# Low-Cost One-Step Production of Solar Silicon from Natural Quartzite

Silicon is the dominant material for photovoltaic (PV) technologies due to its abundance, low cost, and good PV efficiency. Today, the most common way to produce polysilicon for PV applications is via the Siemens process, which consists of carbothermic reduction, synthesis, purification, and chemical vapor deposition of toxic explosive chlorosilanes. This process is inherently complex, difficult to scale, energy-intensive (~300 kWh/kg), and unsafe due to the presence of toxic, flammable, and dangerous chemicals such as silane ($SiH_4$) and hydrochloric acid (HCl). In addition, because it emits a considerable amount of greenhouse gases (GHGs), the Siemens process is a "non-green" production method used for a "green" purpose.

To enable more sustainable silicon production, Massachusetts-based SilarTek, LLC is developing a novel process with funding from the U.S. National Science Foundation (NSF). The company's method produces high-purity silicon from natural, 99.7–99.9% pure quartzite ($SiO_2$) in only one step by utilizing molten salt electrolysis (MSE) with a state-of-the-art molten salt composition.

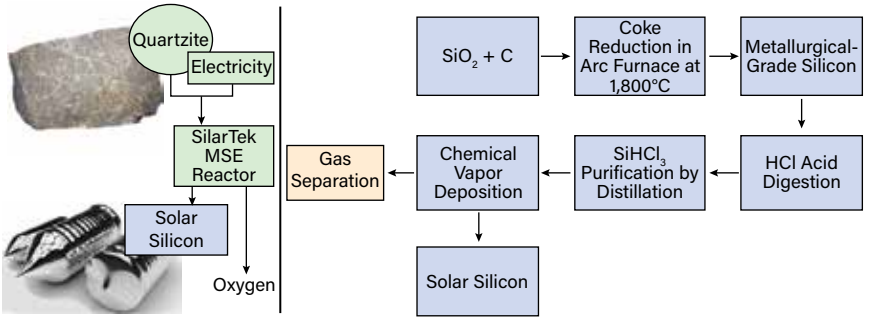
The novel molten salt bath exhibits many desirable characteristics, including: low volatility (<0.1 μg/cm$^2$sec), low viscosity (<5 mPa-sec), high ionic conductivity (>4 S/cm), high $SiO_2$ solubility (>5 wt%), and high compatibility with yttria-stabilized zirconia (YSZ) solid oxide membranes (SOM).

SilarTek's process can potentially produce silicon with up to 99.999% purity (*i.e.,* 4–5N) using <30 kWh/kg, with a pure oxygen byproduct, zero direct GHG emissions, and ~90% reduction in energy use. Achieving 4–5N product purity would be sufficient for directional solidification or direct boule/wafer production — techniques that can increase the purity level of silicon from 4–5N to 6N, which is appropriate for solar applications.

SilarTek's state-of-the-art molten salt bath composition could reduce energy use and increase the safety and scalability of high-purity silicon production. In this innovative process, $SiO_2$ fed to the bath dissolves and is electrolyzed to form solid silicon at the cathode, while oxide ions migrate through the YSZ SOM at the anode and produce pure $O_2$ gas. All anodes in each cell connect to the anode side of the large direct current (DC) bus, comparable to an aluminum production plant, while a set of switches at each cell periodically reverse current at a subset of cathodes to dissolve incipient roughness and make dense solid silicon. The process runs at 950–1,200°C. With SilarTek's technology, fewer electronegative impurities remain in the bath, and the low impurity solubilities in solid silicon result in a purer product than raw material.

Currently, SilarTek is working on consolidating the produced silicon, which will pave the way to directly produce silicon ingots. According to technoeconomic analyses, SilarTek's technology will produce solar-grade silicon at a cost of $2.20–2.70/kg, a cost that is 90% lower than using the Siemens process at a cost of $25/kg. The 2019 International Technology Roadmap for Photovoltaic (ITRPV) report predicted reductions in the amount of silicon/wafer, silver, and aluminum used in PV cells, as well as reductions in module glass thickness. These reductions could lead to significant cost savings; however, no change in silicon price was expected. Hence, SilarTek technology alone could reduce module costs by up to 20% by 2029.

SilarTek envisions that its technology for producing cheaper and sustainable solar silicon will help fight climate change through electrification. The enormous cost advantages of their process should enable the company to maintain a competitive price advantage and appeal to solar silicon wafer manufacturers and PV cell manufacturers with an integrated wafer production unit. Moreover, cleaner silicon production increases customers' ability to comply with environmental regulations. Harry Malkasian, Senior Vice President of Engineering Operations at CubicPV, says, "The combination of SilarTek low-cost silicon at $2–3/kg, with our Direct Wafer technology using 1.5 g polysilicon per watt of PV, could lead to polysilicon cost well below 1 cent per watt." CEP




▲ The SilarTek one-step process (left) is based on molten salt electrolysis (MSE) and is much simpler in nature than the multi-step Siemens process (right).

This technology was funded through the NSF Small Business Innovation Research Program.

This article was prepared by the National Science Foundation in partnership with *CEP*.