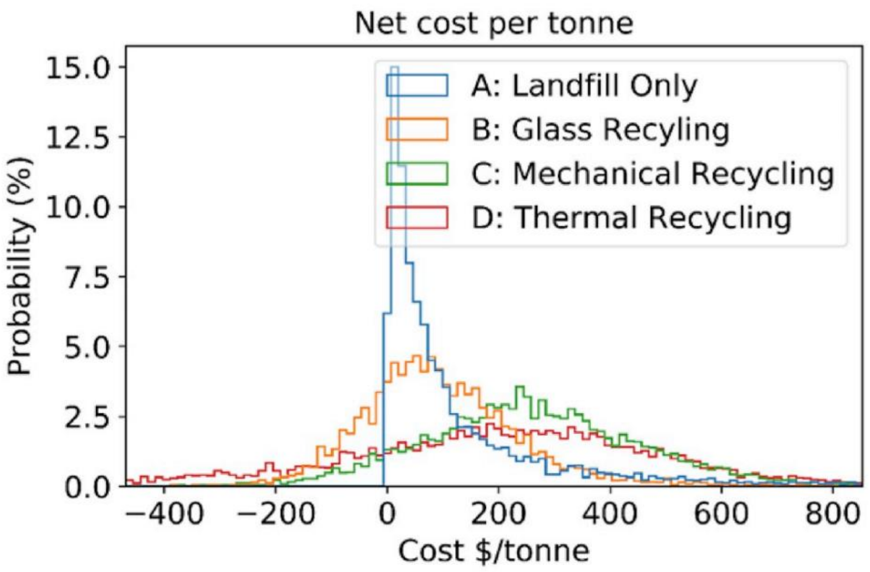
- Chemical
- Thermal
- Optical
- Mechanical
- Combnation

- Patent filing for c-Si:



Komoto et al., 2018 (Task 12)

PV Recycling



End-of-life Scenario	Net Recycling Cost ($/ton)
A: Landfill	**65** (10 – 426)
B: Glass Recycling	**80** (-69 – -267)
C: Mechanical Recycling	**252** (16 – 517)
D: Thermal Recycling	**208** (-210 – 540)

Deng et al., 2019

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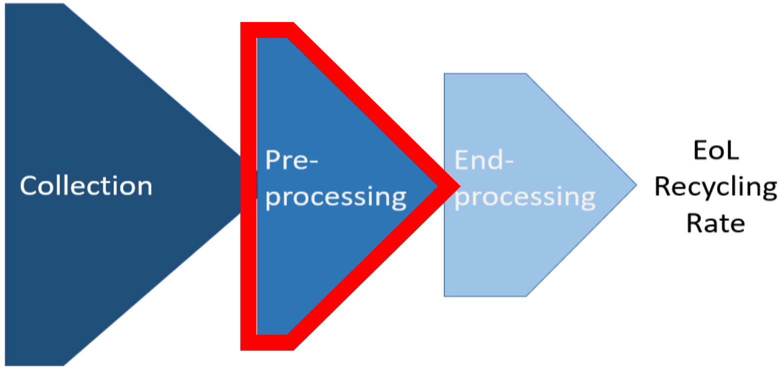
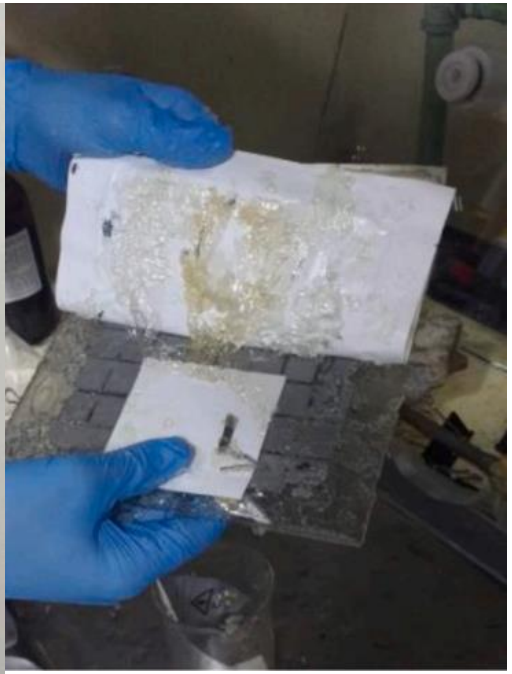
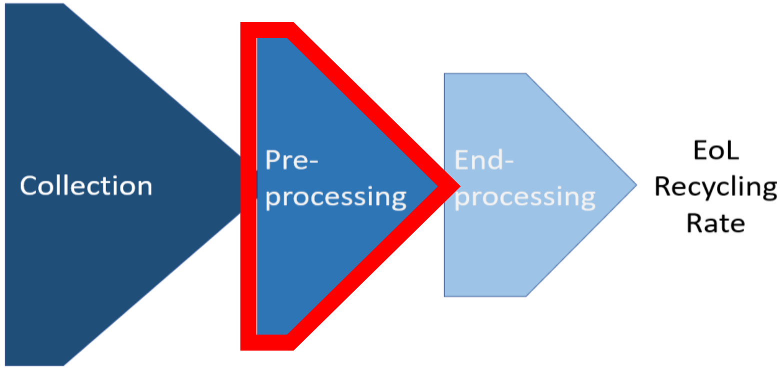
Chemical

