CIRCULAR SUPPLY CHAINS: REDUCING POLLUTION AND WASTE THROUGH COOPERATION

10 June 2021

EU GREEN WEEK 2021 PARTNER EVENT

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Agenda

15.00 – 15.10 - Introduction - 10 min

- Tom Rommens, VITO
- Naoko Tojo, Lund University
- Anse Smeets, VITO: Environmental assessment of PV and reducing the pollution

15.10 – 15.30 - Main presentations - 20 min

1. The circularity of solar PV - Tadas Radavičius, SoliTek
2. Waste reduction: practical issues for the re-use of PV modules - Arvid van der Heide, Imec
3. The transition from a waste society to a circular society - Wolfram Palitzsch, LuxChemtech
4. Solar circular supply chain from service providers' point of view – Lisa Wendzich, SunCrafter

15.30 – 16.00 - Panel discussion – 30 min

Moderator: Naoko Tojo, Lund University

16.00 – 16.10 – Final remarks

Tom Rommens, VITO


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Circularity in the solar power industry: is it worthwhile?

Anse Smeets, VITO

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Solar is booming!

Giga factory, Tesla, U.S.

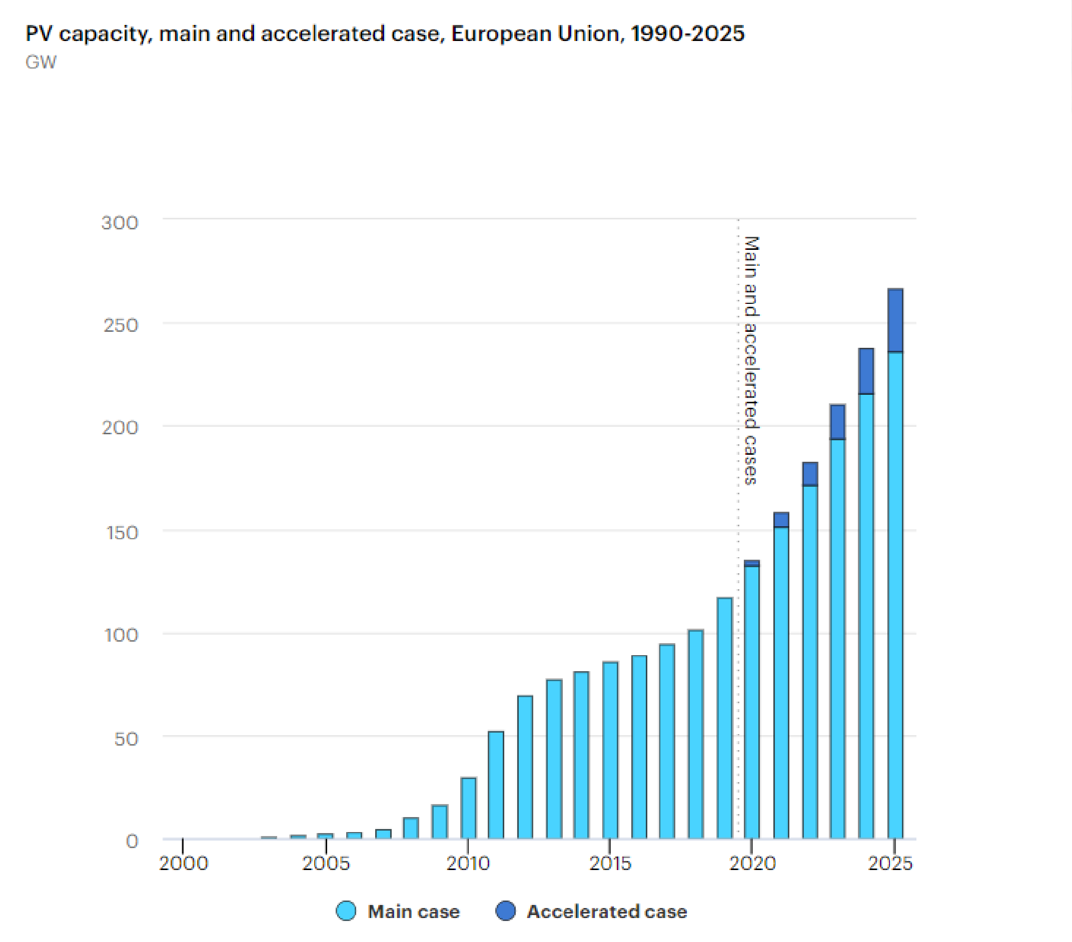
Solar is booming!

"Renewable electricity expanded at fastest pace in two decades, with huge additions of solar becoming the 'new normal' going forward"

"Larger projects dominate the solar PV market"

"Corporate procurement expands as PV costs continue to decline"

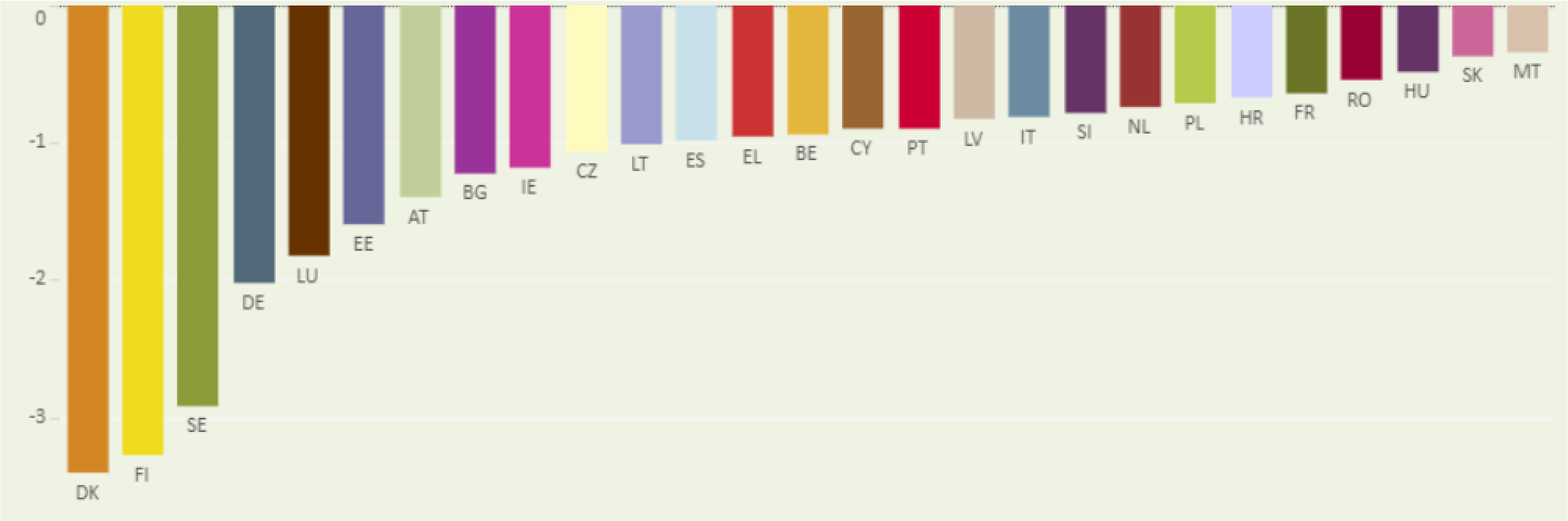
Source: IEA, Renewable Energy Market Update 2021



