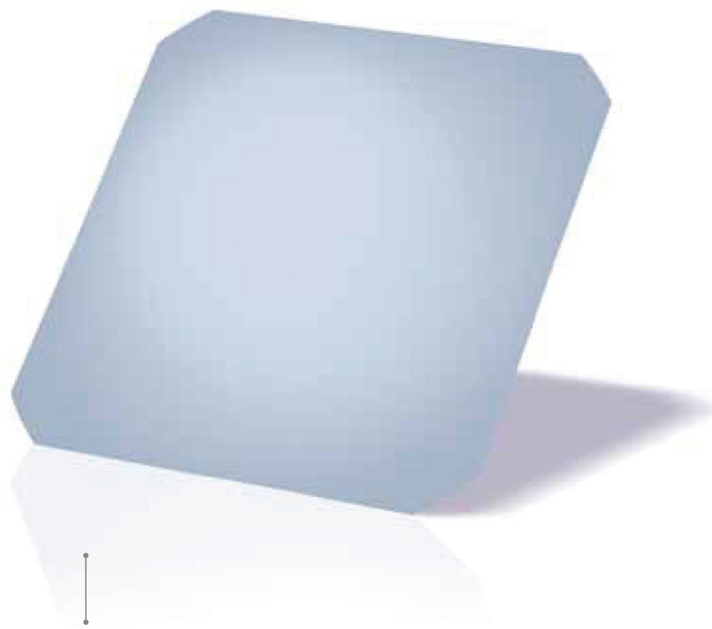
Energy for you and me

How Solar Panels are Made

FROM SAND TO SOLAR PANEL

The journey that starts with silicon and ends with a large-scale solar facility is long, with many stops along the way.

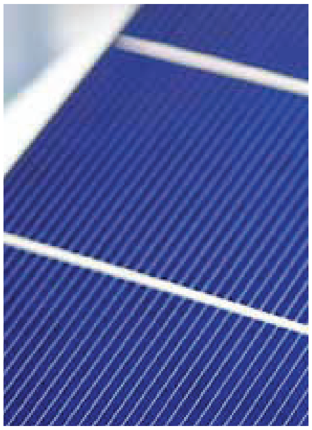


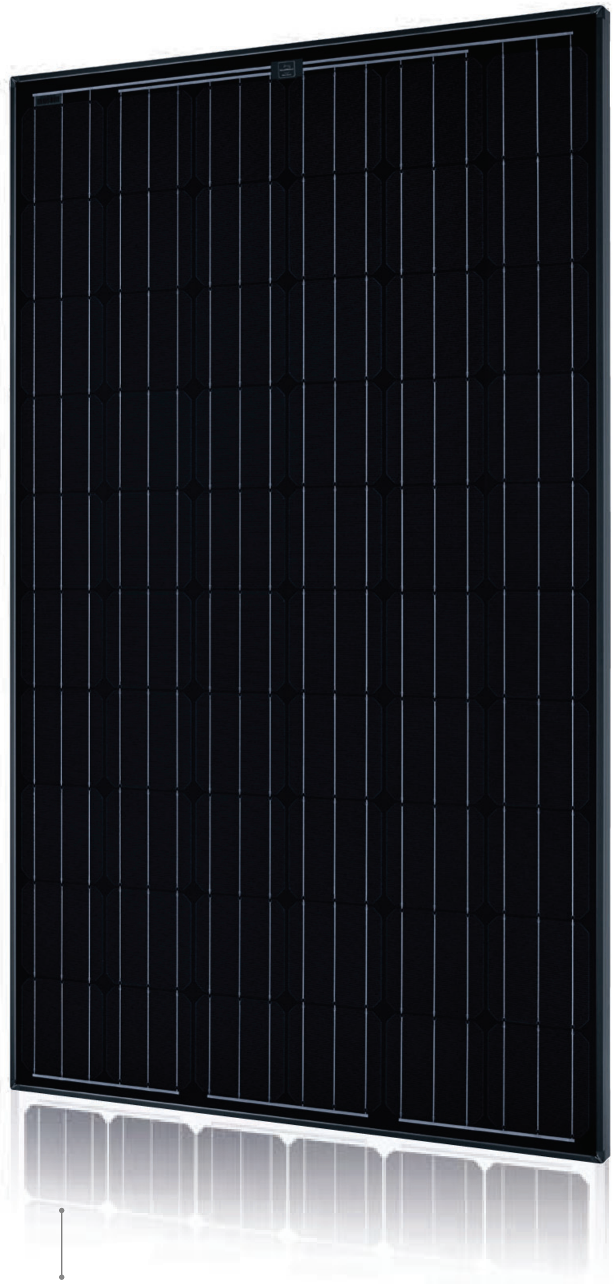
Silicon

Silicon is the starting point of our solar production cycle. It is extracted from sand, which is made up primarily of silicon dioxide. As the second most common element of the earth's crust, there is an almost endless supply.

Solar wafer

In the second production step, highly pure silicon forms into crystal structure at 2,500 degrees Fahrenheit and it then hardens. The crystallized silicon is then shaped into rectangular columns. These columns are cut into extremely thin slices, or wafers, using state-of-the-art wire-cutting technology. After cleaning and thorough final testing, the monocrystalline and polycrystalline wafers form the basis for the production of solar cells.