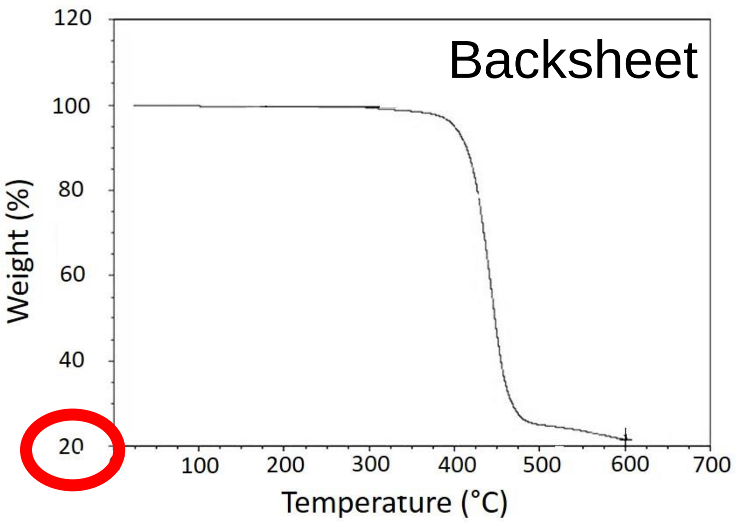


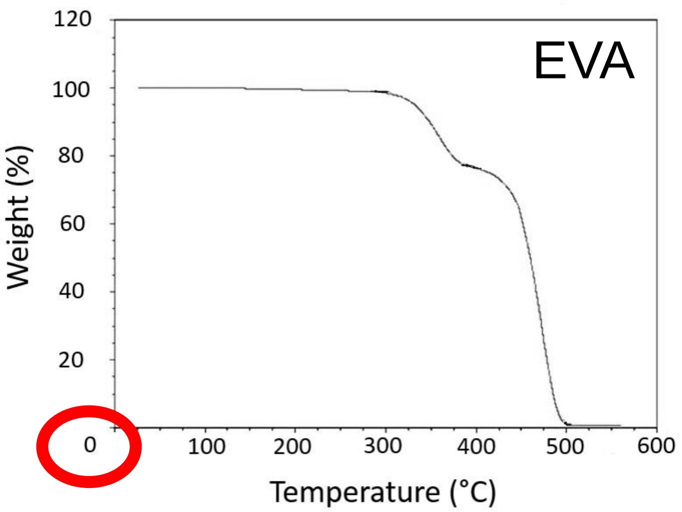


Dias et al., 2021

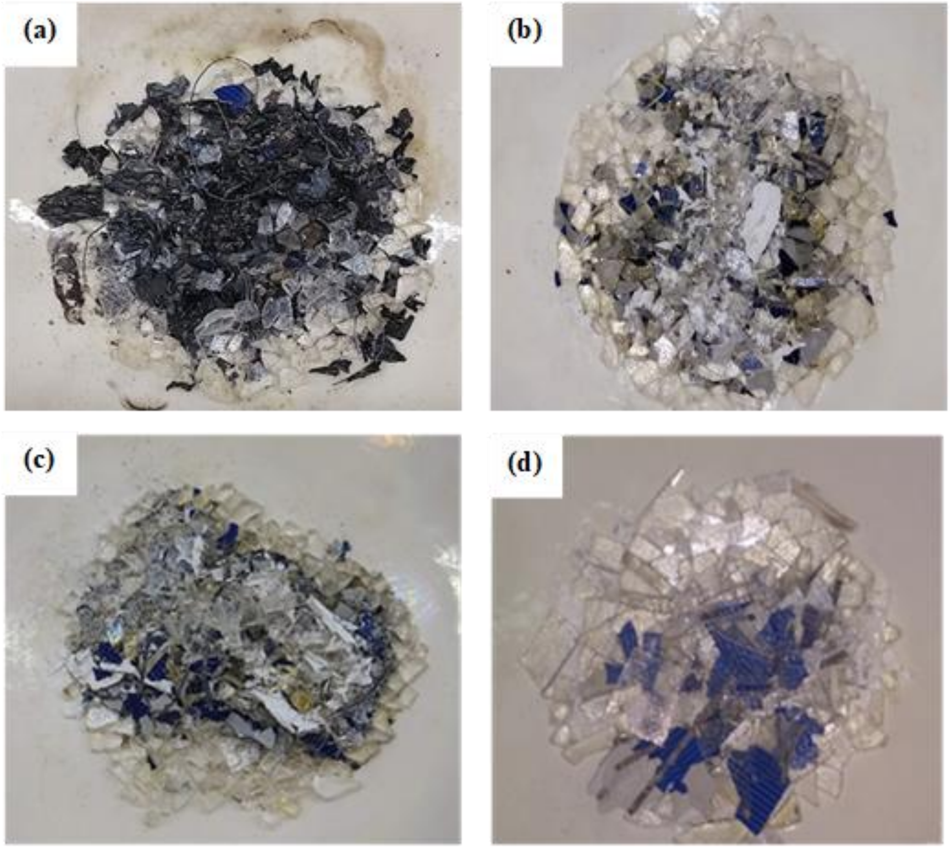
Thermal





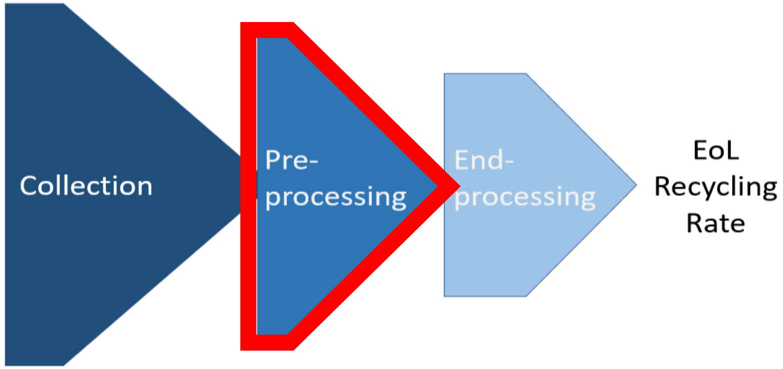


