

Review

Importance of SLAPE Solar Panels, Electrochemical CO₂ Reduction, Alkaline Electrolyzers and Alkaline Fuel Cells Development to Achieve United Nations Sustainable Development Goals

Ibram Ganesh *

Centre of Excellence for Artificial Photosynthesis, International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Balapur Post, Hyderabad – 500 005, Telangana, India; E-Mails: ibramganesh@arci.res.in; dribramganesh@gmail.com

* **Correspondence:** Ibram Ganesh; E-Mails: ibramganesh@arci.res.in; dribramganesh@gmail.com

Academic Editor: Rajesh Kumar Raju

Recent Prog Sci Eng

2025, volume 1, issue 3

doi:10.21926/rpse.2503013

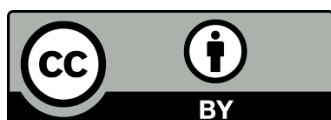
Received: July 31, 2025

Accepted: September 08, 2025

Published: September 17, 2025

Abstract

The United Nations Organization (UNO) in the year 2015 formulated seventeen sustainable development goals (UNO's 17 SDGs) to be achieved by the end of the year 2030. The so far achieved progress indicates that none of these UNO's 17 SDGs can be achieved before the deadline. In fact, all these goals can be achieved by developing suitable technologies to fully capture and utilize all the renewable energy resources available on earth to meet all the energy needs of society without any backup from fossil fuels. In this review article, i) how the present *silicon photovoltaic cell (SPVC)* solar panels are causing a million times higher global warming when compared with the one that could be caused by the equivalent CO₂ gas present in atmosphere, and how it can be overcome, ii) all the renewable energy resources and their availability and capabilities, iii) details about whether anytime human society can entirely depend only on renewable energy resources to meet all the energy needs, and what needs to be done to do so, iv) the possibility of utilizing gravity in conjunction with water buoyancy to generate unlimited amount of electricity, v) what measurements so far taken by the governments across the globe to achieve these goals, vi) how the problems related to urban heat island (UHI) effect can be solved, and how the vii) development of SLAPE (*silicon and liquid assisted photothermal effect*) solar panels, viii)



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electrochemical CO₂ reduction (ECR) reaction, and reduction of the cost of ix) alkaline electrolyzers, and x) alkaline fuel cells are essential to achieve SDG-1 (*no poverty*), SDG-2 (*no or zero hunger*), SDG-7 (*affordable and clean energy*), SDG-8 (*decent work and economic growth*), SDG-10 (*reduced inequalities*), SDG-11 (*sustainable cities and communities*), SDG-13 (*climate action*) and SDG-14 (*life below water*) have been described while citing all the relevant and essential references.

Keywords

Dangers of silicon photovoltaic solar panels; semiconductor and liquid-assisted photothermal effect; electricity generation using gravity in conjunction with water buoyancy; rubber-based porous membranes; global warming; photovoltaic local heat island effect; urban heat island effect

1. Introduction

The *United Nations Organizations (UNOs) Seventeen Sustainable Development Goals* (UNO's 17 SDGs) are listed in Table 1 [1-7] along with the processes that can be employed to achieve eight of these 17 goals namely; *SDG-1, SDG-2, SDG-7, SDG-8, SDG-10, SDG-11, SDG-13, and SDG-14*. In fact, these eight UNO's SDGs can be achieved by developing suitable technologies to fully utilize all the so far identified eight renewable energy resources namely; i) *solar energy*, ii) *wind energy*, iii) *tide energy*, iv) *bioenergy (or biomass)*, v) *nuclear energy*, vi) *geothermal energy*, vii) *hydroelectricity*, and viii) *gravity in conjunction with water buoyancy* to meet all the energy needs of the society (i.e., 100% world primary energy requirement (WPER) must be met without any back-up from fossil fuels) [8-33]. As far as SDG-1 (*no poverty*) is concerned, during the initial period immediately after announcing the UNO's 17 SDGS in the year 2015, some progress was made towards reducing extreme poverty across the globe [1]. However, after the COVID-19 pandemic, this progress has become dead slow. At the end of the year 2022, UNO declared that about 670 million people (i.e., ~8.4% of the total population) were facing extreme poverty across the globe [1]. As far as achieving SDG-2 (*zero or no hunger*) is concerned, based on UNO's data in the year 2023, nearly *one in every eleven people* met with hunger problems, and about two billion people were facing very severe food insecurity problems [1]. In fact, to achieve both SDG-1 and SDG-2 and either to produce sufficient food grains in every country, or to generate enough revenue required to procure the food grains from other countries, a clean, carbon-neutral, abundantly available, Omni present and easily accessible renewable energy resource is needed to draw energy round-the-clock (RTC) without any interruption, and without any back-up from fossil fuels. Even for achieving SDG-7 (*affordable and clean energy*, i.e., to overcome energy poverty), SDG-8 (*decent work and economic growth*, i.e., to get rid of unemployment completely from the society across the globe), SDG-10 (*reduced inequalities*, i.e., to generate sustainable and stable revenue by each and every family around the world) and SDG-11 (*sustainable cities and communities*, i.e., for getting best education, best medical care, best facilities to maintain high living standards, to have safe colonies and society to live in peacefully, etc.), a stable and sufficient economy generation by every country has to be achieved, and to accomplish this again a suitable renewable energy resource is