Solar cells

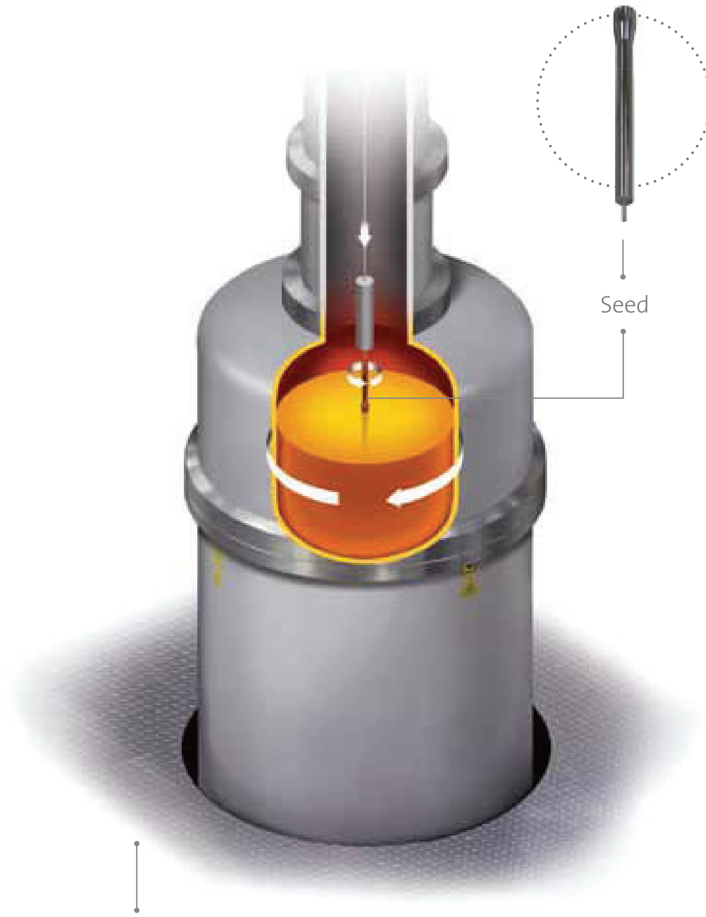
The wafers are further processed into solar cells in the third production step. They form the basic element of the resulting solar panels. The cells already possess all of the technical attributes necessary to generate electricity from sunlight. Positive and negative charge carriers are released in the cells through light radiation, causing electrical current (direct current) to flow.

Solar panel

Solar cells are merged into larger units – the panels – in panel production. They are framed and weather-proofed. The solar energy panels are final products, ready to generate power. Sunlight is converted into electrical energy in the panels. The direct current produced this way is converted to alternating current by a device called an inverter so that it can be fed into the utility grid or, if applicable, straight into the house.

GROWING CRYSTAL FROM ROCK

In its monocrystalline process, manufactures heats and melts poly-silicon rock until it forms a white-hot liquid, then re-solidifies the molten silicon into a single giant crystal in which all atoms are perfectly aligned in a desired structure and orientation.