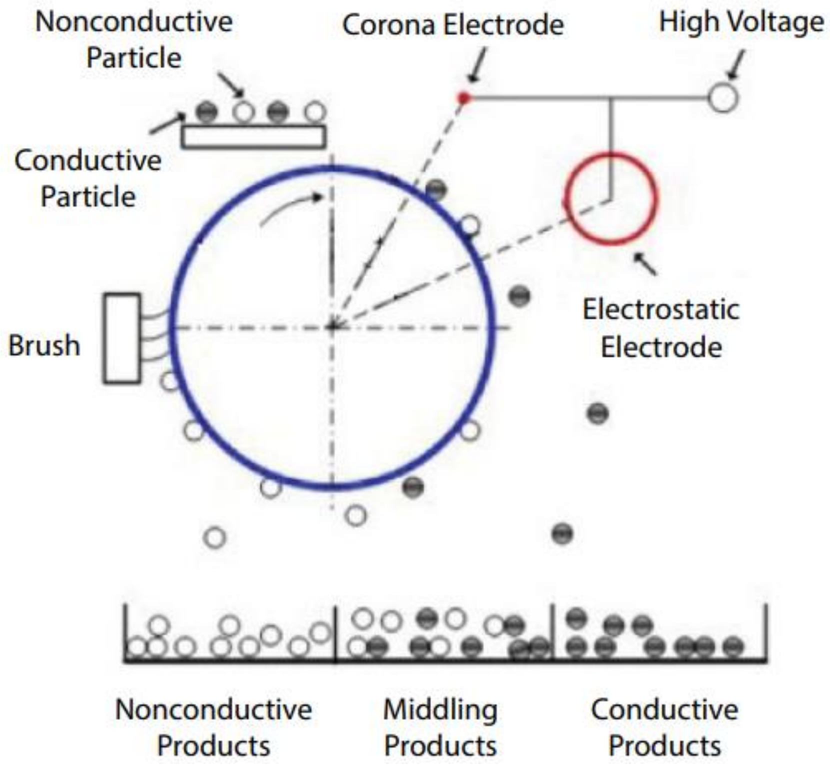
Dias PR et al., 2016

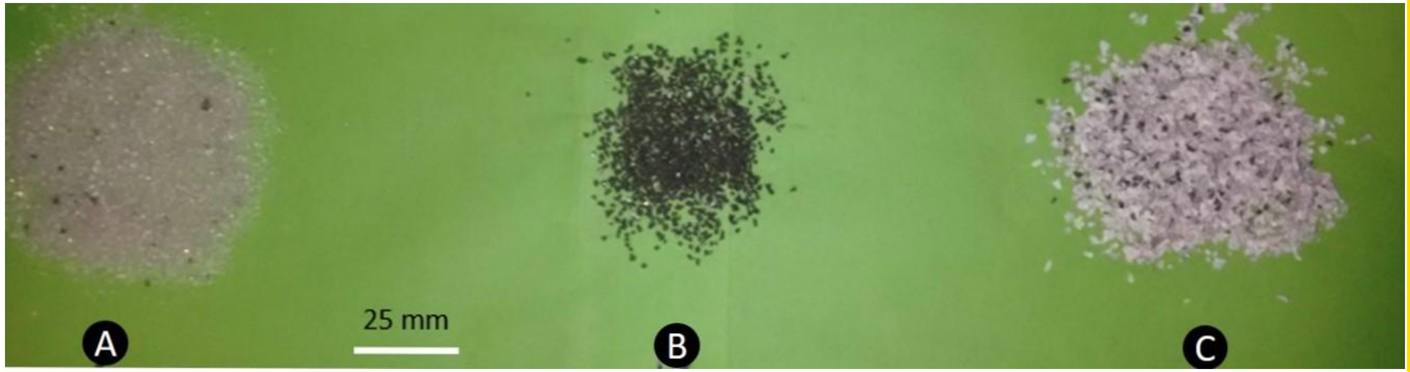


Camargo, 2021

Mechanical

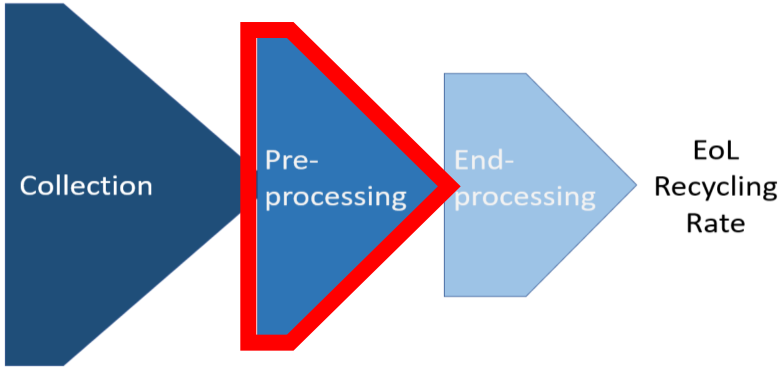


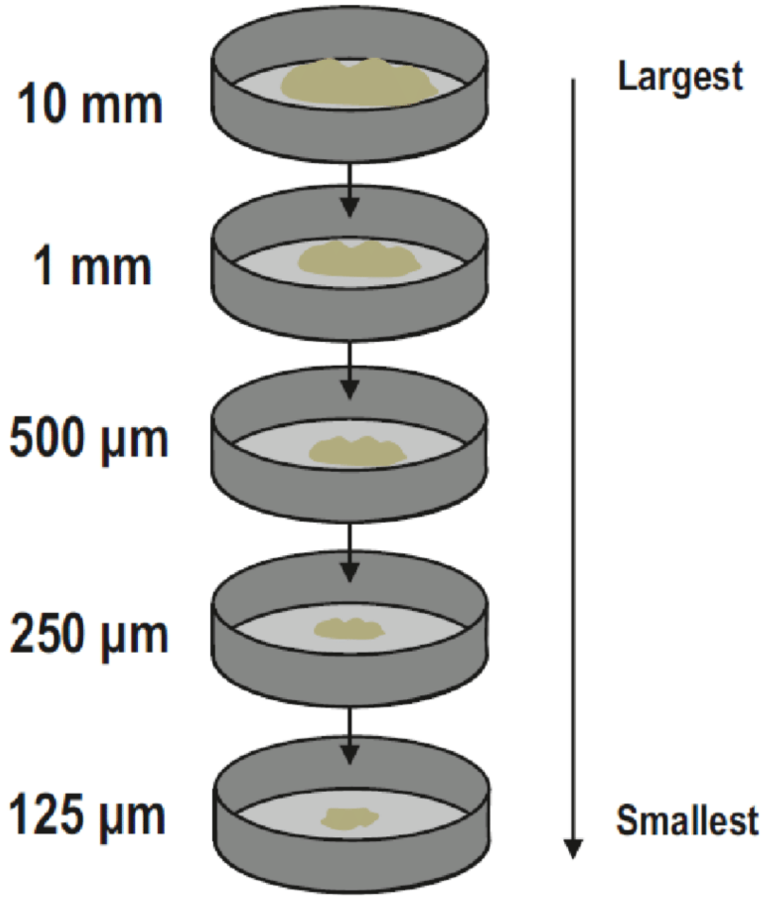




Dias et al., 2018b