required. Today, >81% of the world economy is generated by burning fossil fuels only, which are releasing greenhouse CO₂ gas into the atmosphere. In the year 2024, about 41.6 billion tons of CO₂ gas were released into the atmosphere by burning fossil fuels to meet ~81.45% of % energy needs of human society (i.e., to get ~81.45% WPER) [1]. Not only that, but these fossil fuels cannot sustain our civilization's economic growth. In fact, the large-scale fossil fuel utilization started mainly after the beginning of the Industrial Revolution in the year 1970, which lasted till about 1840. The CO₂ gas entering into the atmosphere today do not also allow achieving SDG-13 (*climate action*, i.e., stopping of floods, tsunamis, heat waves and wildfire occurrence by forests burning across the globe during every summer season, etc.) and SDG-14 (*life below water*, i.e., avoiding further acidification of ocean thereby saving life in seawater, etc.) [34-40]. In fact, today, one ton of CO₂ gas released into the atmosphere can cause damage equivalent to ~185 US\$ according to the most recent information on the internet, by causing extreme rain events and floods owing to its greenhouse and global warming effect. That means the CO₂ gas released into the atmosphere in 2024 can cause a loss of about 7.69 (= 41.6 billion tons × 185 US\$ social cost of carbon) trillion US\$ worth of wealth loss to human society [41].

Table 1 The United Nations Organization's seventeen sustainable development goals (UNO's 17 SDGs) and the methods that can be employed to achieve these goals. [†]

Goal	Sustainable Development Goal name	Technology is needed to achieve the goal
1.	No poverty	Yellow H ₂ production
2.	Zero hunger	Yellow H ₂ production
3.	Good health and well-being	-
4.	Quality education	-
5.	Gender equality	-
6.	Clean water and sanitation	-
7.	Affordable and clean energy	Yellow H ₂ production & PAP process
8.	Decent work and economic growth	Yellow H ₂ production & PAP process
9.	Industry, innovation, and infrastructure	-
10.	Reduced inequalities	Yellow H ₂ production
11.	Sustainable cities and communities	Yellow H ₂ production
12.	Responsible consumption and production	-
13.	Climate action	PAP process
14.	Life below water	PAP process
15.	Life on land	-
16.	Peace, justice, and strong institutions	-
17.	Partnerships for the goals	-

[†] The yellow H₂ production means H₂ gas generated by electrolysis of water using electricity generated from sunlight, and the PAP process means synthesizing solar fuels using CO₂ and water with electricity derived from sunlight.

Although, UNO through *Intergovernmental Panel on Climate Change (IPCC)* and *United Nations Framework Convention on Climate Change (UNFCCC)* is trying its best by conducting *Kyoto protocol-1997*, *Paris agreement-2015*, COP26, COP27, COP28 and COP29, etc. [1, 42], to minimize

the global warming effect by reducing the usage of fossil fuels, and by increasing of usage of renewable and carbon-neutral energy sources mainly solar and wind energies, nothing stopping occurrence of dangers to human society across the globe in the form of frequent floods, rain fury, landslides, extreme heat waves and forest burning during summer seasons, etc., every year. In fact, global warming can also trigger the occurrence of Earthquakes inside the seawater, thereby causing the occurrence of tsunamis [43]. When a lot of water gets evaporated from seawater and oceans at certain specific sensitive locations where the balance between the inside volcano pressure and pressure suppressing the eruption of volcano is very minimal, the water evaporation due to severe global warming in conjunction with gravity pulling of Moon (during full Moon days) can trigger the eruption of volcanos at those specific locations inside seawaters leading the occurrence of tsunamis. Similar to how the boiling of water is highly influenced by the atmospheric pressure, the volcanic eruption can be triggered due to the combined effect of water evaporation and gravity pulled by the Moon, and it is based on a cause-and-effect principle [43]. Due to these calamities, there is a continuous wealth and life loss across the globe, and year after year, it is increasing rather than decreasing. It indicates that there is something wrong with the approach of IPCC and UNFCCC towards actions taken to stop the occurrence of climate change. The actual reason for the frequent occurrence of all these detrimental natural calamities during the past ten-year period is explained in the following paragraph [1, 42].

