The objective of RESiLEX is to improve the resilience and sustainability of the entire Silicon value chain and reduce EU dependence on critical raw materials for solar panel and battery production. Silicon is considered a critical raw material for the EU due to its high supply risk and economic importance, mainly because of heavy reliance on imports

Testing recycled Silicon for PV applications

During 2024, the project partner NTNU (Norwegian University of Science and Technology) produced recycled silicon through different processes. Another partner, CEA, evaluated the suitability of this material as an alternative feedstock for solar cell production. This factsheet briefly presents the results obtained with the recycled silicon produced via a Czochralski (Cz) growth process, which was presented here.

Silicon utilized for the Cz growth at NTNU

Production of Recycled Silicon via Czochralski Process

The recycled silicon for this process was produced by NTNU, starting from silicon refined using the slag refining technique with an initial purity of 97.79%. For the crystal pulling experiment, it was necessary to mix 15 kg of this recycled silicon with 15 kg of electronic grade (EG) silicon, which is much purer. This mixing was done to reduce the total impurity concentration, given the limited tolerance of the furnace used for the high initial impurity content.

The Czochralski (Cz) growth process involves several stages, including melting the silicon mixture, initiating crystal growth (starting from a "seed"), forming a thin section ("neck"), growing to the desired diameter ("crown" and "shoulder"), and finally growing the main body of the ingot ("body") before the final stage ("tailing"). During the experiment, visible impurities were made to nucleate and were removed from the surface of the melt ("fishing").

After this crystal pulling process, the recycled silicon reached a purity level of 5N (this means a purity up to 99.999%) in the main part of the ingot (first 70%).

Detailed evaluation of the recycled silicon

CEA received a recycled silicon ingot produced via the Cz process from NTNU in October 2024. Tests were carried out to evaluate its suitability for solar cell production. The main tests were measurements using Glow Discharge Mass Spectrometry (GDMS). Five samples were taken along the height of the ingot to analyze 25 elements.

Ingot produced at NTNU and sent to CEA for tests

From the GDMS results, it was found that:

- The highest purity level (5N) is found in the main part of the ingot.
- The boron concentration is similar across the five samples, between 1.5 ppmw and 2.7 ppmw. This concentration is about 7 times lower than that found in recycled silicon treated with directional solidification (the other process studied).
- The phosphorus concentration in the main part of the ingot is about 2.1 ppmw, while it is higher (5.8 ppmw) in the lower part. This concentration is also reduced compared to the other recycling process, by about 1.4 times.

The concentrations of metallic elements (such as Aluminum, Magnesium, Iron, Manganese, Titanium, Chromium, Calcium, Cobalt, Nickel, and Copper) are very low, which represents a significant improvement compared to recycled silicon treated with directional solidification.

Simulation and Cz ingots growth for photovoltaic applications

Based on the results of the GDMS measurements on this Cz process recycled silicon, a simulation was performed to check if it would be possible to produce a Cz ingot with the characteristics required for solar PV applications. The desired characteristics for a Cz ingot for heterojunction solar cells at CEA INES are: to be n-type, have a resistivity between 0.8 Ω.cm and 1.6 Ω.cm, and a silicon load of 30 kg. Ideally, the purity of recycled silicon should approach electronic grade (9N).

The simulation was performed considering a 10% mixing of this recycled silicon (using the average boron, aluminum, and phosphorus concentrations measured in the purest samples) with 90% electronic grade silicon. An additional concentration of phosphorus was added to achieve the desired resistivity. The results of this simulation show that:

- The resistivity along the height of the simulated ingot is within the required range (from 1.6 Ω.cm to 0.2 Ω.cm at 70% solid fraction).
- The entire simulated ingot is n-type, as required for the target cells.

These simulation results indicate that the recycled silicon produced via the Czochralski process, with purity up to 5N and low concentrations of metallic impurities, appears compatible with the production of Cz ingots for solar photovoltaic applications.

Given the low concentration of metallic impurities, CEA has decided that it is possible to use this material in its Cz growth furnace. CEA pulled with success two 30kg Cz ingots first quarter of 2025, with respectively 11% recycled silicon (after the additional Cz process) / 89% EG and 12% recycled silicon (after the additional Cz process) / 88% EG.


Cz ingot unloading: (left) 11% recycled silicon/89% EG ; (right) 12% recycled silicon/88% EG

The resistivity varies between ~2.5 ohm.cm at the head of the ingot and 0.5 Ohm.cm at the tail end. They meet the resistivity and type objectives compatible with the manufacture of heterojunction solar cells on the CEA pilot line.

This experiment will allows for the evaluation of the actual impact of the dopant and other impurity concentrations in the recycled silicon on the growth and properties of the Cz ingot. Further assessment on the performances of this material at solar cell level is on-going.

Wrap up

The recycled silicon obtained through the additional Czochralski process has shown significantly improved purity and low concentrations of metallic impurities. Tests and simulations indicate that it is potentially suitable for use in the production of silicon ingots for solar PV cells when mixed with electronic grade silicon. Two successful 30kg ingots were then pulled at CEA using 11% and 12% of the recycled silicon. The material will know be evaluated at the solar cell level.

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