Source: IEA

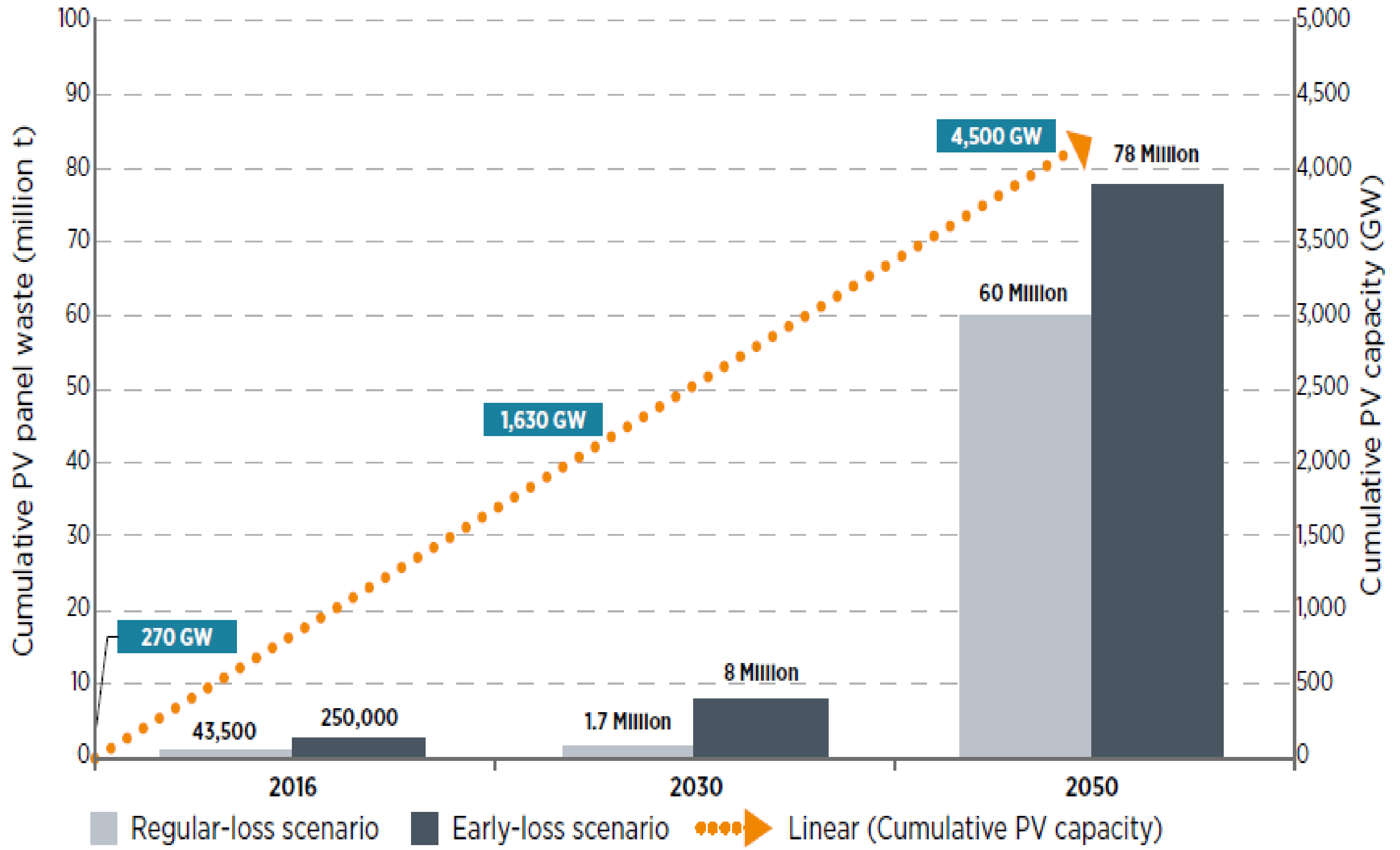
… and has a large pollution reduction potential

Avoided GHG emissions by solar PV, proxy for 2019
(ton CO_2 per capita)



Source: EEA Renewable energy impacts dashboard, 2020

Global PV waste projections



Source: IRENA/IEA PVPS, 2016

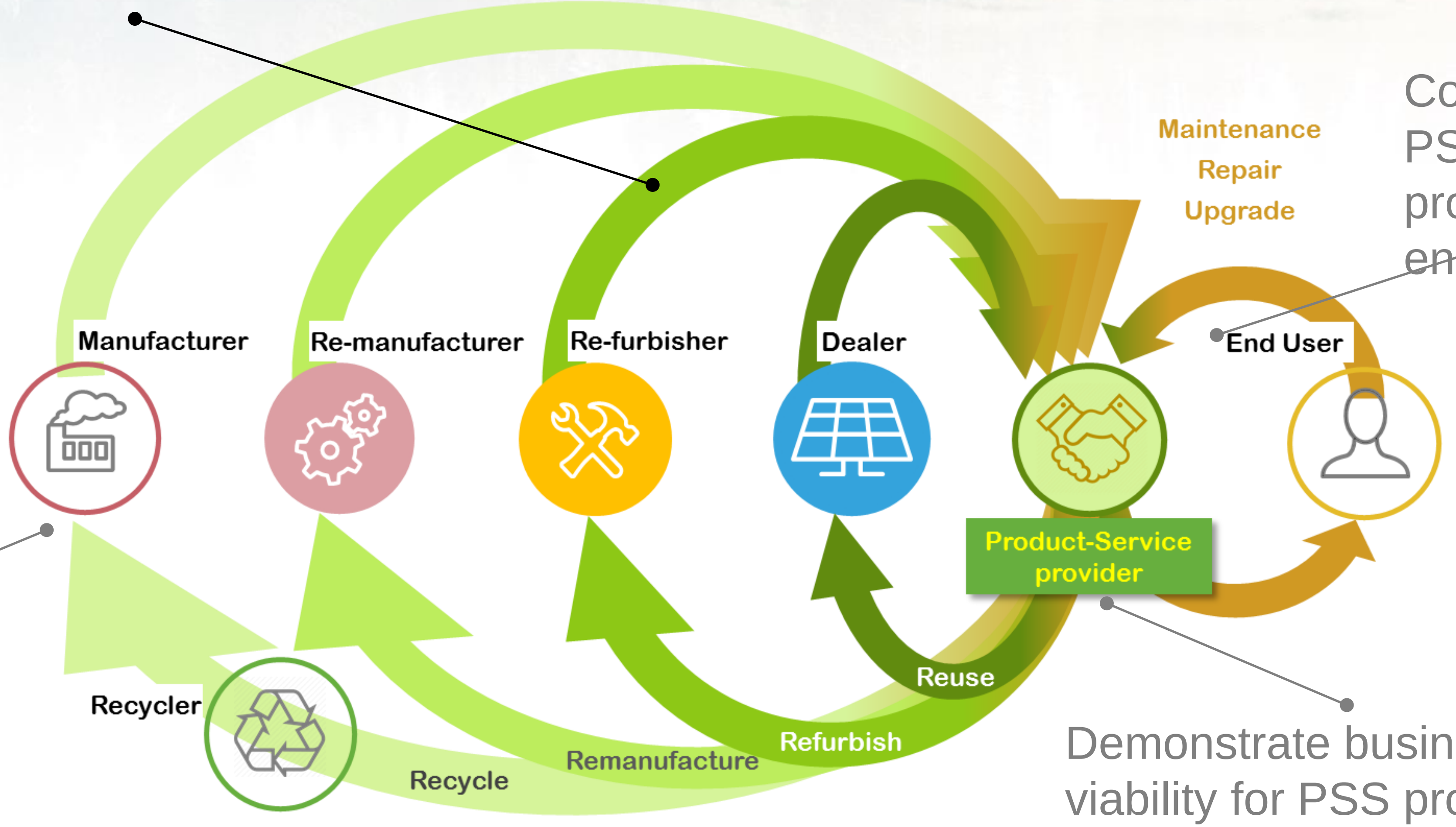
What happens after decommissioning?

Is **RECYCLING** the only option?

What about **REPAIR** and **REUSE**?

The most **CIRCULAR** paths should be prioritized!