Even if one percent excess sunlight gets converted into waste heat energy than the one that is converted into electricity by the *silicon photovoltaic cell (SPVC)* solar panels, then that one percent excess heat energy is a million times higher than the one that could be generated by the CO₂ gas present in the atmosphere [44-51]. This is due to the fact that the concentration of CO₂ gas in the atmosphere today is only about 421 ppm (i.e., 0.041%) [52], whereas the *silicon (Si)* in SPVC solar panels is ~100% [44-51]. That means Si absorbs a million times excess sunlight than the amount that could be absorbed by the CO₂ gas present in the atmosphere. In fact, CO₂ does not absorb any sunlight reaching the earth's surface, but the long wavelength infrared heat waves generated by the earth's surface after absorbing a fraction (or a few percent) of sunlight and got heated up. These long-wavelength infrared heat waves travel at the speed of light to escape from the atmosphere into space. These infrared heat waves are absorbed by the CO₂ gas present in the atmosphere; otherwise, it cannot absorb any sunlight. The Si semiconductor in SPVC solar panels absorbs ~70% sunlight reaching the earth's surface owing to its band-gap energy of ~1.1 eV, which corresponds to ~1137 nm wavelength light [44-51]. Out of the absorbed ~70% sunlight by these SPVC solar panels, ~20% is converted into electricity, and >30% sunlight is converted into heat energy, which is dissipated into the atmosphere in the form of *long-wavelength infrared heat waves via* three heat transfer mechanisms: *radiation*, *conduction*, and *convection* [44-51]. That means, Si in SPVC solar panels absorbs sunlight with a wavelength ranging from ~290 nm to 1137 nm (about 70% sunlight reaching the earth's surface), and it does not absorb the remaining sunlight with a wavelength between 1137 nm and 2400 nm. For example, when Si is irradiated with a sunlight *photon (hv)* having energy equivalent to about 3.0 eV (i.e., with a wavelength of ~413.6 nm), out of this photon energy, ~1.1 eV equivalent sunlight is converted into electricity due to the *photovoltaic* (i.e., *photoelectric*) *effect*. The remaining energy (i.e., 1.9 eV = 3.0 eV - 1.1 eV) is converted into *heat energy* due to the *photothermal effect*, which is released into the atmosphere. Semiconductors also exhibit *Joule heating effect* ($H = I^2Rt$; where “*I*” is current flowing through the semiconductor, “*R*” is resistance offered by the semiconducting material to

the current flow, and “ t ” is the current flow time through the semiconductor) exactly similar to the resistive heating elements do [44-51]. That is the reason why more sunlight is converted into heat energy than the amount that could be converted into electricity by SPVC solar panels. In fact, under *open circuit voltage (OCV)* and *short circuit current (SCC)* conditions, these SPVC solar panels do not generate any electricity but 100% heat energy only. The heat waves that are dissipated through conduction and convection mechanisms are absorbed by the complete air composition, and are transferred to a maximum height of about a few hundred meters above the earth's surface, whereas the radiation heat waves travel a complete ten kilometers above the earth's surface before they escape into space. As the concentration of CO₂ gas increases in the atmosphere, the absorption of heat traveling in the form of radiation also increases owing to the permanent dipole movement property of CO₂ gas (i.e., greenhouse effect). That means whatever the benefits offered by the SPVC solar panels are completely compensated by the excess 10% waste heat energy generated by them out of the absorbed sunlight in comparison to the one converted into electricity [44-51]. This total waste heat energy is being released into the atmosphere today to protect the efficiency of the SPVC solar panels.

When the SPVC solar panels generate more electricity than the waste heat energy generated by them, in that case, the amount of CO₂ gas generation avoided by burning fossil fuels to generate that much electricity at thermal power plants (TPPs) shall be taken into consideration [44-51]. Since they are generating more waste heat energy than electricity, they are not doing any benefit to human society or the environment. In fact, they are causing a very severe and dangerous million times higher global warming to the environment in comparison to the one that is caused by the equivalent CO₂ gas present in the atmosphere. When a SPVC solar panel with dimensions of 2 meters × 1 meter is deployed, it occupies a volume of about ten liters in the atmosphere, as its thickness is about half a centimeter (i.e., 10 liters $\cong$ 10,000 cm³ = 200 cm × 100 cm × 0.5 cm). It does not make any changes to the concentration of CO₂ gas present in the atmosphere except displacing 10 liters of air [44-51]. In the year 2024, about 2,132 terawatt-hours (TWh) (equivalent to ~ 7.675 exajoules (EJ) = 2,132/277.8, where 1 EJ = 277.8 TWh) of electrical energy was generated by using all the so far installed SPVC solar panels across the globe [53]. Whereas, in the same year 2024, the total WPER for meeting all the energy needs of the eight billion people living today on Earth was about 620 EJ, which was 2% more than the one utilized in the previous year 2023. That means only about 1.24% WPER was met from electricity generated from sunlight by using solar panels, and the remaining >98.76% WPER did not come from solar panels. In the year 2024, the contribution of fossil fuels (i.e., crude oil, coal, natural gas, and their derived products such as diesel, petrol (gasoline), LPG, CNG, LNG, etc.,) to the total 620 EJ WPER was about 505 EJ (i.e., $\sim 81.45\%$) [54]. The number of times excess energy supplied by fossil fuels in comparison to the amount provided by solar panels is about 65.68 times (= 81.45%/1.24%).

