Reuse of Whole Glass Sheets from End-of-Life Waste in Making New PV Panels

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1. Introduction:

To keep the global temperature below 2 °C, 1 TW of solar PV must be installed annually [1]. Due to this, the recent decades have seen major growth in PV deployment, and this trend is expected to continue due to the world's commitment to mitigating climate change [2]. However, along with this advancement, the world will see considerable PV waste shortly. Considering the life span of 30 years, it is predicted that by 2050 the world will see 5.5-6 million of module waste [3]. Being a first-generation and widely used solar module, crystalline silicon (c-si) contains some precious materials like silicon (Si), copper (Cu), silver (Ag), aluminum (Al), and some highly toxic materials like chromium (Cr), cadmium (Cd), and lead (Pb) [4]. Improper treatment of these modules can contaminate the soil and groundwater, threatening the ecosystem and public health [5]. Many modules have already found their way to landfills till now [6,7]. This is not sustainable as it can have a negative outcome. As a result, it has become crucial to recycle these PV modules to protect the environment and achieve a circular economy [8,9].

2. Analysis:

The cover glass is the main component of PV volumetrically and by weight. The cover glass in a solar panel typically weighs 7.5 kg/m^2 and is 3 mm thick [10]. Massive infrastructure is necessary to produce millions of these sheets of cover glass to supply the PV industry [11]. Besides, bifacial solar panels, which use glass on both sides to capture solar radiation, are also getting popular in the market, and analysts predict that this technology will dominate the market in the upcoming decade [12]. As a result, the demand for glass will be increased. Researchers predict that by 2100, the world will see installations of 80-170 TW_p of solar power, and 122–215 million tonnes of glass will be consumed for this purpose [13]. At present, there is a huge demand for rolled glass for solar PV applications over float glass because there are certain benefits of using roller glass. For example, a ton of rolled glass is less energy-consuming than float glass. Also, low-iron flat glass having lowered reflection is necessary for solar thermal applications since this type of glass can trap more sunlight. On the other hand, float glass has high optical qualities, and module efficiency is negatively impacted by the reflection on the float glass's surface. However, float glass is expected to dominate the PV market in the future due to decreased production costs [14].

However, producing this glass will require a considerable amount of energy. For example, 2 to 3 kWh of energy is required to produce 1 kg of glass due to high melting temperatures [15]. So, to produce 122 million tonnes of glass, the energy requirement will be 244-366 TWh. Also, energy is required to source and process the raw materials necessary for glass production. Generally, soda ash (Na_2CO_3), soda feldspar (Na_2O–Al_2O_3–$6SiO_2$), silica sand (SiO_2), limestone ($CaCO_3$), and dolomite ($CaMg(CO_3)_2$) are used for making glass. Among these raw materials, soda ash production is very energy-consuming, and it is estimated that 6.1–10.0 MJ of energy is required to produce 1 kg of soda ash [16]. These energy-intensive productions will emit considerable carbon dioxide in the atmosphere. According to Schmitz et al. [15], 0.74 tons of carbon dioxide (CO_2) are ejected into the atmosphere to produce one ton of flat glass. Therefore, about 90 million tons of CO_2 will be discharged into the atmosphere to manufacture 122 million tonnes of glass. Also, regarding global warming potential from PV manufacturing, solar glass, silicon, and polyvinyl fluoride (backsheet) film, together, are responsible for 45% of the total effect. A similar trend was also observed for acidification potential; silicon stands at first, followed by polyvinyl fluoride film and solar glass at last [17]. Moreover, recycling one tonne of glass can save 1200 kg of virgin materials, saving 25% of energy and mitigating 300 kg of CO_2 emission [18]. Hence, finding alternative ways to meet the glass demand for PV has become necessary. One of the alternatives can be using a recovered cover sheet (whole) in making new PV modules. Therefore, this study aims to determine the economic and energy-saving benefits of using entire glass sheets recovered from the end of PV waste in making new PV panels.

Cover glass in PV panels is often regarded as a low-value and less critical component and is commonly down-cycled into construction materials [19]. Although a glass bottle has an almost similar composition to cover glass, the latter has higher transparency and purity than regular bottles. For example, silica sand with an iron content of less than 90 PPM is used to manufacture this cover glass [20]. Even a minor change (for example, 0.01 mol%) in PV cover glass can reduce 1.1% in output power [21]. Therefore, mixing this high-purity material with low-quality water bottles will be a huge loss .