Extend PV module lifetime via re-use, repair, repurpose

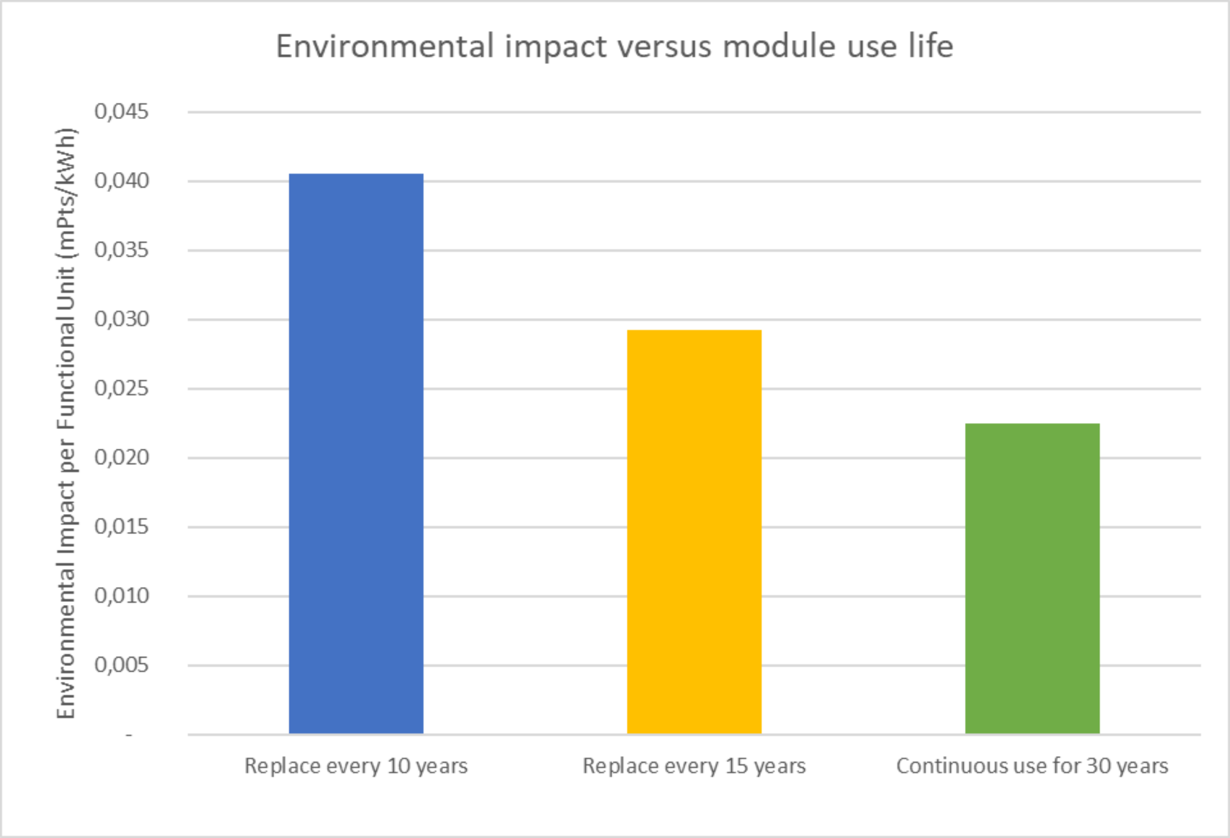


Co-create solar PSS value propositions with end-users

Incentivize “design for circularity”

Demonstrate business viability for PSS providers (and other actors)

More circular = less pollution?



Pollution related impact category	Impact reduction from reuse and repair?
Climate change	✓
Ozone depletion	✓
Ionising radiation	✓
Photochemical ozone formation	✓
Particulate matter	✓
Human toxicity	✓
Acidification	✓
Eutrophication	✓
Freshwater ecotoxicity	✓

So…circularity in the solar power industry: is it worthwhile?

YES! Now how do we make it happen?

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The circularity of solar PV

Tadas Radavičius, SoliTek

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Circular solar PV chain

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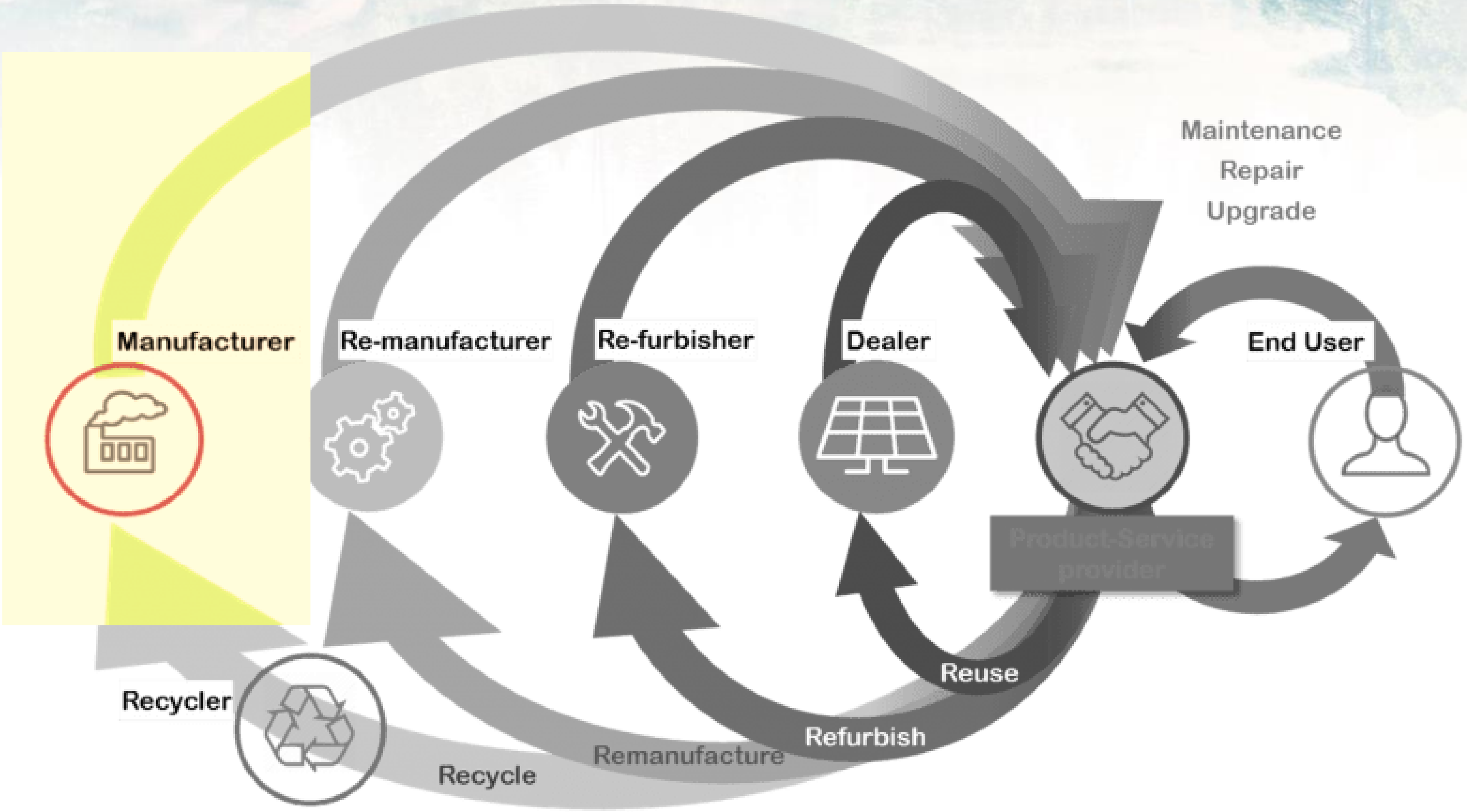
Circular solar PV chain: manufacturer perspective