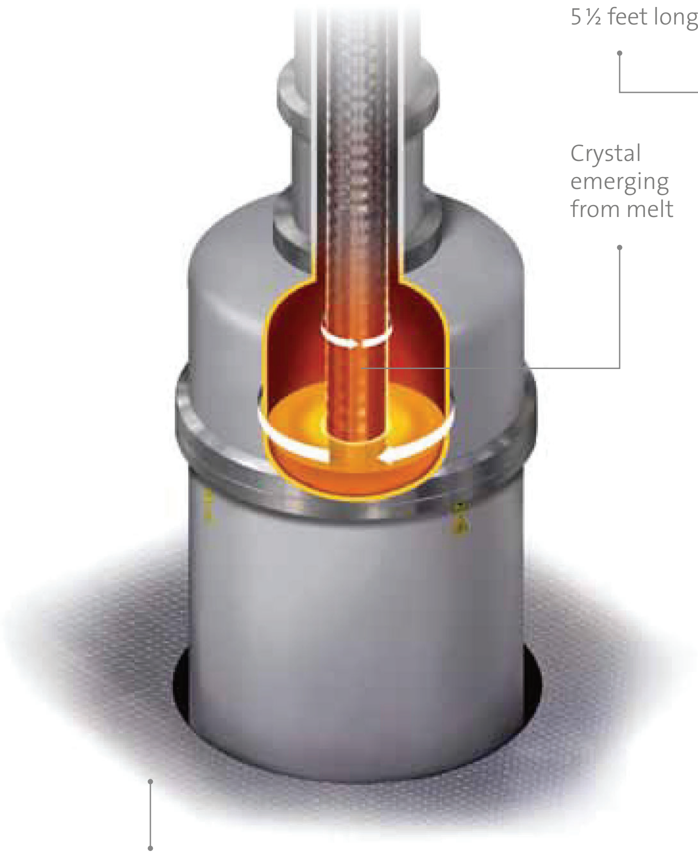


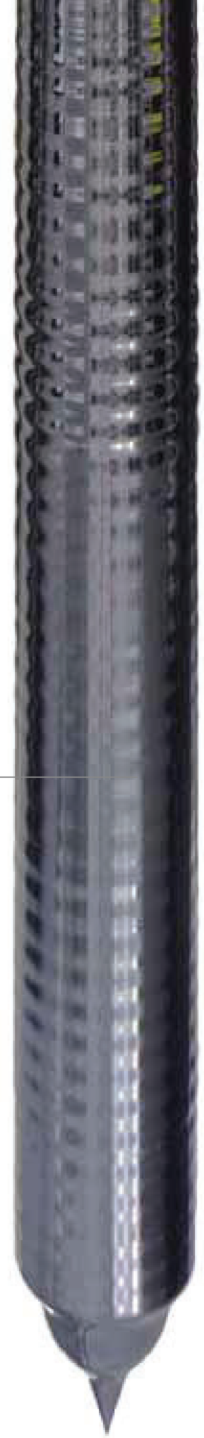
Charging

The magic starts with about 250 pounds of polysilicon rocks carefully stacked in a quartz crucible. The only other ingredient is a silicon disk impregnated with a tiny amount of boron. The addition of the boron dopant ensures that the resulting crystal will bear a positive potential electrical orientation. The crucible is encased within thick walls of insulating graphite and locked inside a cylindrical furnace.

Melting

As the crystal-growing furnace heats up to temperatures ranging around 2,500 degrees Fahrenheit, its silicon contents liquefy into a shimmering melt. Once computerized monitors register the right temperature and atmospheric conditions, the alchemy begins. A silicon seed crystal, hung from a narrow cable attached to a rotary device atop the furnace, is slowly lowered into the melt.





WORD TO KNOW

Crystal: A crystal is a solid with molecular building blocks, such as atoms or ions, that have arranged themselves in an identically repeating pattern along all three spatial dimensions.

Growing

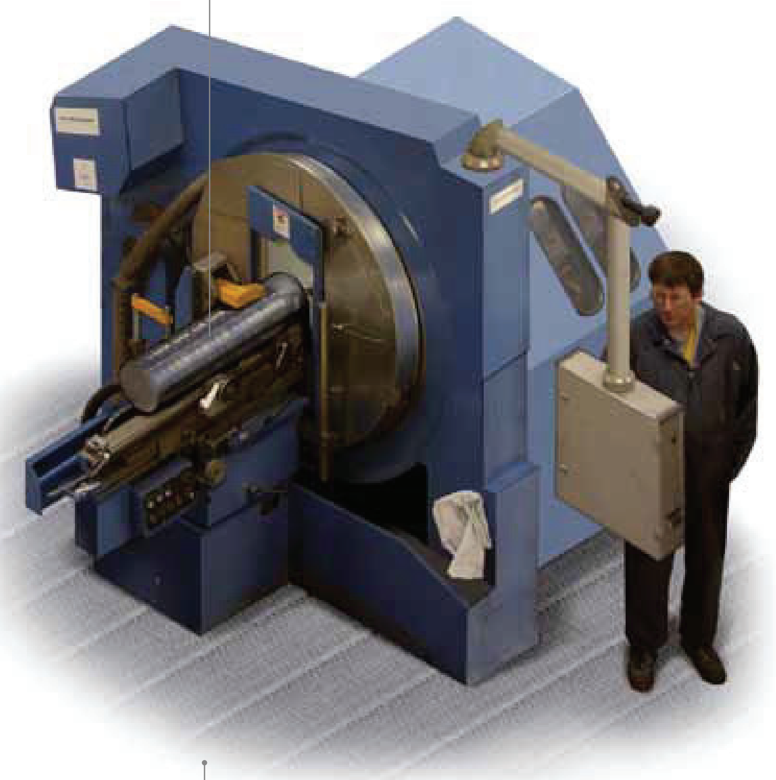
The crucible starts to turn, and the seed crystal begins to rotate in the opposite direction. The silicon melt freezes onto the seed crystal, matching the seed's crystalline structure. The crystal grows, the cable and seed slowly ascend, and the crystal elongates at a controlled diameter. As the growth depletes the silicon melt, the crucible also rises.

Cooling

Flash forward about 3½ days since the crucible was charged with polysilicon: After hours of cooling to about 300 degrees Fahrenheit, the furnace hood and shaft lift away from the crucible encasement to reveal a completed cylindrical crystal, ready to move to the second step and next production room.

CUTTING CRYSTAL INTO WAFERS

A silicon crystal must change shape several times before it winds up as the precisely calibrated wafers that form the foundations of photovoltaic cells.