The number of times SPVC solar panels cause global warming when compared with the amount that could be caused by equivalent CO₂ gas in the atmosphere is $\sim 9,99,513$ times (= 10,00,000 million times - 421 ppm - 65.68 times). That means, today, so far deployed SPVC solar panels present on earth are causing $\sim 9,99,513$ times higher global warming when compared with the one caused by 41.6 billion tons of CO₂ gas released into the atmosphere in the year 2024. In that case, the social cost of *silicon (Si)* is about 76,86,254 (= 7.69 trillion US\$ × 9,99,513 times) trillion US\$. It is a massive loss to human society, and it is impossible for any country in today's world to bear these kinds of losses. Not only for occurring of extreme rain based calamities such as, very severe

floods, landslides occurring in India, in China, and around rest of the world, tsunamis occurring around the globe, but also for occurrence of heat waves around the globe like those occurring in central India and Delhi every year, and for occurring forest burning every summer somewhere in the world such as, those occurred recently in *California, USA* (around 13.5 million hectares forest got burned in the year 2024 leading to a lot of billions of dollars of wealth loss) [55] and in Israel, etc., the million times higher waste heat energy generation by today deployed SPVC solar panels around the globe are responsible. At specific locations, the today deployed SPVC solar panels are generating $\sim 20^{\circ}\text{C}$ higher temperature due to the *photothermal effect* in comparison to room temperatures (RTs). Generation of $\sim 14^{\circ}\text{C}$ higher temperature by “*silicon photovoltaic (SPV) cells*” when placed in SLAPE solar panels in comparison to that of the ambient room temperature was recorded (Video S1) [9, 44-50]. In fact, the amount of temperature generated in a square kilometer (km^2) area by the SPVC solar panels is equal to the temperature generated by atmospheric CO_2 gas present in one million km^2 area in the absence of SPVC solar panels. Since the total area of India is ~ 3.28 million km^2 , the SPVC solar panels deployed in an area of around 4 km^2 can double the RT of the entire area in India. Today, for example, just M/s. *Gujarat Hybrid Renewable Energy Park*, Khavda, Rann of Kutch desert, Gujarat, alone deployed SPVC solar panels in $\sim 726 \text{ km}^2$ area [56]. The other solar farms deployed across India cover a few thousand km^2 area. That means India alone generates ~ 431.5 times higher RT when considering an area of $\sim 1726 \text{ km}^2$ covered with SPVC solar panels, when compared with the temperature generated by CO_2 gas in the absence of SPVC solar panels. When the temperature generated by the entire SPVC solar panels deployed today across the globe to generate $>2,132 \text{ TWh}$ equivalent electrical energy is considered, it can raise the global temperature by many degrees, which is indeed responsible for all the natural calamities occurring around the globe. In fact, the heat energy generated and released by the SPVC solar panels into the atmosphere does not cause a direct rise in RT. In fact, it is compensated by causing evaporation of water from various water bodies such as ponds, lakes, rivers, seas, oceans, and from leaves of trees and plants due to the occurrence of increased transpiration process [44-51]. Furthermore, the heat released by SPVC solar panels and the water evaporation occurring due to that released heat are responsible for the occurrence of floods, landslide, tsunamis, heat waves, burning of forests during summer periods every year, etc., across the globe, which are in turn responsible for the loss of not only several trillions of dollars wealth loss but also for the loss of human life. To avoid these losses, the waste heat energy released by SPVC solar panels has to be stopped immediately by trapping it to serve the human society [51]. Then only the occurrence of dangerous natural calamities related to floods, landslides, tsunamis, heat waves, wildfires, forest fires, etc., can be avoided or minimized.

In fact, there are two reasons for the need for solar panels to generate electricity. The first one is that fossil fuels are non-renewable, exhaust one day, and cannot sustain today's human civilization's economic growth, hence, an alternate energy is needed to replace fossil fuels. The second reason is that fossil fuels are releasing greenhouse CO_2 gas into the atmosphere, thereby causing global warming; hence, their usage shall be stopped [44-51]. By telling these two reasons, today, SPVC solar panels are being deployed all over the world by almost all governments. But these installed SPVC solar panels are causing a million times higher global warming than the one that could be caused by the equivalent amount of CO_2 gas present in the atmosphere. Surprisingly, nobody is talking about these dangerous adverse effects of SPVC solar panels. The “*photovoltaic local heat island effect*” is a well-known phenomenon, and they generates in some areas $\sim 20^{\circ}\text{C}$

higher temperature than the RTs, and dissipates heat into the atmosphere [51]. In fact, several articles published so far mentioned how much global temperature can be raised by the anthropogenic CO₂ gas entering the atmosphere, whereas no article reported how much global temperature is being raised by the heat released by the SPVC solar panels into the atmosphere. To avoid the additional global warming caused by the heat released by the SPVC solar panels, the heat generated by SPVC solar panels has to be trapped and used for the beneficial purposes of society. At the same time, the utilization of other alternative safe, clean, and carbon-neutral renewable energy resources has also to be increased by many folds [44-51].