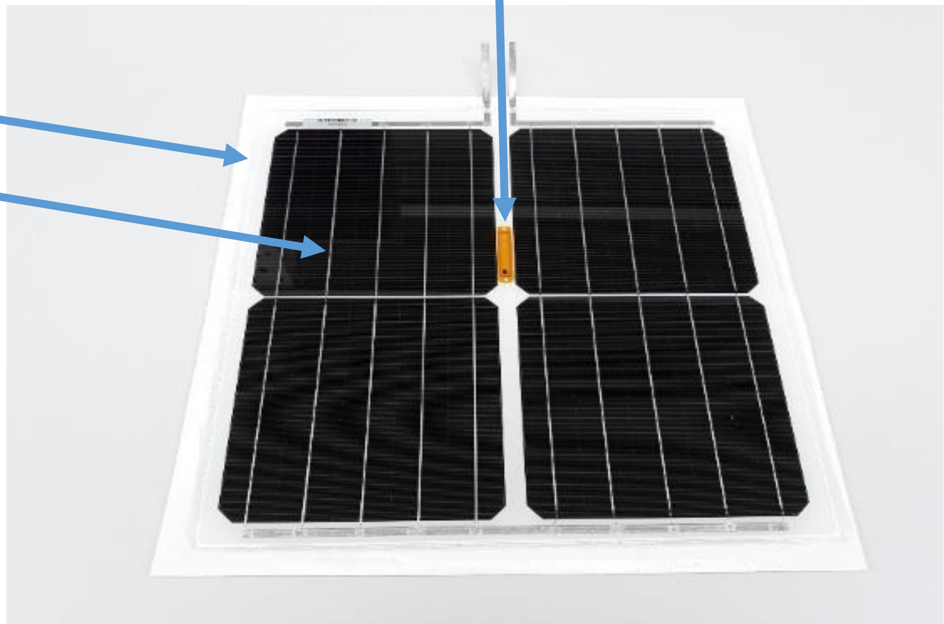


Circular PSS Model = Circular Product Management + Value-added Product-Service

Circular solar PV chain: changing design of the module

- Near-field communication (NFC) tags;
- Fluorine-free back sheet;
- Lead-free ribbons (bismuth as replacement):

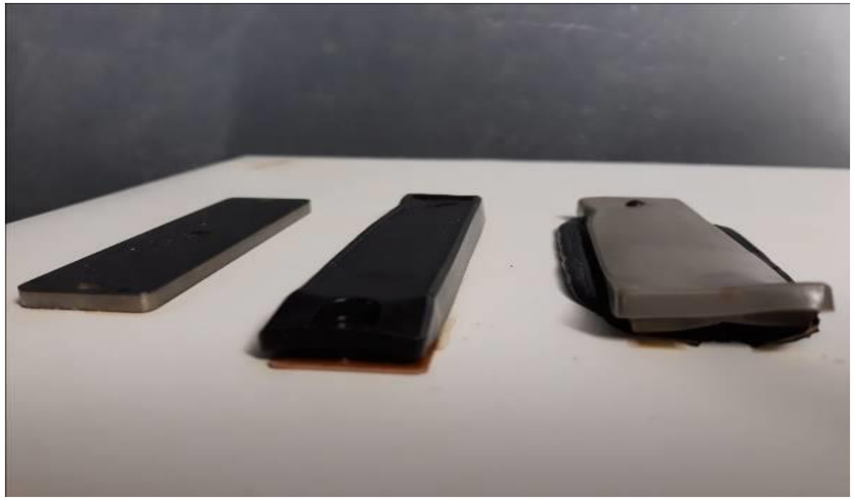
- 90-95% of bismuth is by-product of lead smelting.



Circular solar PV chain: database to enhance EoL operations

- Database for solar modules.
- RFID tags for traceability and identification for reusability, recyclability, etc.

QR codes, RFID tags, barcodes, etc.....
Which is the most fitting for solar modules?



Circular solar PV chain: opportunities for manufacturer to produce a circular product

- Design out toxic materials;
- Enable product to be circular (repairable, recyclable, trackable, etc.).

Manufacturer must take into account further supply chain actors when changing or creating product design.

Waste reduction: practical issues for re-use of PV-modules

Arvid van der Heide, imec

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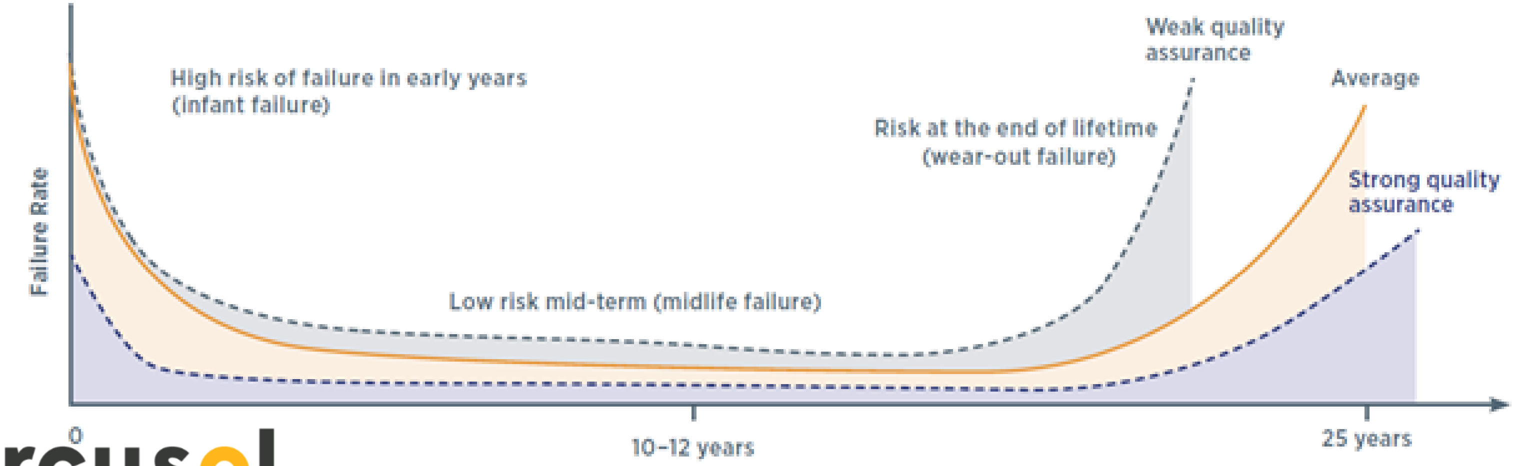
Where to find used PV modules?

- Intact modules from large PV systems partly damaged by extreme weather conditions
- Defect (but repairable) modules that have been removed
- Modules removed on repowering large PV plants
  - Feed-in tariff: only after 20 y, modules (very) old
  - No feed-in tariff: expected after ~10 y



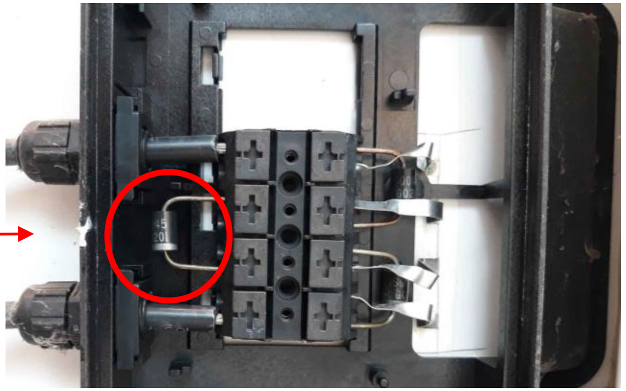
Which issues in used modules? Repair options?

Non-repairable issues (non-exhaustive list):

- Broken glass
- Visible burn marks (dark brown) at solder strip joints, on cells or back sheet
- Large delamination of encapsulant starting at module edges
- Back sheet material failure leading to back sheet cracking

Repairable issues:

- Defect or missing connector/cable (replacement)
- Damaged junction box (replacement)
- Defect bypass diode (replacement)
- Back sheet scratch (covering scratch)



Where to re-use modules, where to buy & at which price?