Most solar panels nowadays use 60 or 72 cells, and their typical size is between 1.8 m^2 and 2.2 m^2 [10]. If whole cover glass can be recovered from these panels after their lifetime, it could be used in some high-value architectural or horticultural applications. Having a high-quality market for cover glass can increase the value of glass instead of using it in small pieces. One possible method for recovering the whole sheet of glass is the hot knife method (figure 1) [22]. Within 40 seconds, this process can separate the cell of a module from the glass. At first, the module is placed between two rollers to guide its movement. Then, the module is advanced until it comes into contact with a one-meter-long steel blade (heated to 180-200°C) and separates the glass and cell. Some other studies have also recovered the whole glass sheets and stated that recovered glass can be used in making new solar panels and architectural applications [21,23]. Further, recent industry decisions to standardize module sizes in the future will facilitate the re-use of old glass in new modules, which has been impossible in the past due to frequent changes in module dimensions [24,25].

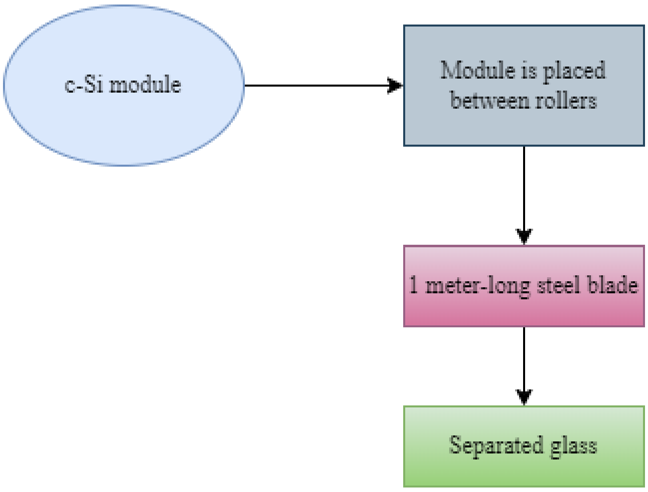

Figure 1: Hot knife process [22].

3. Method:

In this analysis, three scenarios are considered to estimate energy and environmental saving by using a recovered whole sheet of glass in making new solar panels.

Scenario A: Glass manufacturing process

Scenario B: recycled cullet injection (external cullets) in manufacturing new cover glass.

Scenario C: Using the whole recovered cover sheet as a new cover glass.

Figure 2 gives the glass manufacturing process details. Generally, glass is made of soda-lime-silicate, which usually comprises 15% soda (sodium oxide, Na_2O), 10% lime (calcium oxide, CaO), 75% silica (silicon dioxide, SiO_2), and a small amount of aluminum oxide (Al_2O_3) and magnesia (MgO). Energy is required to source and process these raw materials. Among these raw materials, soda ash is the most energy-intensive to produce. Commonly, Solvay (synthetic), Trona (natural), or Hou (synthetic) process is used to make soda ash. For example, the European Union (EU) and the UK produce 99% of their soda ash via the Solvay process [26]. It is estimated that to produce 1 kg of soda ash via this process, 6.1–10.0 MJ of energy is required. Overall, to produce 1 kg of molten glass, it is estimated that the total energy needed to source all the raw materials is 3.8–4.8 MJ [26]. Melting raw or primary materials consumes 60-70% of the total energy consumption of glass production. Overall, 40% of total energy consumption in melting is dedicated to both heating the batch of raw materials and its chemical progression. The theoretical energy needs for glass production are the endothermic heat required to melt the raw materials (for glass reaction), sensible heat for glass heating, and sensible heat for batch or intermittent gases (gases from glass reaction). The manufacture of glass requires 2671 kJ/kg of energy if cullet is not used. If 100% cullet is used, the energy requirement decreases to 1886 kJ/kg [26]. However, this manufacture process is very carbon intensive. For the flat glass manufacturing process, 208 kg of CO_2 is emitted per ton of raw materials. In comparison, the process and energy-related CO_2 emission factors produced per ton of glass are 190 and 337 kg, respectively [27]. If whole sheet is recovered and reused in manufacturing new solar panels, then this amount of energy and emission can be saved.

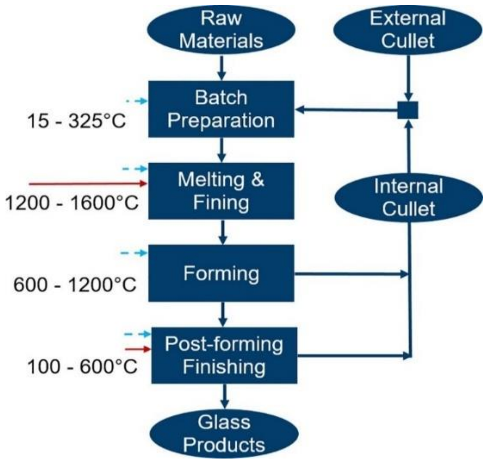

Figure 2: Glass manufacturing process

4. Conclusion:

Reusing recovered whole glass sheets from end-of-life PV waste is expected to significantly reduce waste problems, glass production's energy needs, and carbon intensity. Also, a high-quality alternative market can be established for these glasses since these glasses possess high quality. Therefore, care should be given to developing proper recycling strategies.

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