It is also a known fact that to depend human society entirely on solar energy, wind energy, or tidal energy, they need to be stored in a suitable manner as they are intermittent in nature to get energy round the clock (RTC) without any interruption. Today, one of the primary electricity storage methods is pumping of water into dams during the daytime, and regenerating it back again in the absence of sunlight (i.e., during morning and evening hours, which are peak hours of energy consumption) by using turbines [44-51]. In the Telangana state of India, electricity generated by using SPVC solar panels is purchased by the government at the rate of Rs. 3/- per kWh (i.e., for one electrical unit), and it is sold at the rate of Rs. 9/- per kWh during peak hours. However, the complete electricity generated today by using the entire SPVC solar panels deployed so far cannot be stored by pumping water into the dams, as there are not many dams available to do so. Furthermore, when the dams are at full capacity and are overflowing, water cannot be pumped into these dams using electricity obtained from solar panels. Mother Nature suggests that any amount of energy can be stored by using CO₂ and water as energy storage materials [44, 45]. For doing so, first sunlight has to be converted into electricity by using any of the safe solar panels, which do not cause any global warming. Thus, the electricity obtained from sunlight has to be stored either by splitting water in alkaline electrolyzers in the form of H₂ and O₂ gases or by reducing CO₂ gas in electrochemical cells. The H₂ and O₂ gases can be stored in cylinders for a few years without any leakage [44, 45]. In fact, the energy stored in batteries leaks automatically when they are not in use, even for a few months.

It is also a known fact that the required amount of solar energy cannot be stored in the form of biomass by following natural photosynthesis (NP) process, as its efficiency is only about 0.2% [57]. This is due to the fact that it uses atmospheric CO₂ gas as an energy-storing material, whose concentration today is only ~421 ppm (i.e., 0.0421%). By using such a low concentration of CO₂ gas in the atmosphere, the NP process cannot store solar energy more than 0.2% efficiency. Furthermore, biomass burning do not add any extra anthropogenic CO₂ gas into the atmosphere, and this biomass is formed out of the atmospheric CO₂ gas during relatively same period, whereas, fossil fuel burning increases the concentration of this anthropogenic CO₂ gas in the atmosphere as these fossil fuels are formed out of CO₂ gas almost a million years ago, and got buried into the earth crust [44, 45, 57]. Fossil fuel burning means the CO₂ gas sequestered in the form of biomass a million years ago is taken out and released into the atmosphere while meeting energy needs. Furthermore, the solar energy stored by the NP process over a period of several million years is being consumed by human society within a three to four-hundred-year period. By storing solar energy at the rate of 0.2% efficiency, it is not possible to harvest solar energy to the extent of >550 EJ in the form of biomass equivalent to the energy obtained by burning fossil fuels today. Nature indicates that any amount of energy can be stored by using CO₂ and water as energy storage materials while beneficially contributing to the environment [57]. Despite such a low efficiency,

Mother Nature is successfully feeding the entire eight billion people living today on Earth, along with all the animals, with the solar energy stored in the form of food materials and biomass.

On the other hand, electricity generated from geothermal energy, nuclear energy, and hydroelectricity can be used as and when required on a demand basis as they are available RTC. Only biomass can be used similarly to fossil fuels used today, as it is a chemical energy source. However, the energy density of biomass is relatively low when compared with that of fossil fuels. Out of these seven renewable energy resources, namely solar, wind, tide, geothermal, nuclear, hydroelectricity, and biomass, the first six generate electricity, whereas biomass is a chemical energy source. Among these seven renewable energy resources, only sunlight comes in abundance, but not 24 hours a day. At present, there are two additional problems with depending entirely on solar energy. First one is, today only ~1.24% of WPER is being produced by using solar panels, and to generate more electricity, more solar panels have to be deployed, which needs additional land at the cost of what is used today for cultivating food materials and biomass to feed human beings and animals. The second problem is that commercial SPVC solar panels are causing a million times higher global warming than the one that could be caused by the CO₂ gas present in the atmosphere. That means further deployment of solar panels means further contributing to the global warming effect.

Fortunately, nature has given another yet to be utilized renewable energy resource in abundance in the form of gravity and water buoyancy. When a weight is lifted in water, there is about 25% less energy consumption owing to water buoyancy when compared with the energy needed for lifting the same weight in air against gravity. When that weight is dropped against the gravity in air by attaching an electricity generator (i.e., an alternator), that 25% energy difference gives electricity. Practically, even if 10% efficiency is achieved, it will solve many problems that today's human society is facing, and thereby it facilitates achieving all the UNO's 17 SDGs. Since gravitational force is a result of attraction between the electrons of atoms of one material (i.e., matter like Earth) with protons of atoms of another material (i.e., matter like the Moon) and *vice versa*, it exists as long as Earth exists [49].