Re-use for:

- Repair of feed-in tariff systems with identical module to keep subsidies (high module prices)
- Off-grid applications at low voltage
- Medium sized systems in Africa, Pakistan, Afghanistan
- Replacement of all modules in existing systems that are severely underperforming

But NOT expected for:

- Residential applications, BIPV
- New utility scale plants in Europe (re-use modules are around 50% cheaper than new ones, but modules are only 30% of total investment, while performance and remaining lifetime of re-use modules are less)

In Europe ~ 5 German companies are trading in re-use modules, there are also ~ 10 Chinese ones

Re-used c-Si modules (rare)	Re-used c-Si modules (mainstream)	New c-Si modules (mainstream)	New c-Si modules (high efficiency)
Up to 5 €/W_p	0.125 €/W_p	0.25 €/W_p	0.33 €/W_p

How about legislation and standards?

Outside Europe, modules are usually considered as general waste

In Europe, legislation for electronic waste (WEEE) is applicable

- Important risk: dumping of non-functional modules, calling them modules for re-use

- To be no waste, an electronic device must be functional. However, not clear for an energy generating device: which limit for remaining power, 60%, 70%, 80%?

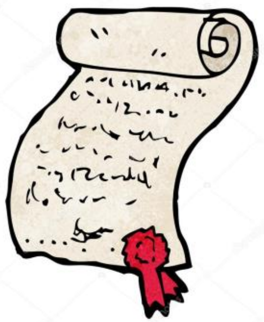
- Concerning quality standards, for new modules they exist (from IEC), but not for re-use modules

- In Circusol, we propose to include certain (cost-effective) quality checks for re-use modules in international standards, the IEC has been contacted and a project team is expected to start soon

Important challenges for module re-use

- Used modules not much cheaper than new ones: not interesting for all applications given their lower power output and remaining lifetime.

- Issue of functionality and quality of re-use modules: need for minimum power limit ar international quality standards. Important for trust and to avoid dumping of module Important challenge is to keep testing and sorting procedures cheap but effective.



- Many modules are now shipped to Africa and other regions without local recycling facilities

The transition from a waste society to a circular society

Wolfram Palitzsch, LuxChemtech

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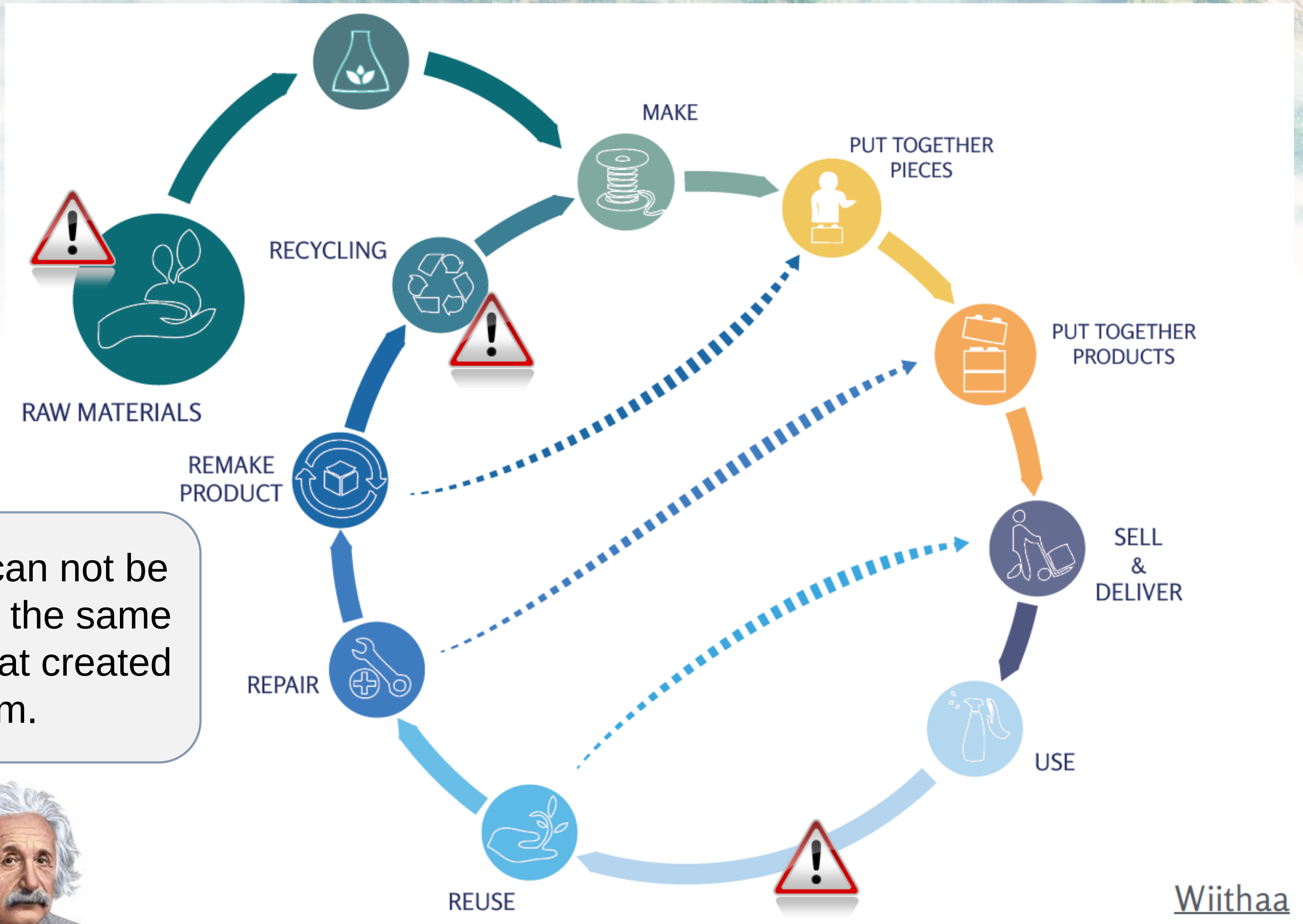
Closed System Definition: A closed system is a type of thermodynamic system where **mass is conserved** within the boundaries of the system**, but energy is allowed to freely enter** or exit the system.

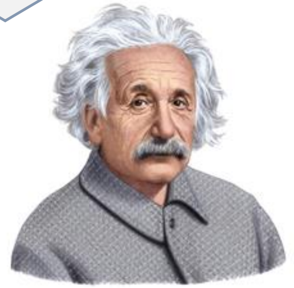
Whether raw material or waste – everything consists of corresponding elements:

