



Life-Cycle Environmental Performance of Silicon Solar Panels

The main life-cycle environmental negative impacts of silicon solar panels come from the production phase and include: (1) the energy consumed during panel production and the emissions associated with that energy generation; (2) water consumption, which is cleaned and returned to the watershed; and (3) some hazardous by-products which are released to the air or recycled and reused in further production processes. All air emissions are routed to pollution control equipment and covered under a Department of Environmental Quality (DEQ) air permit. All wastewater is treated and monitored prior to discharge under a DEQ water permit. The positive impact during the panel use or energy generation phase is the emissions-free energy that displaces carbon intensive energy generation from sources such as coal and natural gas. The positive impacts of that displacement far outweigh the negative impacts of the production phase of the life cycle of silicon solar panels.

Assumptions: Most of today's PV cells consist of monocrystalline or multicrystalline silicon. The life-cycle impacts of silicon solar panels are represented in the following table. The silicon solar panels are assumed to have a lifespan of 30 years and the inverter lifespan is 15 years. The system performance ratio is 0.75 and the irradiation value is 1700 kilowatt-hours per square meter per year. The end-of-life phase of the life cycle assumes disposal since recycling processes for panels are not currently available.

Environmental Performance

Energy and Climate Pay Back:

- Over their lifetime, crystalline silicon solar panels generate 9 - 17 times the energy required to produce them [4].
- Depending on the type of PV technology, the clean energy payback of a PV system ranges from one to four years [5].
- 100% of solar electricity is produced emissions free. Factoring in the emissions due to production of the solar panels, 87 - 97% of the energy produced by PV systems will be free of pollution and greenhouse gas emissions [5].
- Replacing electrical power from the national grid mix with electricity generated by solar panels results in an 89% reduction in greenhouse gas emissions and air pollutants and a 60% reduction for the Pacific Northwest grid mix (less of a reduction due to the higher concentration of renewable energy sources in the grid mix) [2].
- Based on the national energy grid mix, producing 1,000 kWh of solar electricity reduces emissions by nearly 8 pounds of sulfur dioxide, 5 pounds of nitrogen oxides, and more than 1,400 pounds of carbon dioxide [5].
- The balance of the system (BOS) and frame of a solar panel system typically consists of concrete, aluminum and steel structures for mounting the panels, power-conditioning equipment and power storage devices. BOS can contribute heavily to the life-cycle greenhouse gas emissions of solar panels, especially for ground-mounted systems [4]. Using the existing transmission and distribution grid system eliminates the need for power storage devices.

Hazardous Materials:

- Life-cycle criteria pollutant and heavy metal emissions, such as sulfur dioxide, nitrogen oxide and lead, associated with solar panels are due primarily to raw material extraction (diesel) and energy consumption in the manufacturing process [2].

End-of-Life Management of Materials:

- Recycling technologies for reusing silicon from solar cells (from production waste or after module decommissioning) are not yet commercially available in the United States. According to the European Photovoltaic Industry Association and PV Cycle, it will take 1/3 of the energy to make a solar panel from a recycled one rather than using new materials, such as silicon [7].
- End-of-life management strategies are being developed by the PV industry to recover silicon, glass, EVA foil and aluminum from solar panels. Currently, some panel manufacturers are harvesting silicone from recovered computer chips.

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	Material Inputs	Manufacturing and Production	Use	Disposal and/or Reuse
Energy Use and Greenhouse Gas Emissions	<p>Major Impact:</p> <ul style="list-style-type: none"> Fossil fuels (diesel) are used for materials extraction and for transporting those materials to manufacturing plants. Energy from the electrical grid is also used for refining those materials. 	<p>Major impact:</p> <ul style="list-style-type: none"> Life-cycle greenhouse gas emissions are 40 – 55 grams per kilowatt-hour of generation capacity for standard silicon panels and 25 - 32 grams per kilowatt-hour for the newer thin-film technologies [2] and [1]. 45% of the total energy usage is from the production of polycrystalline silicon [2]. It is anticipated that with new technologies, life-cycle emissions will be reduced to 15 grams per kilowatt-hour [1]. 	<p>No impact:</p> <ul style="list-style-type: none"> Solar panel systems do not cause emissions of carbon dioxide or other greenhouse gases during their use. 	<p>Minimal impact:</p> <ul style="list-style-type: none"> It takes 1/3 of the energy to make a solar panel from a recycled one rather than using new materials [7].
Habitat Impacts	<p>Major impact:</p> <ul style="list-style-type: none"> Extraction of natural resources, such as quartz, silicon carbide, glass and aluminum can cause habitat disturbances analogous to sand and gravel pit mining but there is no leaching or precipitation process involving acids. 	<p>Major impact:</p> <ul style="list-style-type: none"> Solid waste production is minimal. The fabrication of silicon solar cells requires large volumes of high purity water for silicon wafer cleaning. Many plants are designed to minimize water consumption through recycling. All wastewater is treated and monitored prior to discharge under a Department of Environmental Quality (DEQ) water permit. 	<p>Minimal impact:</p> <ul style="list-style-type: none"> Solar panel arrays should be sited to have the least impact on the land and wildlife. 	<p>Major impact:</p> <ul style="list-style-type: none"> The amount of waste generated by retired panels is currently very small. By 2020, this developing industry will produce a growing PV waste stream. PV products are mostly safe for landfills, because PV materials are usually encased in glass or plastic and many are insoluble. Some panels could be classified as hazardous waste due to lead content from soldering or from glass encapsulation, which has the potential to leach.
Local Air Impacts	<p>Minimal impact:</p> <ul style="list-style-type: none"> Emissions of solvents and alcohols contribute to photochemical ozone formation and both direct (the solvent itself) and indirect (ozone) respiratory problems. All air emissions are routed to pollution control equipment and covered under a Department of Environmental Quality (DEQ) air permit. 	<p>Minimal impact:</p> <ul style="list-style-type: none"> Fluorine and chlorine are emitted resulting from the neutralization of etching and texturing solutions and from flue gases. Fluorine and chlorine may be emitted to the air as a component of dust particles. 80% of lead emissions of production are released during material processing related to solar glass manufacturing and soldering. All air emissions are routed to pollution control equipment and covered under a Department of Environmental Quality (DEQ) air permit. 	<p>No impact:</p> <ul style="list-style-type: none"> Unlike fossil fuels, PV systems produce no air pollution (sulfur dioxide, nitrous oxides, particulate matter [soot], and toxic materials such as mercury) while operating. 	<p>No impact:</p> <ul style="list-style-type: none"> PV materials are usually encased in glass or plastic and do not release particles to the air.
Occupational Health and Safety Impacts	<p>Minimal impact:</p> <ul style="list-style-type: none"> Silica particles can be released in the mining and refining stage. If they are small enough to be inhaled they may cause the lung disease silicosis—one that can easily be prevented with safety equipment. 	<p>Minimal impact:</p> <ul style="list-style-type: none"> Silicon panel production can include fluorine, chlorine, nitrates, isopropanol, sulfur dioxide, nitrogen oxide, carbon dioxide, silica particles, echants, acids and solvents, some of which are considered to pose acute and/or chronic hazards to occupational safety. The hazards of these substances are controllable with standard safety protocols usually employed in semiconductor industries. 	<p>Minimal impact:</p> <ul style="list-style-type: none"> Solar cells require very little maintenance, though they can be difficult to repair when maintenance is needed due to the risk of electrical shock. 	<p>No impact:</p> <ul style="list-style-type: none"> Recycling technologies for reusing silicon from solar cells (from production waste or after module decommissioning) are not commercially available in the United States.

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Resources

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