Mechanical

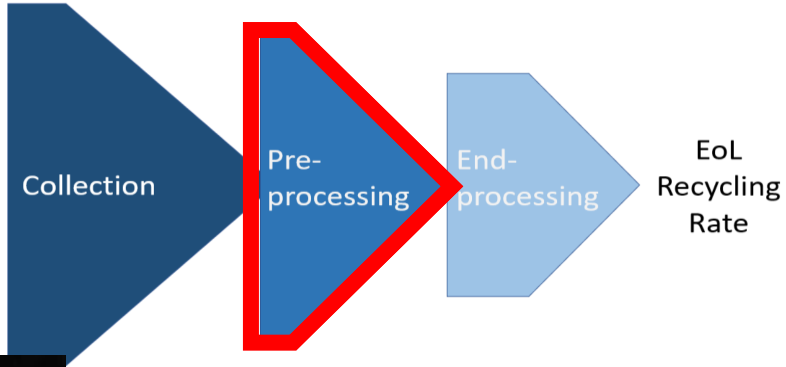


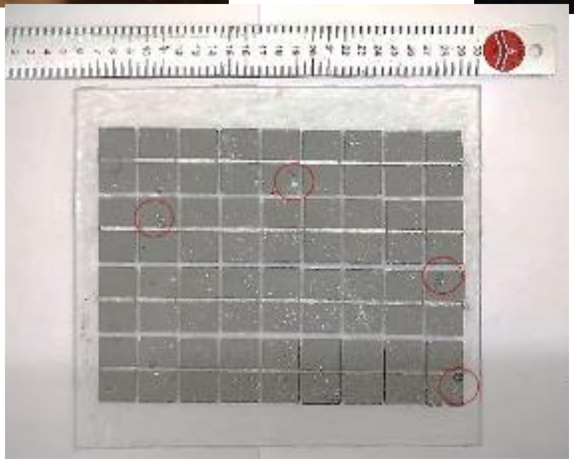


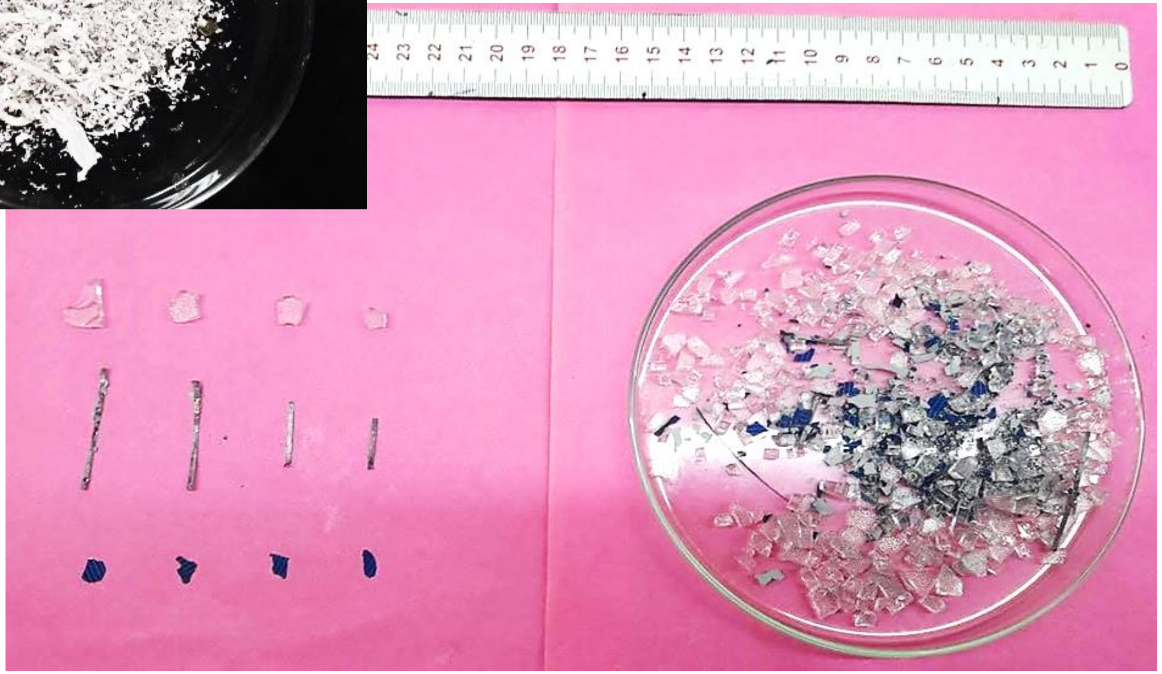
	Particle Size		
	< 0.5mm	0.5mm > n > 1.0mm	> 1.0mm
Cu	11%	18%	72%
Ag	81%	10%	9%