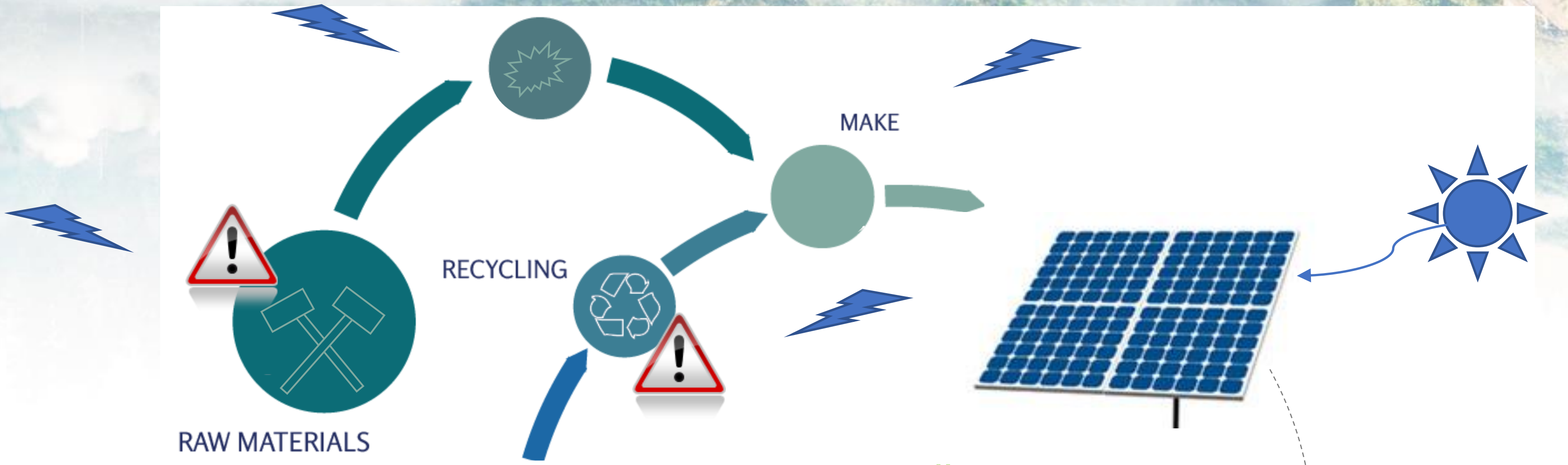
Waste is a no longer contemporary name for a mixture of elements!

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	
			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	



Problems can not be solved with the same mind set that created them.





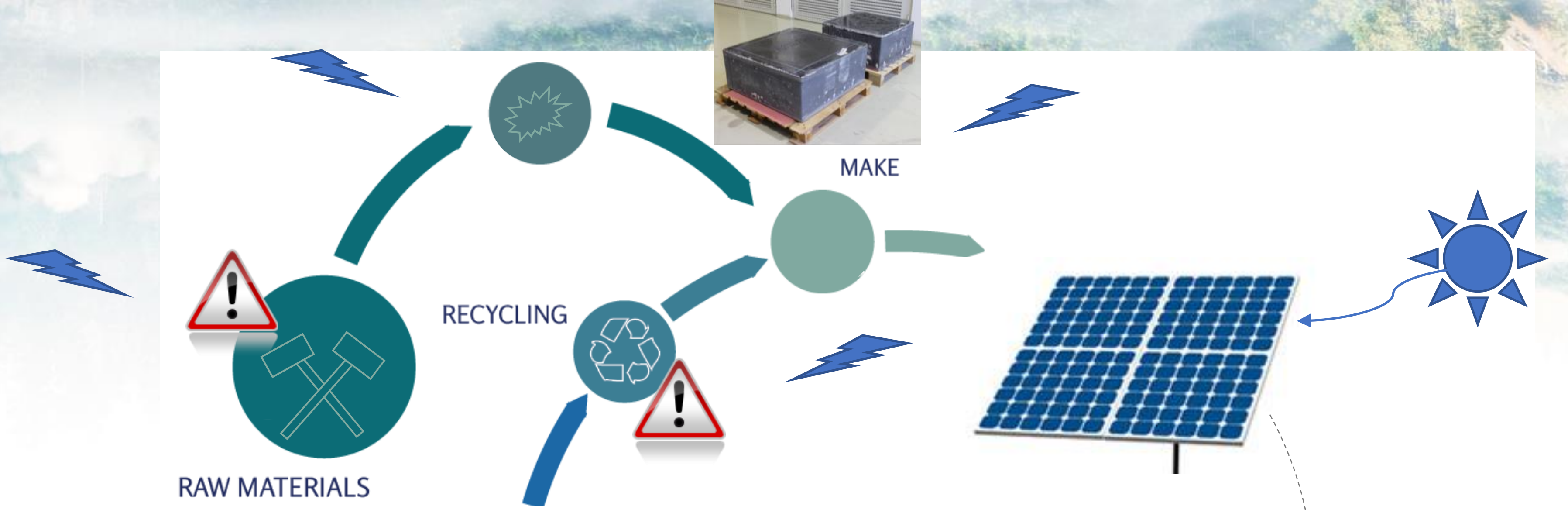
quartz

feldspar

1 Tonne cullet saves
6 Tonnes mining and
25% energy

glass cullet from PV module scrap

References:
https://sparklerockpop.com/collections/crystals/products/quartz-crystal-geode-11
https://www.pyramidtatvanepal.com/natural-stones/item/317-red-aventurine-new-raw



quartz

the same for silicon

and silver and copper, …

References:
https://sparklerockpop.com/collections/crystals/products/quartz-crystal-geode-11
https://www.pyramidtatvanepal.com/natural-stones/item/317-red-aventurine-new-raw

Go out of the linear mindset, to think circular.

Linear →	Circular
Simple →	Complex
Predictive →	Adaptive
Competition →	Cooperation

Economic perspectives on the reuse of PV modules

Lisa Wendzich, SunCrafter

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Can 2nd life solar modules be competitive?

- **Demand side**
  - Reuse modules are environmentally beneficial
  - Reuse modules economically competitive to new modules under conditions
    1. Use Case\Application
    2. Rehabilitation Cost
    3. Financial Benchmark

- **Supply side**
  - Combination of waste management strategies 'reuse' and 'recycling' to reach economic and ecologic optimum

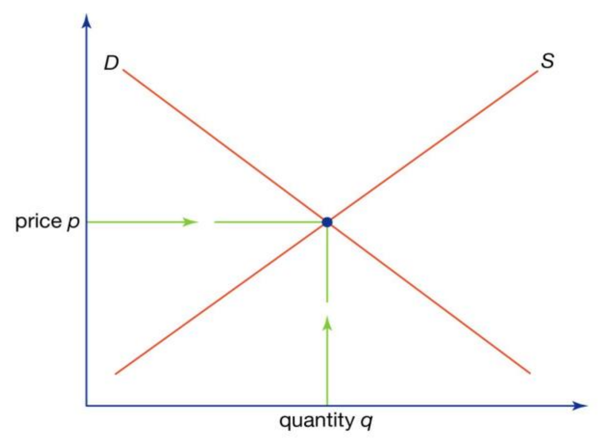


Figure 1: price point dependent on supply and demand (stock, 2020)

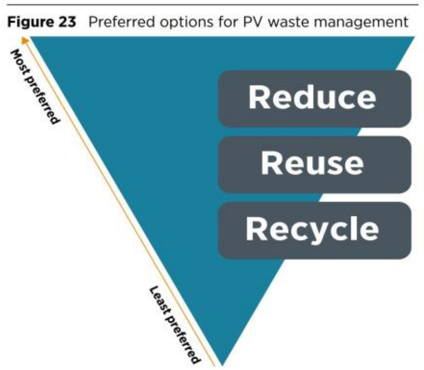


Figure 2: Waste Hierarchy (IRENA & IEA, 2016)

Technical Use Cases

- 1. High-Voltage, grid connected, e.g. residential

- high quality standard required
- many damage types not usable, even when repaired
- requiring extensive testing and rehabilitation

- 2. Low-voltage, stand-alone, e.g. solar home system

- Lower quality standard acceptable
- Many damage types and repairs usable
- Requiring testing and refurbishment, but less extensive

Figure 3: Large solar field (stock photo)

Figure 4: SunCrafter EasyPanel at Rio Negro, Brazil (Own source, 2019)