In view of the above, to generate sustainable energy along with required revenue and economy, and to make safe environment while achieving UNO's 17 SDGs i) an improved methods have to be developed to harvest sunlight in the form of stable chemical fuels (i.e., in the form of solar fuels) by using CO₂ and water as energy storage materials [58-71], ii) all the other remaining renewable energy resources available today have to be utilized fully, iii) the new renewable energy resources such as, gravity in conjunction with water buoyancy has to be utilized to generate electricity, and iv) no waste heat energy generated by SPVC solar panels has to be released into the atmosphere.

2. Efforts Made So Far Towards Achieving the United Nations Organization's Seventeen Sustainable Development Goals

All the efforts made so far to achieve the UNO's 17 SDGs across the globe have been surprisingly based on deployment and efficiency increase of already existing renewable energy systems such as, i) efficient usage of fossil fuels, ii) increase of efficiency of energy consuming home appliances, iii) saving of energy consumption by judiciously using it, and by increasing efficiency and deployment of iv) SPVC and other photovoltaic (PV) solar panels, v) wind mills, vi) nuclear energy generation, vii) hybrid renewable energy systems (HRES) containing PV solar panels

with a pumped hydropower storage system in dams, etc. [9-34]. In a study, a mathematical analysis was made by Makhzom *et al.* [26] to determine the amount of CO₂ gas generated while generating electricity by burning crude oil. One megawatt-hour (MWh) of electricity generation requires the burning of 291 kg of diesel, which requires about 1,141 kg of crude oil refinement. The CO₂ gas to be generated for obtaining an MWh of energy is calculated to be ~1253 kg. The share of the oil sector in the emitted CO₂ gas has been found to be about 6.4%, whereas the share of the electricity generation sector has been about 93.6%. Yet in another study, Fathi *et al.* [27] studied the adverse effects of using diesel generators on the economy and environment when they are employed during the power cuttings. They suggested that the usage of conventional energy resources in combination with renewable energy would be an ideal situation to achieve both economic and environmental sustainability. In another study, Eteriki *et al.* [28] explored the energy consumption pattern in a household sector with traditional home appliances in a typical Libyan home, and compared the energy consumption pattern to assess the energy efficiency potential in improving home appliances. Furthermore, it was found that the majority of electrical energy consumption in the residential sector (72%) is for air-conditioning, lighting, electrical heater, and electrical water heater. The apartment's annual energy consumption was determined as 12,757.56 kWh. A significant reduction in energy consumption amounted to 52% upon replacing the old appliances with modern and more efficient ones, and about 73% energy needed for domestic hot water generation has been saved by using solar water heaters. In another study, Makhzom *et al.* [30] probed the amount of CO₂ emission that takes place in the power sector of Libya upon usage of fossil fuels to meet the energy needs, and found that the electric power industry is more harmful to the environment than all estimations that use inventories' emission factors for the environmental agencies. In another study, Nassar *et al.* [32] have suggested the carbon tax for controlling the environmental damage costs due to the CO₂ emissions in the atmosphere as a part of generating energy to meet the energy needs of society by burning fossil fuels. Furthermore, Nassar *et al.* [33] also surveyed the amounts of hazardous gases emitted from different sources in Libya. The annual total air emissions have been found to be about 61.1 million tonnes. The largest share of emissions has been CO₂ (96.76%), followed by CO (2.13%), then PM (0.55%), then SO₂ (0.21%), NO_x (0.18%), then CH₄ (0.089%), VOC (0.061%), and lastly N₂O (0.028%). The annual total emitted CO₂ is equivalent to around 64.6 million tonnes CO₂e, which represents about 9.7 tonnes/year/capita. Their research revealed that most pollutants are emitted from the electricity generating industry with a share of about 33.9% followed by the transportation sector with 30.7% then the residential and commercial sector with 14.2% and finally the cement manufacturing industry with 10.9%.

The amount of electricity generated by using SPVC solar panels has been mentioned in the previous section. In order to improve the efficiency of SPVC solar panels and to solve the problems associated with them, a great variety of new photovoltaic (PV) systems, such as *copper-zinc-tin-sulfo-selenide* (CZTSSe) [10], *Ag-CdSe* quantum dots nano-composite sensitized solar cells [11, 12], the modification of PV cells [13], and the introduction of bifacial SPVC solar panels, etc., have been investigated and developed. In a study, Salim *et al.* [18] investigated a proposed *hybrid renewable energy system (HRES)* consisting of an isolated SPVC solar farm along with a pumped hydropower storage system designed for Brack city, Libya. This proposed solar farm produces 500 MW of solar power, and a dam to store 5,770 MWh of energy by pumping water into the dam using the electricity derived from SPVC solar panels. With this installation, the Brack city of Libya can meet