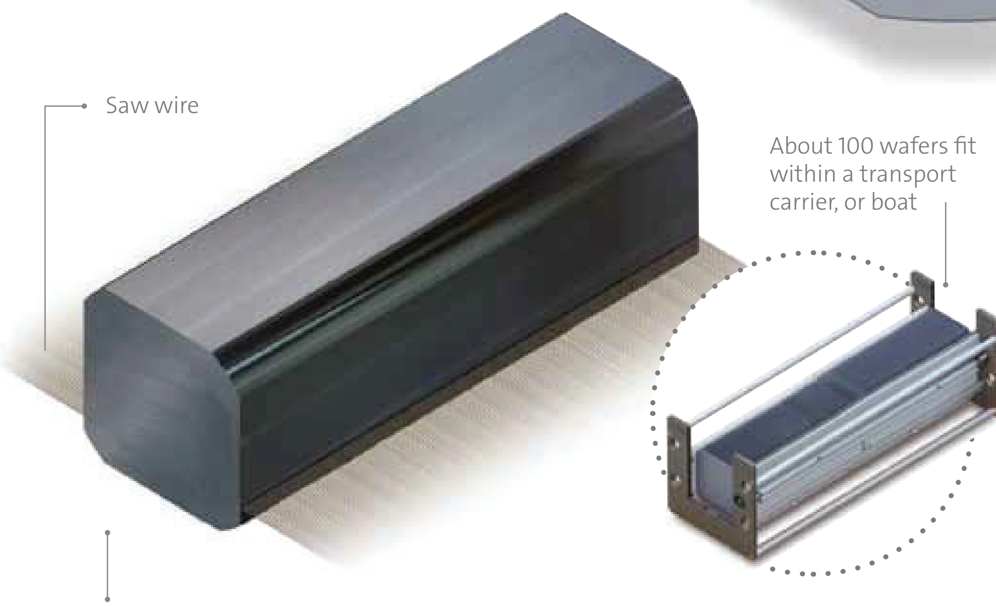


Cutting

First, a saw cuts off the crystal's so-called top and tail, so that a crystal of uniform width remains. Typically, wafering saws draw thin wire bearing a liquid abrasive across the crystal's surface. (Above, a machine mounted with a giant donutlike steel blade does the cutting.) Wire saws also cut the crystal into ingots measuring 2 feet long. Steel holders are mounted on one end of these ingots for the next step.

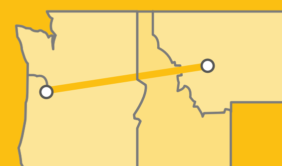
Squaring

Mounted ingots are placed standing on end in a rack bearing 16 at a time inside another wire-slicing machine. There, wire running in a lattice configuration descends on the ingots to shear off four rounded segments, leaving flat sides. The result: The ingots now have a square cross-section, except for still-rounded corners.



PV FACT

Wafering saws use spools of wire to carry the mineral abrasive silicon carbide, effectively forming a miniscule strand of sandpaper. The spools bear wire measuring about 400 miles long.



WORD TO KNOW

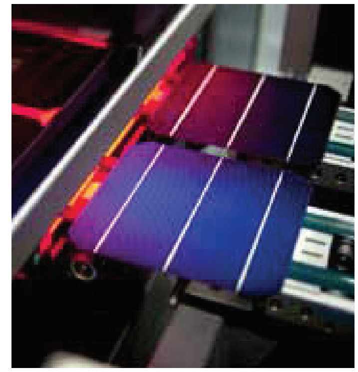
Silicon carbide: Silicon carbide (SiC), silicon bonded with carbon, is another member of the silicon family of materials used in the PV industry. It is a common abrasive in many industries, used in everything from grinding to sandblasting.

Slicing

The next wire saw is more intricate yet. A wire winding hundreds of times between two cylindrical drums forms a web of parallel, tightly spaced segments. As the wire unspools through the machine, ingots mounted sideways on glass and metal holders are pressed two at a time through the wire web, slicing them into the thickness of slim business cards. Each millimeter of crystal yields about 2½ wafers. Detached from their holders, the wafers are loaded into carriers, or boats, for transport to the next step.

CONVERTING WAFERS INTO CELLS

At this point, a wafer is no more capable of producing electricity than a sliver of river rock. The wafer is the main building block of a PV cell, but so far its only notable characteristics are its crystal structure and positive potential orientation. All of that changes in the third, multistep, cell-production phase of PV manufacturing.



Texturing

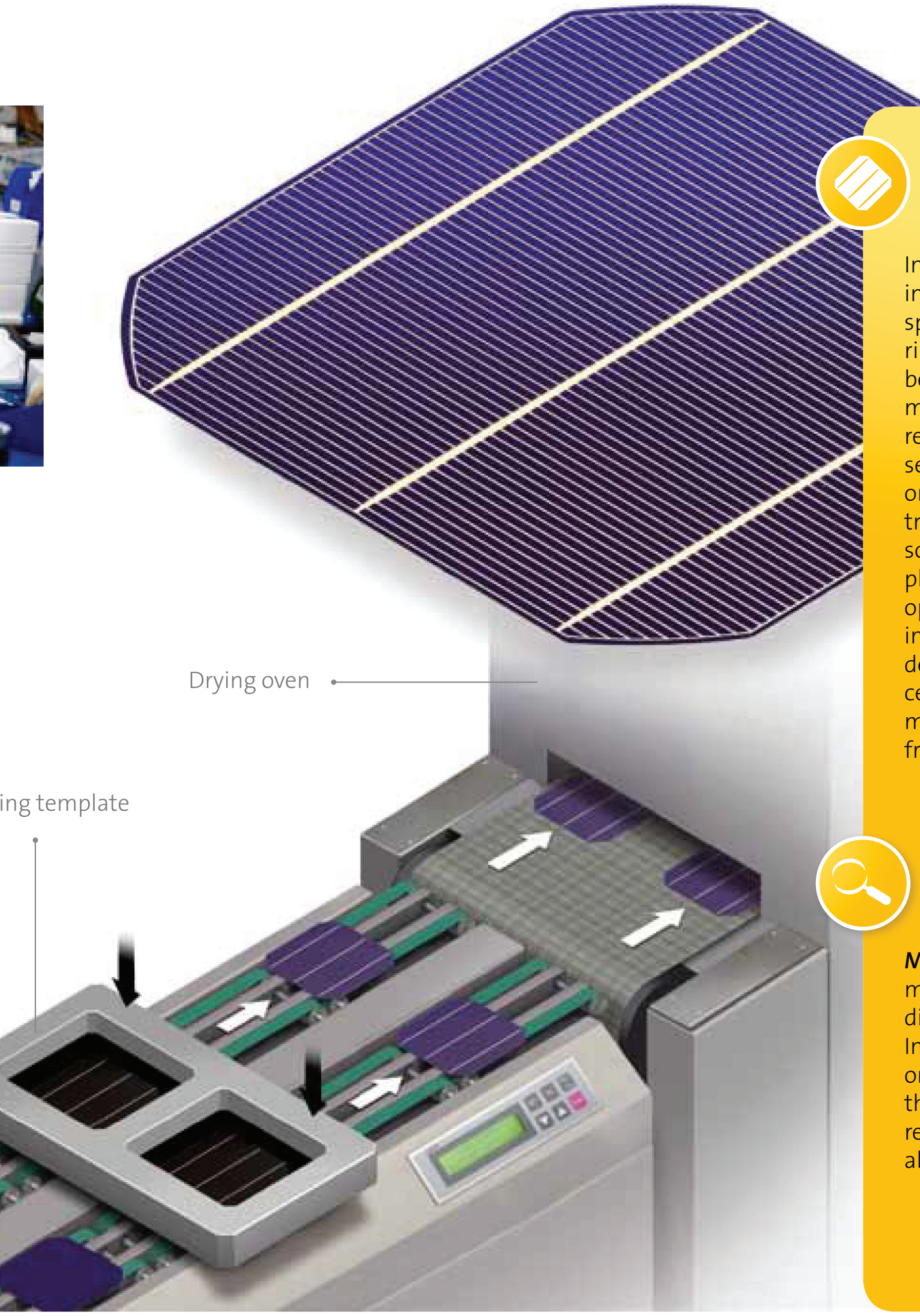
In the only phase requiring a designated clean room, a series of intricate chemical and heat treatments converts the blank, grey wafers into productive, blue cells.