Proposed Rehabilitation Process

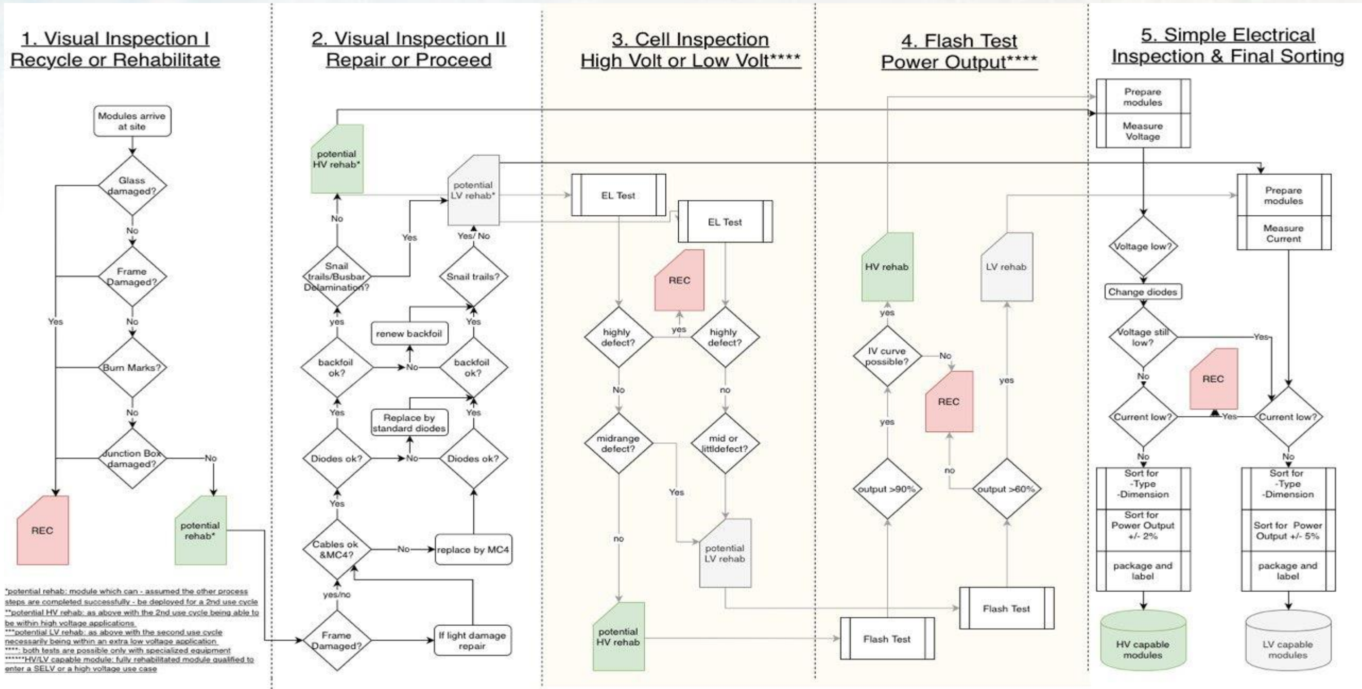
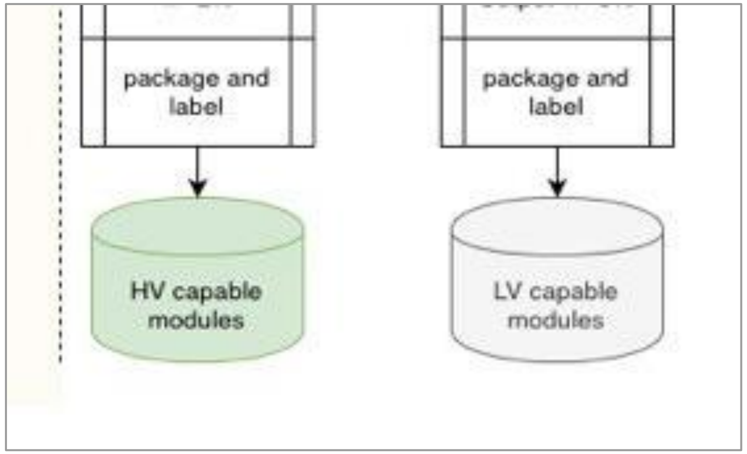


Figure 5: Decision tree for module rehabilitation in two categories (internal memo, 2020)



- > Different treatment paths allow to optimize cost efficiency and quality standards per module category (use case) AND increase rehabilitation rate (increasing total share or successfully rehabilitated modules)

Point of Intervention (PoI)

- Where will the modules be assessed and rehabilitated/refurbished?

1. At power plant itself with mobile equipment
2. At recycling facility with permanent setup
3. At external treatment plant either in EU or in partner country


Figure 6: Stacked disused solar modules
(Own source, 2013)

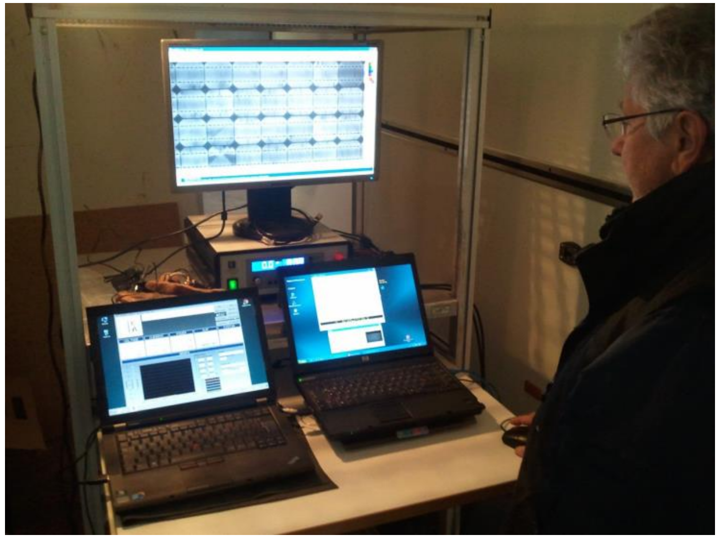


Figure 7: Electroluminescence imaging
(Own source, 2013)

Rehabilitation Cost

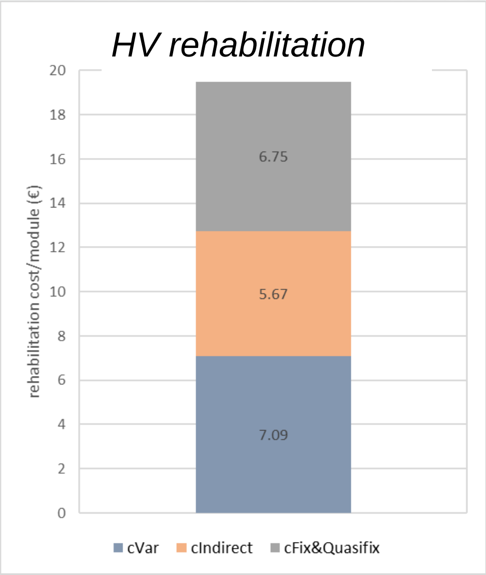


Figure 8: Rehabilitation Cost for PoI "Recycling plant" in EU - HV rehabilitation (internal memo, 2020)

- **Economics of rehabilitation depend foremost on:**

- - Quality Requirements (depending on Use Case)

  - Wage Level (depending on PoI)

  - Rehabilitation Rate (depending on PoI & Use Case)

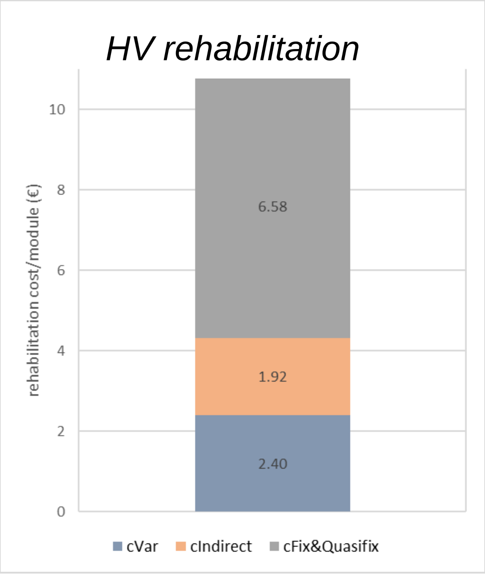


Figure 9: Rehabilitation Cost for PoI "External treatment plant" in Ghana - LV rehabilitation (internal memo, 2021)