an estimated load of 590,019 MWh, and stop the release of 611 tons of CO₂ gas into the atmosphere [21]. In another study, Nassar *et al.* [19] proposed a HRES with an investment of about \$323 to generate electricity of 80 MW from SPVC solar panels, 66 MW from wind mills, and 50 MW from biomass. This HRES is expected to generate about 389 GWh/yr. This generated electricity is said to be enough to meet the complete energy demand of Jenin Governorate, Palestine, which actually needs ~372 GWh/yr [22]. That means they are going to have a surplus energy equivalent to about 4.57%. The estimated *levelized cost of energy (LCOE)* of this HRES has been estimated to be about 0.313 \$/kWh. In another study, Andeef *et al.* [20] compared the benefits to be achieved by establishing a *concentrated solar power (CSP)* plant to stop the usage of electricity generated at *M/s. Ubari thermal power plant (TPP), Wadi-Al-Hayaa, Libya*, by burning *natural gas (NG)* and *crude oil*. This proposed CSP electricity generation was investigated to determine the economic viability and environmental benefits of this project. In fact, they want alternative energy vectors to employ in place of electricity generated by burning crude oil so that this crude oil can be used for some other high-end applications. The details of the proposed CSP power plant are given below:

- i. The share of CSP electricity in total energy consumption is 43.6%.
- ii. The CSP plant capacity - 400 MW.
- iii. Thermal storage tank capacity - 11,331 m³.
- iv. The total land area proposed is 508 hectares.
- v. The capital cost - \$186,102,644.
- vi. LCOE - \$13.48/kWh.
- vii. The amount of crude oil that can be saved annually - 3,187,726 barrels.
- viii. The cost of crude oil saved - \$243,637,912.
- ix. The amount of CO₂ release to be avoided - 1,735,060 tons/year.
- x. The environmental damage that can be avoided annually is \$130,129,247.

In a study, Khaleel *et al.* [24] suggested employing PV, wind, and hydrogen fuel cells in combination to achieve sustainable development in energy generation and to mitigate *greenhouse gas (GHG)* emissions. They examined the recent technological improvements that are responsible for decreasing carbon emissions and the efforts towards achieving the UNO's 17 SDGs. There is a significant decline in the amount of GHGs released into the atmosphere. According to them, the cumulative CO₂ emissions from 2015 to 2023 for China, the USA, the EU, India, and Japan have been 102.0 Gt, 43.0 Gt, 25.4 Gt, 21.7 Gt, and 10.0 Gt, respectively. In another study, Moumani [25] has suggested considering environmental dimensions during the planning process, and if it is not so, it is incomplete and not strong in decreasing pollution problems.

In a study, Khaleel *et al.* [14] reported that the global nuclear power capacity will increase to ~530 GW by 2050, which is about 35% lower than the one projected as part of achieving net-zero emissions (NZE). As a part of this, about 413 GW of nuclear energy was generated in the year 2022, and it is expected to reach about 812 GW in the year 2050. Alternatively, wind energy was also analyzed for its effective utilization to meet the energy needs of society [15]. In a study, Elmariami *et al.* [16] performed a life cycle assessment (LCA) of a proposed wind farm of ~20 MW capacity, and this proposed wind farm had ten numbers of Gamesa turbines each with 2 MW capacity to generate about 2082 GWh in its life time with a *return on investment (ROI)* period of about 6.3 months, and a payback ratio of about 38, an energy intensity of 0.0269 kWh primary/kWh and a net profit of about \$56,485 million. Furthermore, this installation will stop the generation of about

7 million tons of CO₂ gas. In another study, Salem *et al.* [17] investigated seven different types of wind mills manufactured by seven other companies, and out of them, the Suzlon 3.3 MW turbine manufactured by *M/s. Suzlon Energy Ltd.*, an Indian company located in Pune, Maharashtra, India, has been identified as the best one. Furthermore, it was also mentioned that, today, the Libyan electrical energy sector's emission factor is accounted for about 0.967 kg CO₂/kWh, and when a wind turbine farm of ~1000 MW is constructed with an average capacity factor of ~40%, then about 3.82 million tonnes CO₂ generation will be avoided, which in turn results saves \$286.329 million as a carbon tax each year.