A so-called texture etch, for instance, removes a tiny layer of silicon, relying on the underlying crystal structure to reveal an irregular pattern of pyramids. The surface of pyramids – so small they're invisible to the naked eye – absorbs more light.

Diffusing

Next, wafers are moved in cartridges into long, cylindrical, oven-like chambers in which phosphorus is diffused into a thin layer of the wafer surface.

The molecular-level impregnation occurs as the wafer surface is exposed to phosphorus gas at a high heat, a step that gives the surface a negative potential electrical orientation. The combination of that layer and the boron-doped layer below creates a positive-negative, or P/N, junction – a critical partition in the functioning of a PV cell.



PV FACT

In the PV and semiconductor industries, the word tool has a special meaning. Instead of referring to an implement that can be applied to a manufacturing mechanism, tools in these fields refer to entire machines or assembly lines that perform a step or series of steps. In both industries, tools are highly automated so that most workers are employed to install, fine-tune and operate the tools, rather than lifting or moving product. Spider-like devices lift and move wafers and cells on and off conveyor belts for multiple tests along their journey from wafer to cell.

WORD TO KNOW

Micron: In cell production, manufacturing steps occur in dimensions measured in microns. In the metric system, a micron is one millionth of a meter, or one thousandth of a millimeter. For reference, a human hair measures about 100 microns across.

Coating

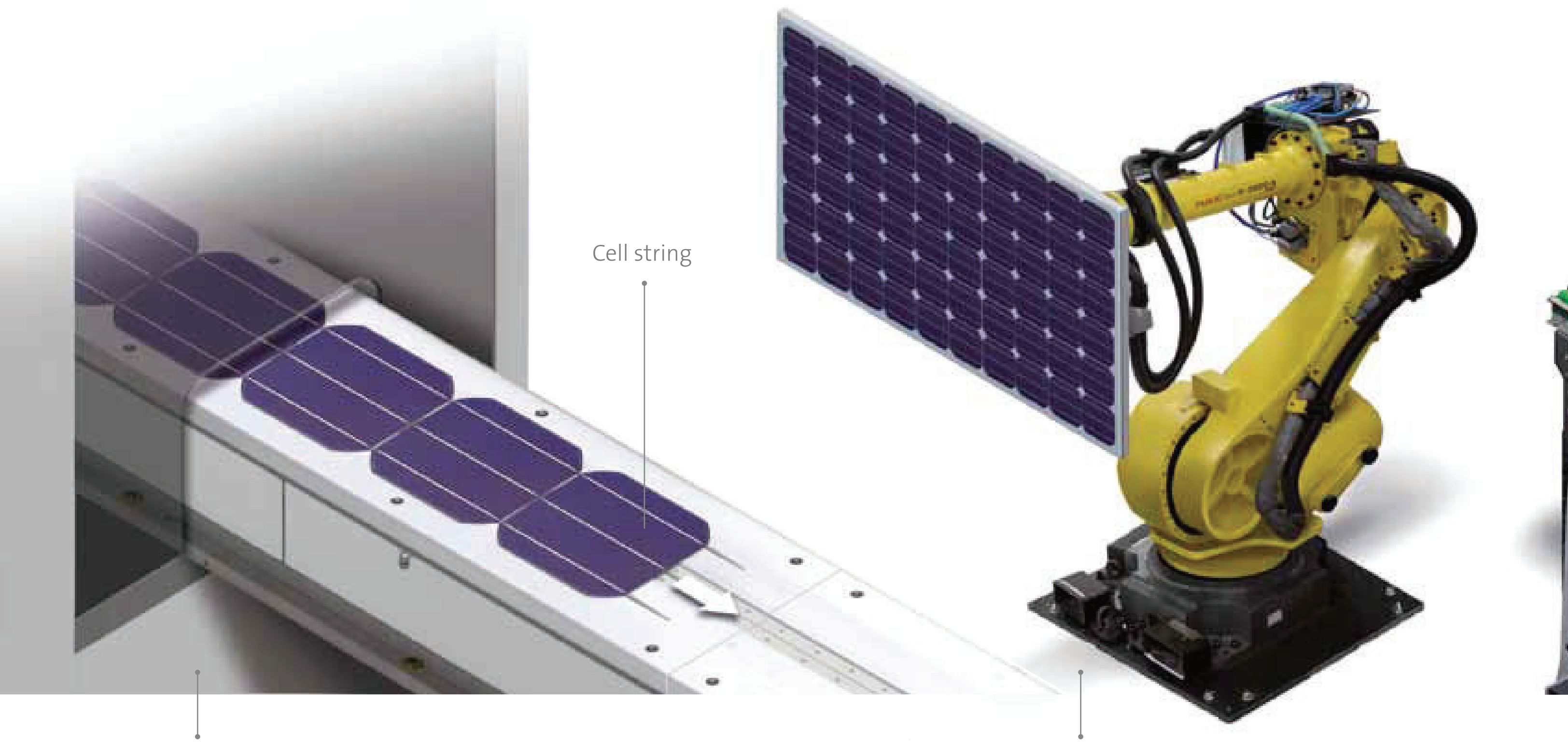
The burgeoning, still-grey cells move in trays into heavy vacuum chambers where blue-purple silicon nitride is deposited onto their tops. The coating with silicon nitride – yet another member of the silicon family of materials – is designed to reduce reflection even further in the energy-dense blue end of the light spectrum. It leaves the cells with their final, dark color.