Dias PR et al., 2016

Combination

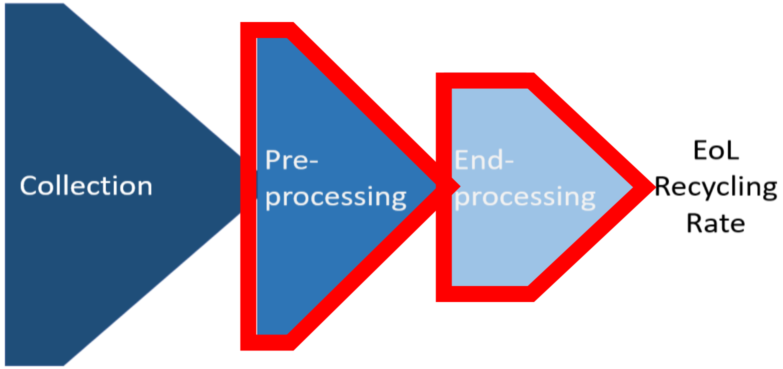




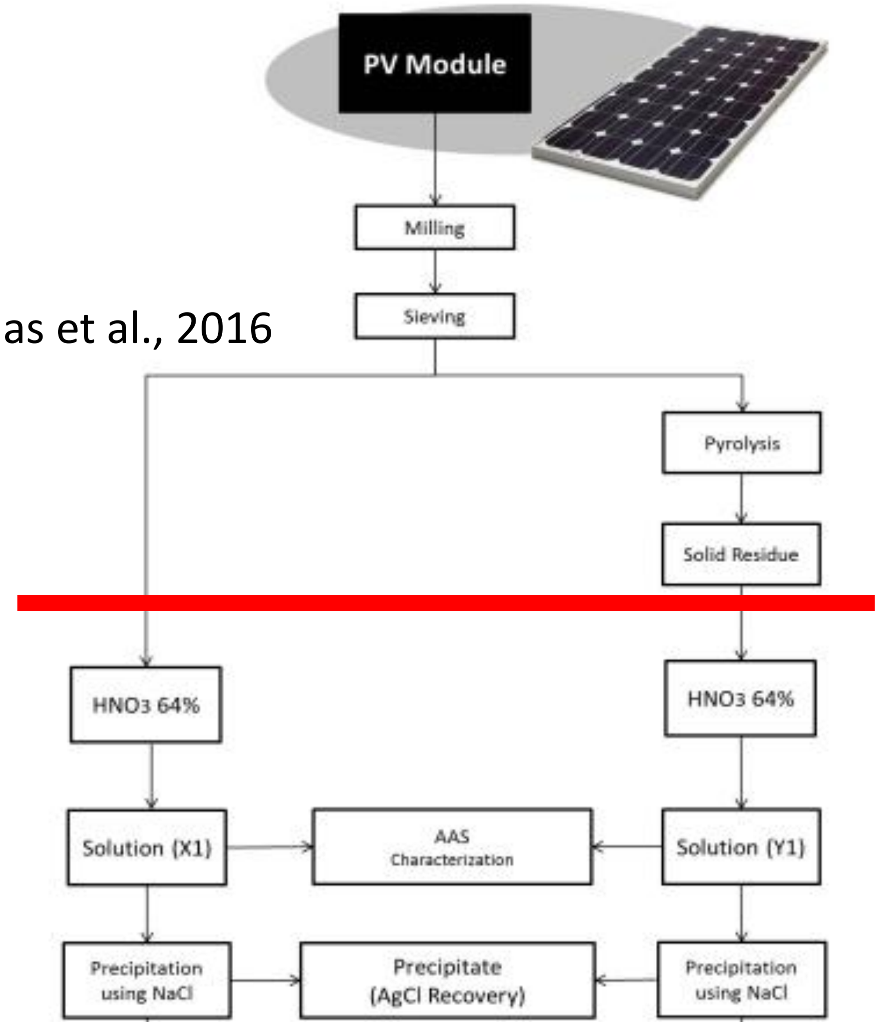


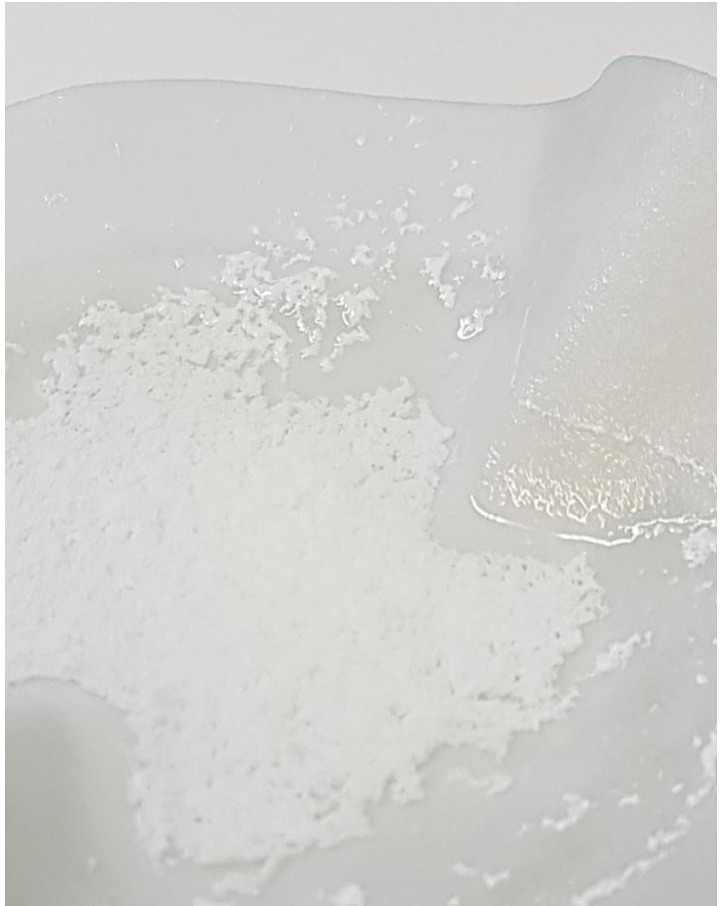
Camargo, 2021

Combination

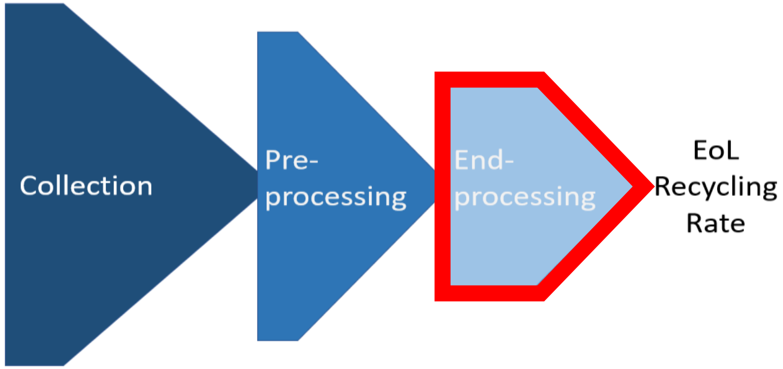


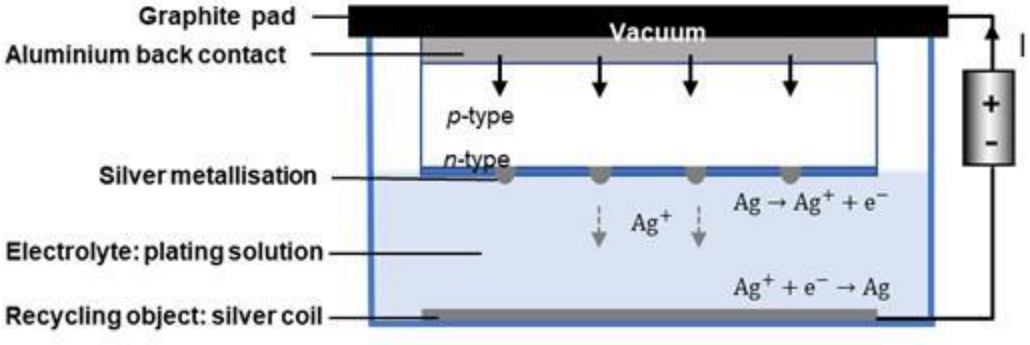
Dias et al., 2016



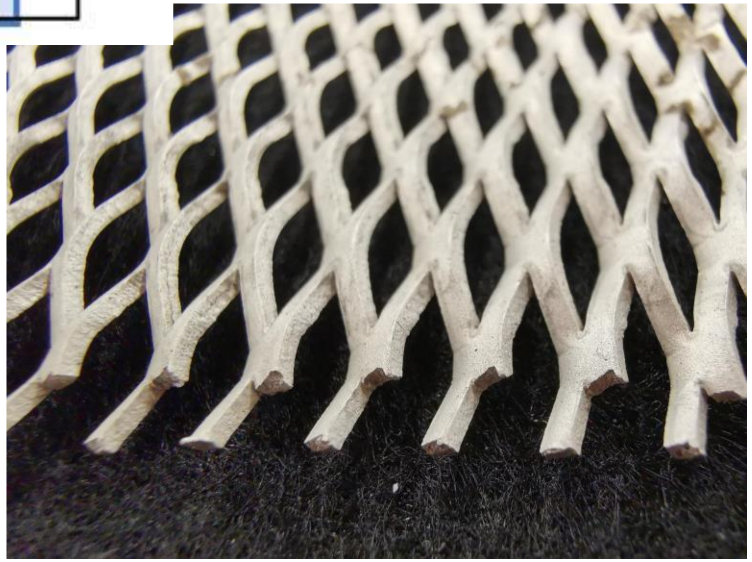


