

Challenges and opportunities for solar glass recovered from high-value recycling

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Motivation & Background

- PV waste expected to exceed **210 million tons by 2050**
- Glass represents **70–95%** of module mass → major recycling challenge
- Need for **high-value recovery routes** to support circular PV manufacturing because of two recycling worlds:
 - Low-value → crushed glass
 - **High-value → intact glass**
- Industrial relevance: float glass, PV module production, local circularity, ...
- But: **Cullet is not just cullet.** For recycled glass to be used effectively, it is essential to **understand the different types** of cullet and to **separate them correctly**.

High-Value Recycling Approach



Delamination process:

- **Water-jet** (c-Si modules) ←
- **Optical flash light** (thin-film modules) →

Output: **intact, clean glass sheets** free of polymers and metals

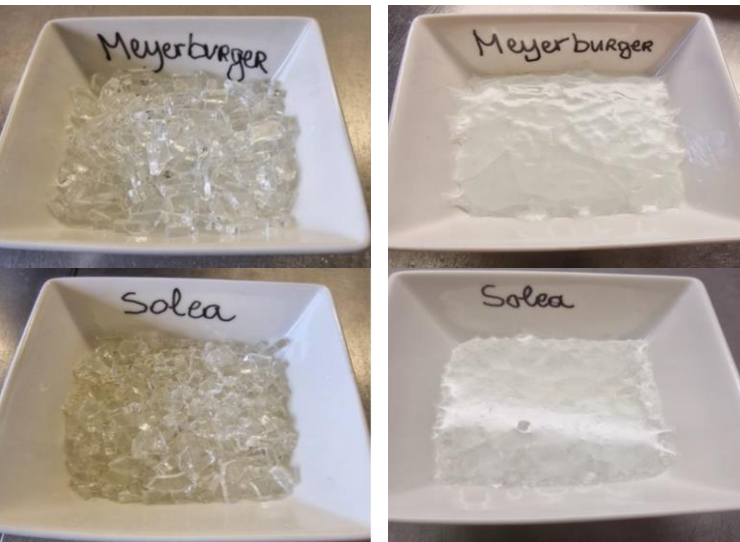
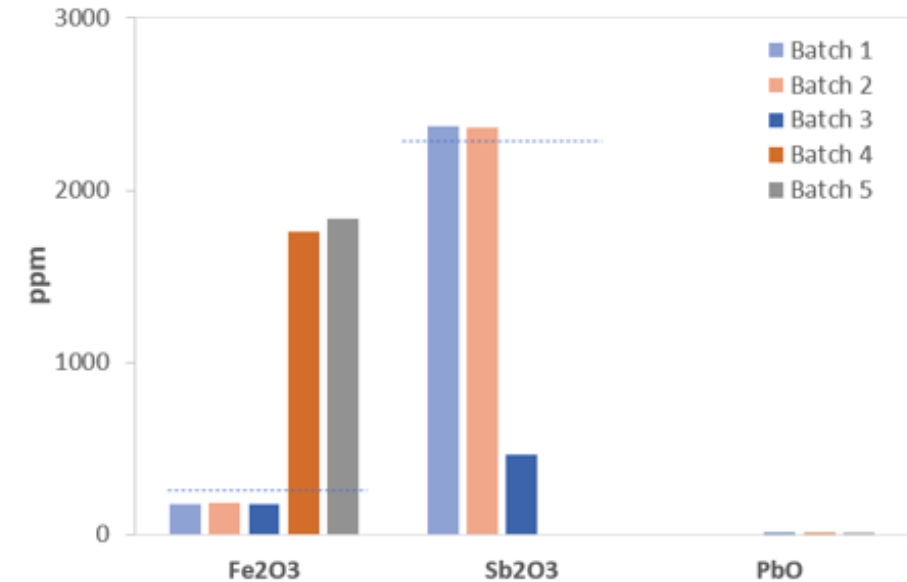
Enables:

- **Cullet production** for industrial melting
- **Direct re-use** of glass panes in new PV modules, etc



Glass Characterization Industrial Feedstock

- **X-RF analysis** (Fe_2O_3 , Sb_2O_3 , PbO)
- Contamination levels < **2500 ppm**
- Comparable to **standard solar patterned glass**
- **Melting tests** at $600^\circ\text{C} \rightarrow 1200^\circ\text{C}$
 - Transparent, inclusion-free blocks
- Conclusion: **Suitable for float glass production**