Printing

Now, the cells can optimally gather photons and produce electricity. They lack, however, any mechanism to collect and forward the power. So, in a series of silkscreen-like steps, metals are printed on both sides of the cell, adding pin-stripe “fingers” and bus-bar circuitry. A functioning cell is born – only sunshine is needed to produce electricity.

STRINGING CELLS INTO PANELS

Each phase of production depends on processes with flavors all their own. Careful control of heating and cooling dominates crystal growing. Wafering employs abrasion and cutting. Cell production concentrates on chemistry. Any factory process would be incomplete without a final assembly step, and in PV such a step is known as panel assembly, or moduling.

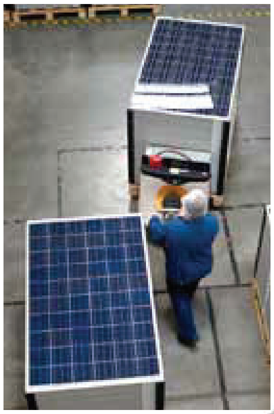


Soldering and laminating

Panel manufacturing is a highly auto-mated process, relying on robust steel robotics to undertake the increasingly heavy lifting of assembling lightweight PV cells into panels weighing around 45 pounds apiece. Each robotic tool works within a safety fence that, by design, prevents human access. First, cells are soldered together into strings of 10, using an over-under-over-under pattern of metal connectors to link the cells. Six strings are laid out to form a rectangular matrix of 60 cells. Each matrix is laminated onto special solar glass.

Framing

To become a solar panel, however, each laminate requires not only a frame to provide protection against weather and other impacts but also a junction box to enable connections among panels or with an inverter-bound conduit. Robots affix those, too.



WORD TO KNOW

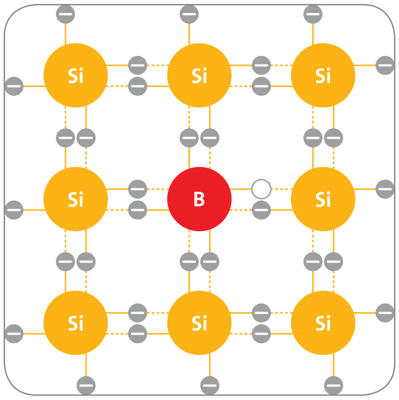
Module: Within the industry, solar panels are called modules, because they link together evenly and interchangeably use electrical connectors to form a circuit within an array, with a building or with a utility grid. To make a module, cell-matrix laminants are mounted into sturdy aluminum frames. The resulting module is robust enough to withstand 50 mph hailstone impacts and up to 112 pounds per square foot of wind or snow load.

Inspecting and shipping

Careful cleaning and inspection provide final touches before each solar panel can be boxed for delivery to homes and businesses. However, inspection does not only take place at the end of the production line. Digitized and automated checks take place at key steps from silicon crystallization through panel assembly, and human inspection of each and every cell and panel.

HOW A PV CELL MAKES ELECTRICITY

Under the sun, a photovoltaic cell acts as a photosensitive diode that instantaneously converts light – but not heat – into electricity.