Recovery

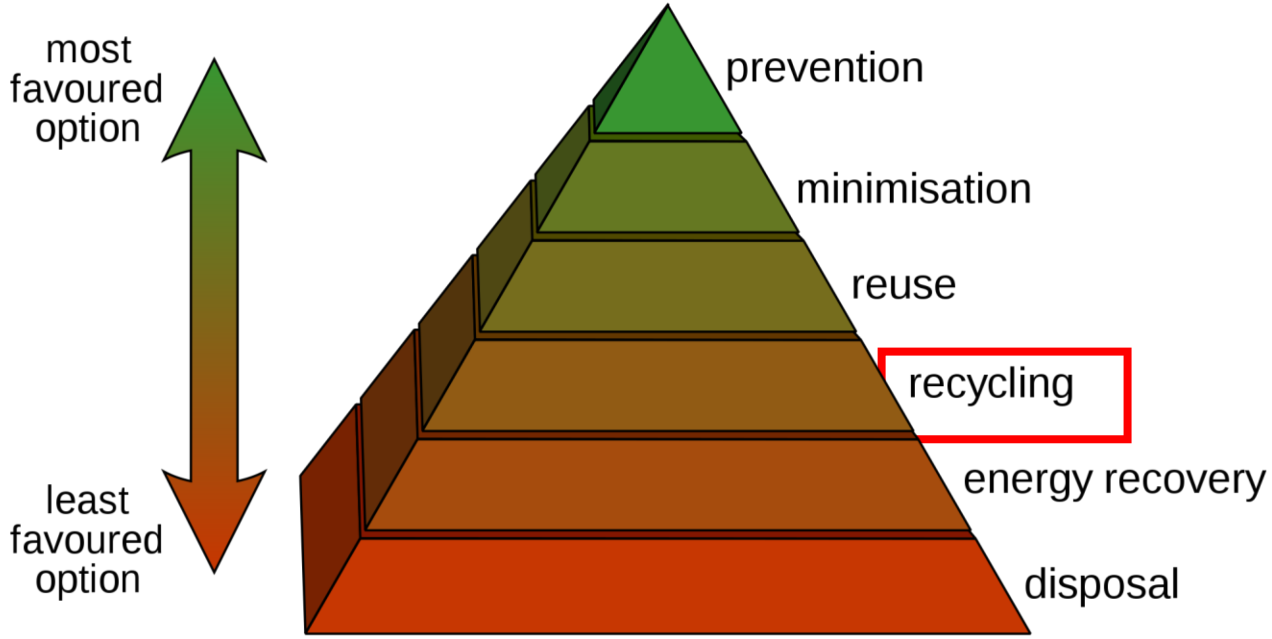




Deng et al., in press



Final Thoughts



- WEEE, but with particularities
- Design for sustainability
- Reuse solutions
- Life cycle assessment
- Techno-economic analysis
- Policy (e.g. Product Stewardship)
- Collection (RL)

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References

Camargo, P.S.S., 2021. Recycling of crystalline silicon photovoltaic modules: separation and concentration of materials (Reciclagem de módulos fotovoltaicos de silício cristalino: separação e concentração de materiais) (Master's thesis). Available at https://www.lume.ufrgs.br/ (Dissertação). UFRGS, Porto Alegre.