Al Compound Error (m%)	Fe Compound	Fe Compound Level (m%)	Fe Compound Error (m%)	Sb Compound	Sb Compound Level (m%)	Sb Compound Error (m%)	Pb Compound	Pb Compound Level (m%)	Pb Compound Error (m%)
0,0346	Fe_2O_3	0,0190	0,0027	Sb_2O_3	0,2300	0,0053	PbO	<LOD	0,0132
0,0350	Fe_2O_3	0,0172	0,0027	Sb_2O_3	0,2431	0,0054	PbO	<LOD	0,0134

Al Compound Error (m%)	Fe Compound	Fe Compound Level (m%)	Fe Compound Error (m%)	Sb Compound	Sb Compound Level (m%)	Sb Compound Error (m%)	Pb Compound	Pb Compound Level (m%)	Pb Compound Error (m%)
0,0676	Fe_2O_3	0,0166	0,0027	Sb_2O_3	0,2377	0,0054	PbO	<LOD	0,0138
0,0665	Fe_2O_3	0,0184	0,0029	Sb_2O_3	0,2370	0,0054	PbO	<LOD	0,0136

Industrial Demonstration

- Cullet batches from **several tons**
- Mechanical & optical sorting
- Successful integration into **industrial float glass line**
- Antimony levels within acceptable ranges for **$\leq 20\%$ cullet share**