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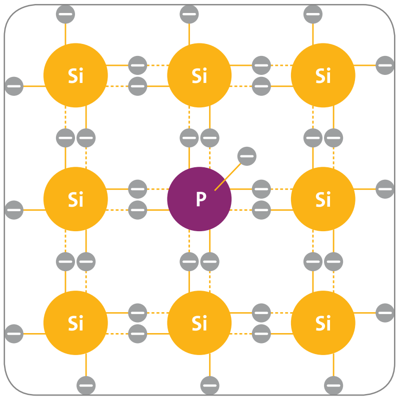

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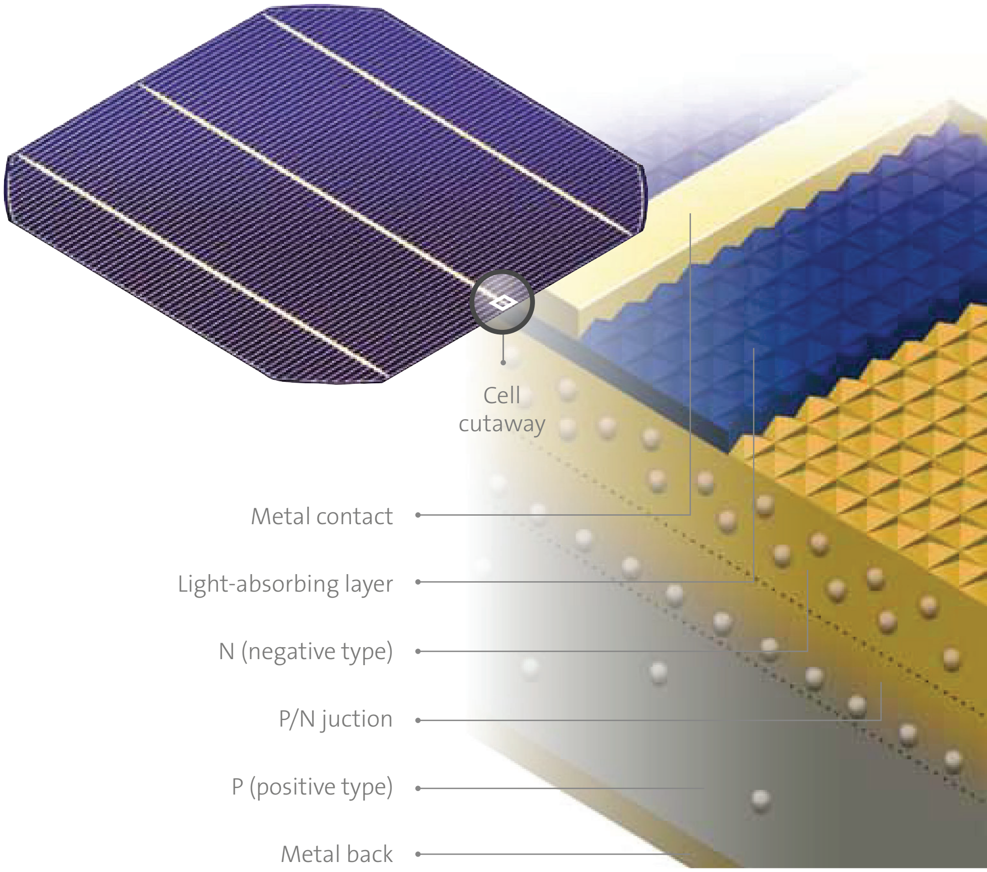
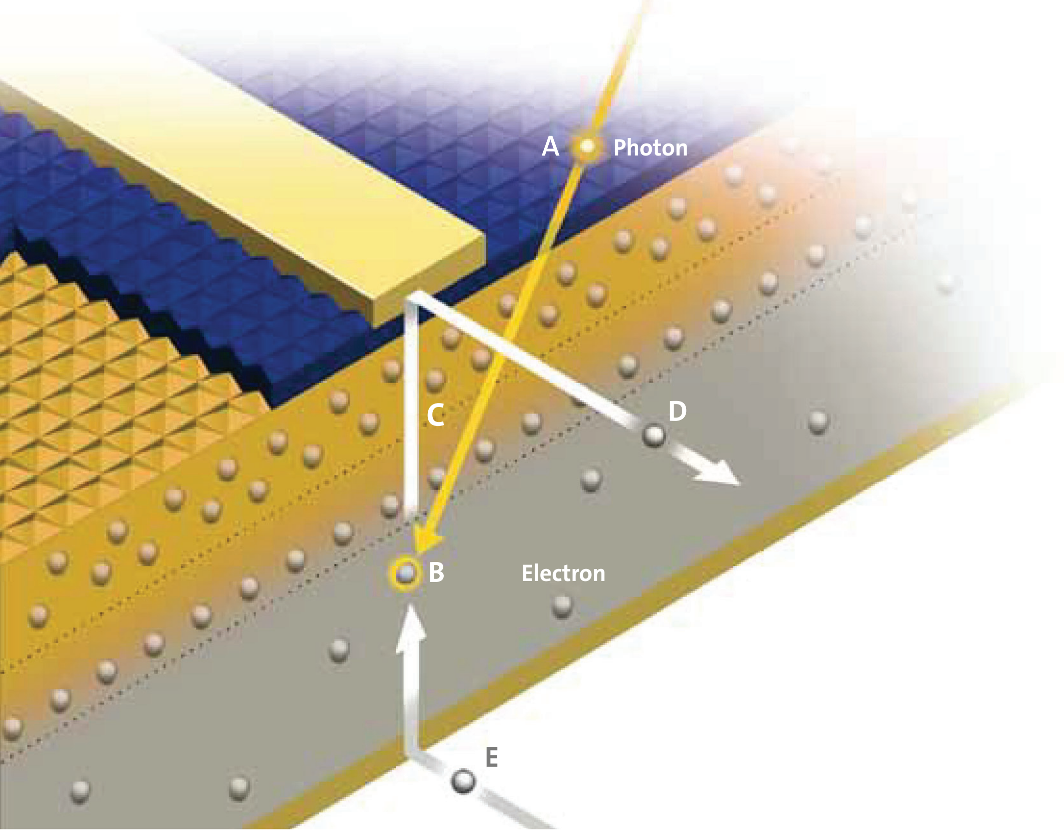


Positive doping

(1) Recall that in the crystallization step a small amount of the dopant boron was added to the polysilicon chunks before they were melted. Boron lacks one electron and therefore takes on an electron from silicon as an acceptor. Because the electron is missing, leaving an electron hole, the semiconductor becomes p-conductive (positive-conductive).