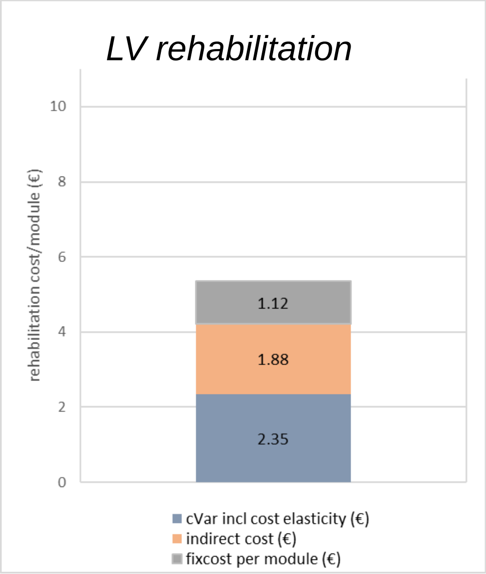


Figure 10: Rehabilitation Cost for PoI "External treatment plant" in Ghana - HV rehabilitation (internal memo, 2021)

Financial Benchmark – Upfront Investment

- Renewable Energy Cost structure:

  Investment expense > O&M & variable cost

€/kW - depend on module age

Less bankable populations benefit from lower upfront cost

  - Impact on SDG 7 – access to energy
  - New target group instead of cannabalization of market

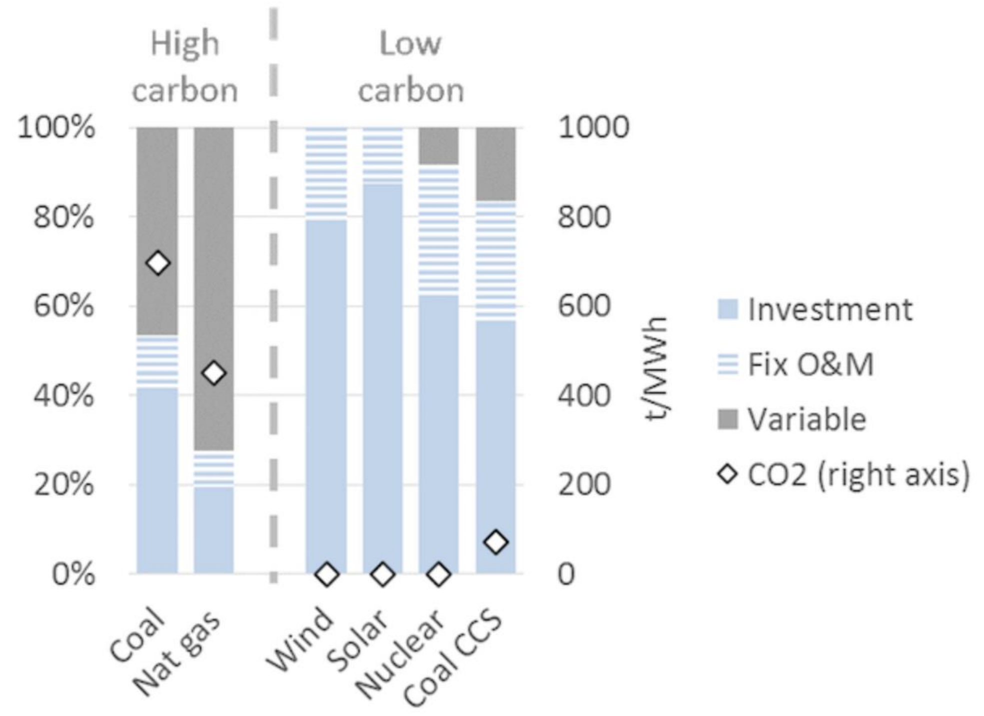


Figure 13: Cost structure of different electricity sources (Hirth, 2013)

Financial Benchmark - LCOE parity

Module AGE is the determining factor as it influences

- original power output of disused module
- remaining power output after degradation
- relative power density compared to new modules and area dependent BOS cost
- remaining lifetime influencing generation and WACC

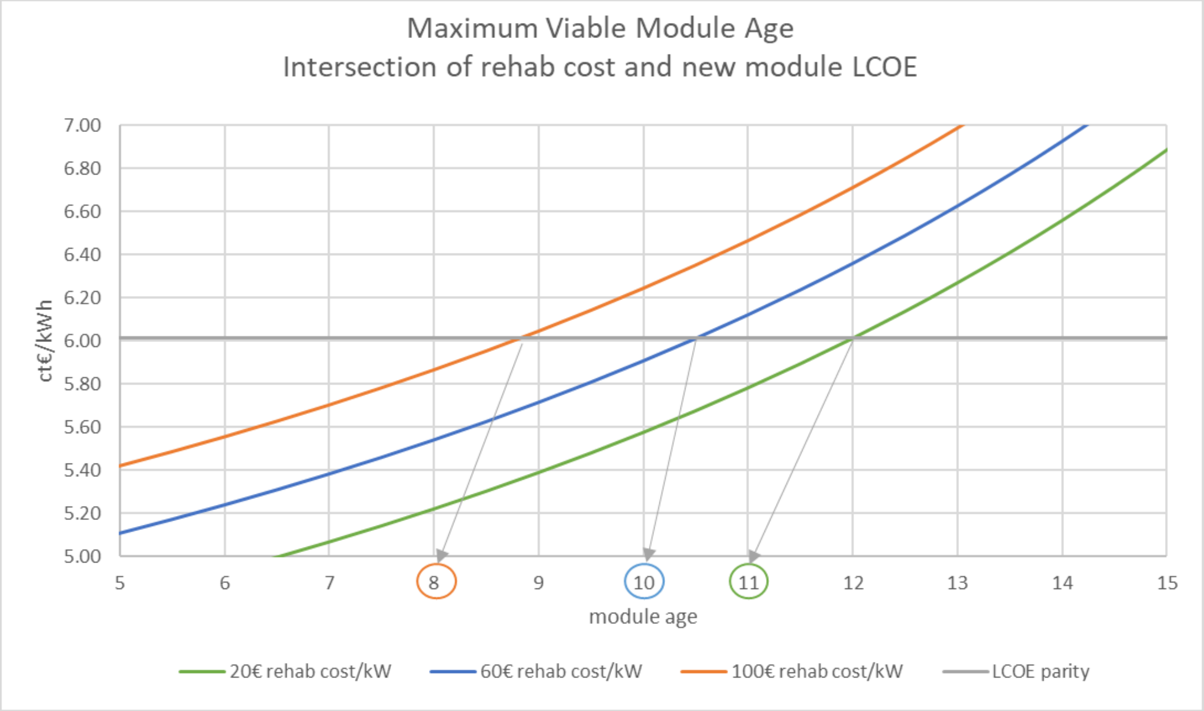


Figure 11: Maximum viable module age derived from LCOE parity as financial benchmark (internal memo, 2020)

Conclusion & Discussion points

Conditions for economic viability are

- a cost efficient and quality ensuring testing and rehabilitation process

- regulatory standards enabling module rehabilitation in countries where reuse is most likely to take place

- inclusion of low-voltage, off-grid applications into reuse scenario

- consideration of different financial benchmarks such as LCOE parity, NPV and upfront investment cost

Practical issues to inquire further

- How can all stakeholders – OEM, reverse logistics agents, plant owners, recyclers etc. be incentivized to support reuse?
- How can the rehabilitation process take place in country of reuse without risking illegal waste dumping?
- How many modules are discarded within the first 8 to 12 years after installation (maximum viable module age for financial benchmark 'LCOE parity') and for which reasons exactly (indicates their reusability)


Panel Discussion
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Final remarks

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