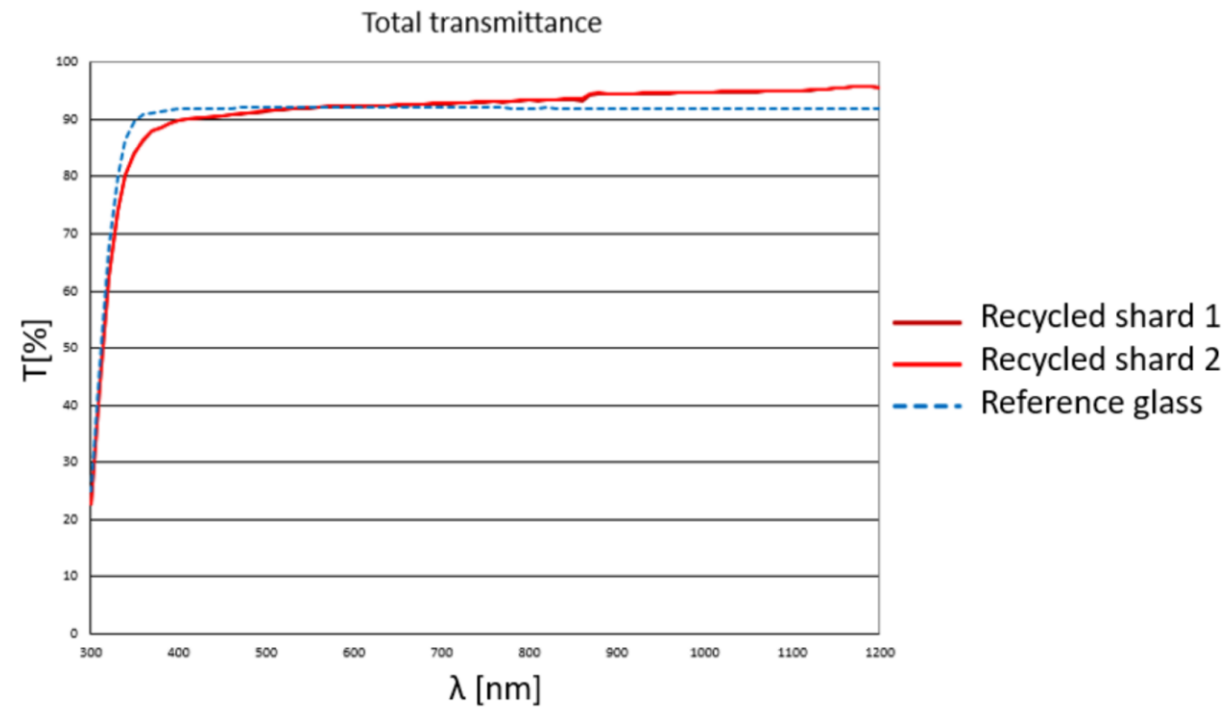


Optical Performance

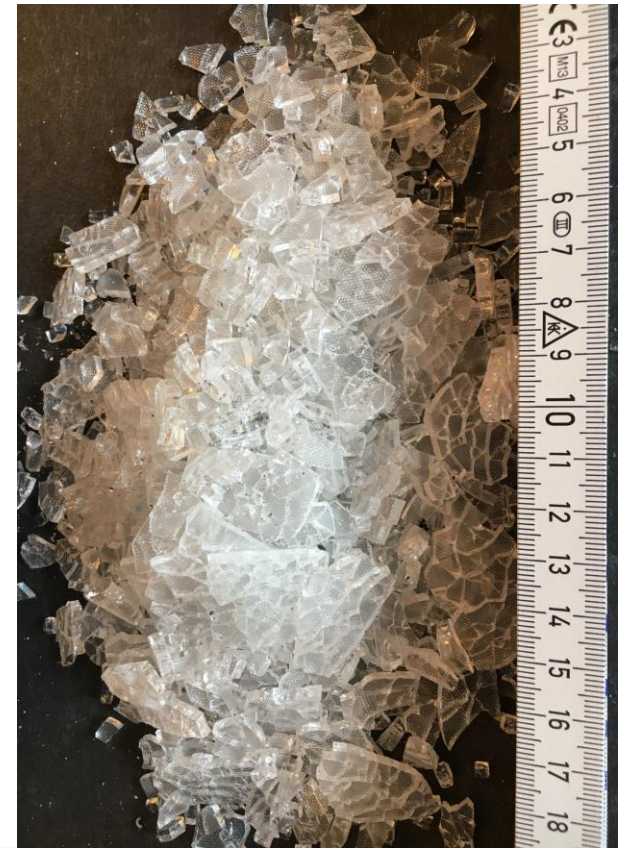
Whole glass panes from
water jet treatment



- Transmittance measured (300–1200 nm)
- Slight decrease at 300–500 nm
- **Positive gain at 500–1200 nm** → optimal for HJT
- RECovered glass **fully suitable** for PV applications



glass shards for
analytics



Direct Re-Use of Glass Sheets in PV Modules



- Assembly of:
 - **4 REC modules** (recovered glass) [TRINA Solar]
 - **3 REF modules** (reference glass) [Interfloat]
- Same specifications:
 - ultra-clear patterned glass, ARC, 4 x 14 G12 HJT cells
 - Encapsulation TF-8
 - Hangzhou Backsheet BEC 301D