Negative doping

(2) Remember that in cell production phosphorus was applied to those layers of the silicon wafer closest to the surface. This dopant, as compared with silicon, has one extra electron, which it can easily release. Thus the silicon becomes n-conductive (negative-conductive).



WORD TO KNOW

Conversion efficiency: This measure gauges the percentage of solar (light) power reaching a panel that is converted into electrical power. Conventional cells now range in the high percentage teens. Theoretical and laboratory conversion rates typically are much higher than rates from mass production.

Cell layers

The top, phosphorus-diffused silicon layer therefore carries free electrons – unanchored particles with negative charges. The thicker, boron-doped bottom layer contains holes, or absences of electrons, that also can move freely. In effect, precise manufacturing has instilled an electronic imbalance between the two layers.

Sun activation

A) Photons bombard and penetrate the cell.

B) They activate electrons, knocking them loose in both silicon layers.

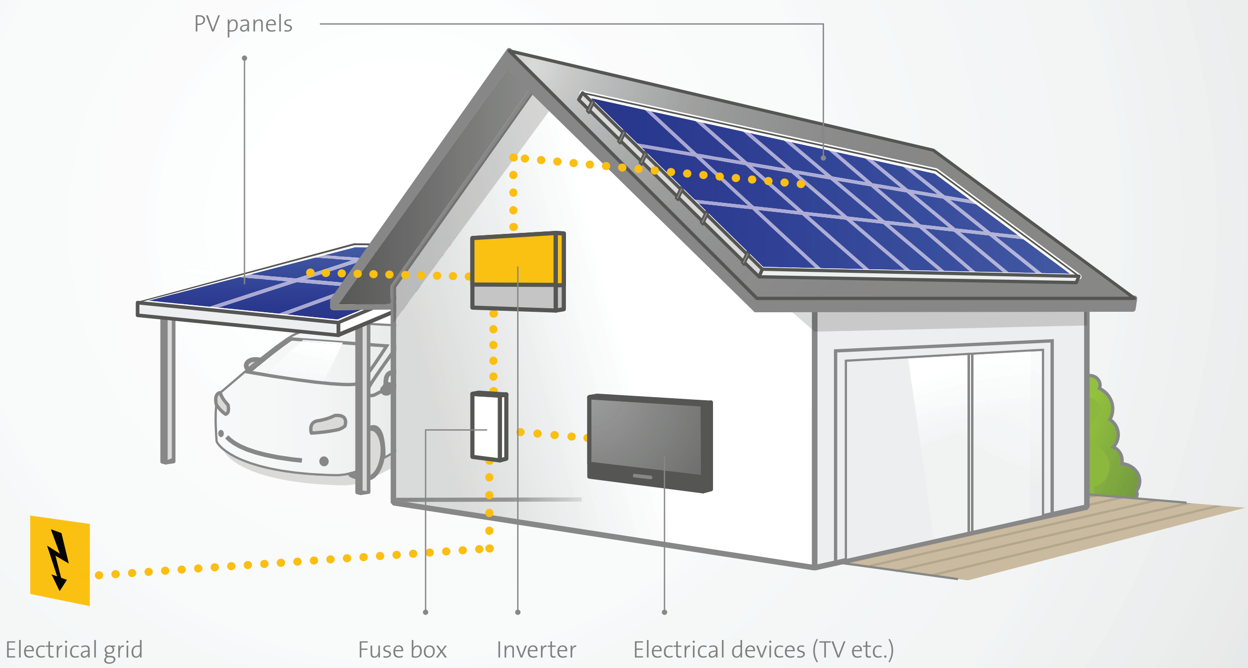
C) Some electrons in the bottom layer sling-shot to the top of the cell.

D) These electrons flow into metal contacts as electricity, moving into a circuit throughout a 60-cell panel.

E) Electrons flow back into the cell via a solid contact layer at the bottom, creating a closed loop or circuit.

SOAK UP THE SAVINGS

The sun provides abundant clean energy every single day, even when it's cloudy – and it never sends a bill. The sun provides enough energy to serve the entire world's energy needs hundreds of times over.



Powering homes and businesses

Current leaving a panel, or array of panels, passes through a wire conduit leading to an inverter. These devices, which are shaped like suitcases and come in various sizes, invert direct current, which flows with a fixed current and voltage, into alternating current, which flows with oscillating current and voltage. Appliances worldwide operate on AC.

From the inverter, the solar-generated power feeds into circuitry of a household, business or power plant and onto the region's electrical grid. A remote, or independent, power system also can form a self-contained circuit without connecting to the grid. The off-grid system, however, requires batteries to store power for times, such as night, when panels do not capture enough light energy from the sun.