Defrenne, Nicolas. PV Cycle. The challenges of PV waste collection. ECO-PV conference 2021. March, 2021

Deng, R., Chang, N.L., Ouyang, Z., Chong, C.M., 2019. A techno-economic review of silicon photovoltaic module recycling. Renew. Sustain. Energy Rev. 109, 532–550. https://doi.org/10.1016/j.rser.2019.04.020

Dias, P., 2015. Characterization and Recycling of Materials of Photovoltaic Modules (Solar Panels) (Master's thesis). Available at http://hdl.handle.net/10183/127924 (Dissertação). UFRGS, Porto Alegre.

Dias, P., Javimczik, S., Benevit, M., Veit, H., Bernardes, A.M., 2016. Recycling WEEE: Extraction and concentration of silver from waste crystalline silicon photovoltaic modules. Waste Manag. 57, 220–225. https://doi.org/10.1016/j.wasman.2016.03.016

Dias, P., Machado, A., Huda, N., Bernardes, A.M., 2018a. Waste electric and electronic equipment (WEEE) management: A study on the Brazilian recycling routes. J. Clean. Prod. 174, 7–16. https://doi.org/10.1016/j.jclepro.2017.10.219

Dias, P., Schmidt, L., Gomes, L.B., Bettanin, A., Veit, H., Bernardes, A.M., 2018b. Recycling Waste Crystalline Silicon Photovoltaic Modules by Electrostatic Separation. J. Sustain. Metall. https://doi.org/10.1007/s40831-018-0173-5

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References

Dias, P., Schmidt, L., Monteiro Lunardi, M., Chang, N.L., Spier, G., Corkish, R., Veit, H., 2021. Comprehensive recycling of silicon photovoltaic modules incorporating organic solvent delamination – technical, environmental and economic analyses. Resour. Conserv. Recycl. 165, 105241. https://doi.org/10.1016/j.resconrec.2020.105241

Dias, P.R., Benevit, M.G., Veit, H.M., 2016. Photovoltaic solar panels of crystalline silicon: Characterization and separation. Waste Manag. Res. 34, 235–245.

Forti, V., Baldé, C.P., Kuehr, R., Bel, G., 2020. The Global E-waste Monitor 2020 120.

Giurco, D., Prior, T., Mudd, G., Mason, L., Behrisch, J., 2010. Peak minerals in Australia: A review of changing impacts and benefits.

Hagelüken, B.C., 2012. Recycling the Platinum Group Metals: A European Perspective. Platin. Met. Rev. 56, 29–35. https://doi.org/10.1595/147106712X611733

Hunt, A.J., Farmer, T.J., Clark, J.H., 2013. CHAPTER 1:Elemental Sustainability and the Importance of Scarce Element Recovery, in: Element Recovery and Sustainability. pp. 1–28. https://doi.org/10.1039/9781849737340-00001

Komoto, K., Lee, J.-S., Zhang, J., Ravikumar, D., Sinha, P., Wade, A., Heath, G.A., 2018. End-of-life management of photovoltaic panels: trends in PV module recycling technologies. National Renewable Energy Lab.(NREL), Golden, CO (United States).

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References

Latunussa, C.E.L., Ardente, F., Blengini, G.A., Mancini, L., 2016. Life Cycle Assessment of an innovative recycling process for crystalline silicon photovoltaic panels. Sol. Energy Mater. Sol. Cells, Life cycle, environmental, ecology and impact analysis of solar technology 156, 101–111. https://doi.org/10.1016/j.solmat.2016.03.020

Mahmoudi, S., Huda, N., Behnia, M., 2019. Photovoltaic waste assessment: Forecasting and screening of emerging waste in Australia. Resour. Conserv. Recycl. 146, 192–205. https://doi.org/10.1016/j.resconrec.2019.03.039

Morris, A., Metternicht, G., 2016. Assessing effectiveness of WEEE management policy in Australia. J. Environ. Manage. 181, 218–230. https://doi.org/10.1016/j.jenvman.2016.06.013

Pinho, J.T., Galdino, M.A., 2014. Engineering Manual for Photovoltaic Systems Retrieved from Rio de Janeiro: CEPEL – CRESESB. Manual de engenharia para sistemas fotovoltaicos.

Sustainability Victoria, 2019. PV Panel Reprocessing: Research into Silicon-Based Photovoltaic Cell Solar Panel Processing Methods, Viable Materials Recovery and Potential End Market Applications. Sustainability Victoria. Resource Recovery Strategies & Programs Division.

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