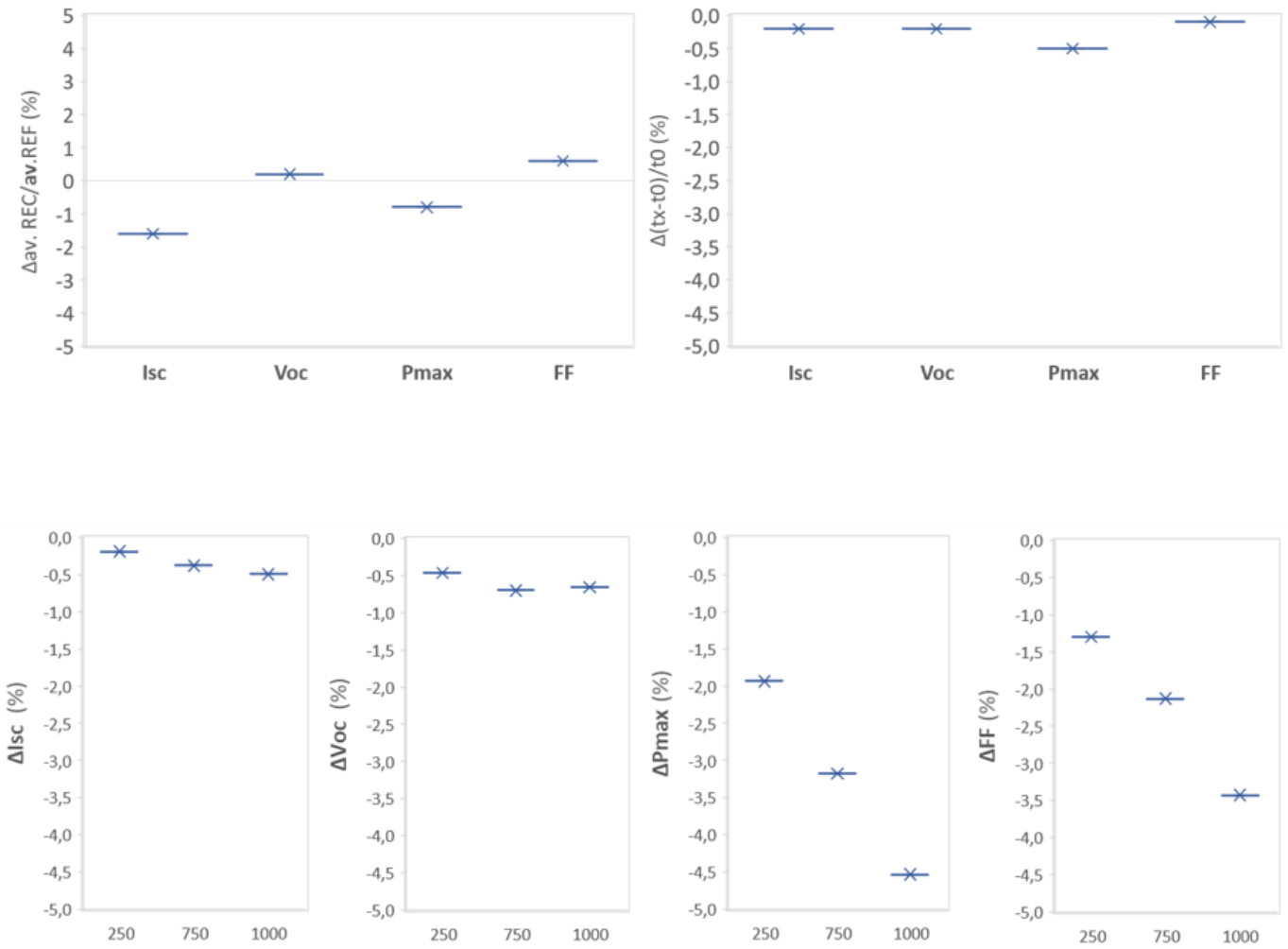
Electrical Performance:

Panel label	I_{sc} (A)	V_{oc} (V)	P_{max} (W)	FF (%)
Mean REference	100%	100%	100%	100%
Mean RECycled	98,35%	99,75%	100,85%	99,42%



Mechanical & Reliability Testing (IEC 61215)

- **Static mechanical load (MQT 16)**
 - Deviations only **0.1–0.5%**
 - Relative deviation of short circuit current, open-circuit voltage, puissance max and and fill factor of the average REC and REF modules series (left) and of one REC module before and after mechanical IEC sequence.
- **Damp Heat (DH 250/750/1000 h)**
 - Isc & Voc losses <1%
 - FF reduction due to metallization/interconnection corrosion
 - **Pmax loss 4.5%** → within IEC limit (5%)
- RECovered modules meet **long-term outdoor reliability**



Circularity Potential

- High-value recycling enables:
 - Industrial cullet integration
 - Direct re-use of glass panes
- Suitable for **niche PV applications**:
 - Community PV
 - Green city installations, green houses
 - Bus shelters, garden setups, small appliances
- First demonstration with **commercial-size modules**



Conclusions

- Glass recycling pays off in several ways:
 - Recycling **one tonne of cullet can save up to 700 kilograms of CO₂**.^{*}
 - At the same time, the demand for natural resources **decreases by roughly 1.2 tonnes of raw materials** .^{*}
 - Energy consumption in glass production also drops significantly: thanks to the lower melting temperature, **energy use is reduced by around 30 percent** .^{*}
- High-value recycling delivers **high-purity glass** suitable for float glass
- RECovered glass panes can be **re-used in new PV modules**
- RECovered modules pass **IEC mechanical and DH tests**
- Strong potential for **circular PV value chains**

^{*} <https://www.pilkington.com/de-de/de/presse/presseinformationen/neues-jahr,-neue-chancen>



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