Although several efforts were made, as explained above, to achieve UNO's 17 SDGs by improving the efficiencies of existing renewable energy capturing technologies, integration of hybrid energy resources, and other types of photovoltaic systems, etc., no significant progress was made towards achieving these UNO's 17 SDGs. In fact, not only SPVC solar panels, all other remaining PV based electricity generating solar panels including dye-sensitized solar cells (or Gratzel cells), CIGS, perovskite solar cells, organic solar cells, and GaAs based photovoltaics generate a million times waste heat energy and release into the atmosphere when compared with the heat energy generated by the equivalent CO₂ gas present in the atmosphere. Hence, some other new approaches and technologies are needed to be invented, developed, and deployed to produce electricity so that human society can entirely depend only on renewable energy resources without any backup from fossil fuels. That means 100% WPER must come from carbon-neutral, clean, and renewable energy resources only, without damaging the environment due to the global warming effect caused by them. Based on the state-of-the-art available today in the society, the best way to achieve the UNO's 17 SDGs is i) to trap the heat energy generated by SPVC solar panels, and use it for the beneficial purposes of the society, and to do so, the SPVC-SLAPE hybrid solar panels have to developed and deployed, ii) the methods for further utilization of other renewable energy resources such as, wind energy, biomass energy, etc., have to be developed, iii) suitable methods have to be developed to generate electricity from gravity in conjunction with water buoyancy, iv) methods to store electricity generated from solar panels for using it RTC without any back-up from fossil fuels, etc., have to be developed.

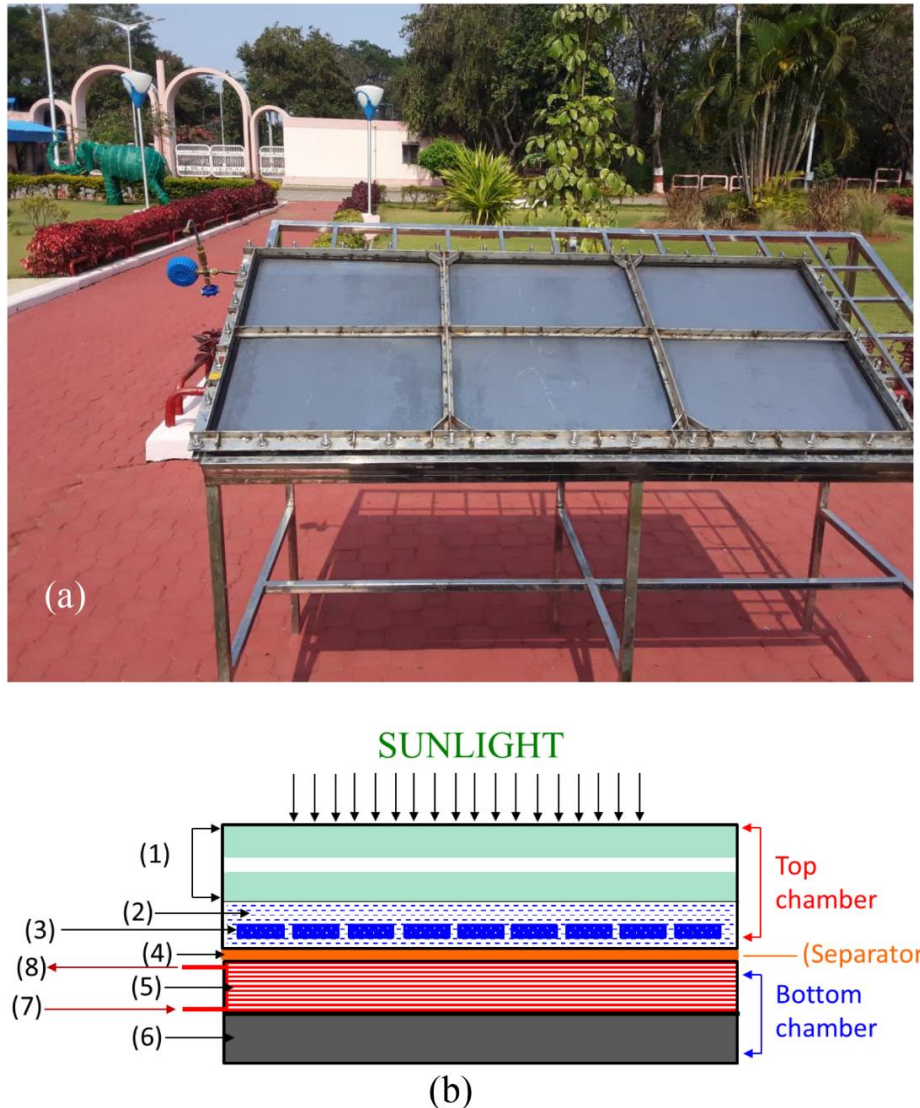
Today, the best way to store electricity derived from sunlight without damaging the environment is to use CO₂ and water as energy-storing materials so that any amount of solar energy can be stored while beneficially contributing to the environment. It is also a known fact that to make the solar energy harvesting methods economically viable to practice in industry, the efficiency of sunlight harvesting in the form of chemical energy must exceed 10% according to the *Department of Energy (DoE)*, USA [9, 44, 45]. For achieving such an efficiency, the solar energy harvesting process has to be performed in three separate steps. In the first step, the sunlight has to be converted into electricity by using solar panels that do not cause any global warming. In the second step, the electricity derived from sunlight has to be stored by splitting water into H₂ and O₂ gases, and by reducing CO₂ gas into CO gas in suitable electrochemical cells. In the third step, either H₂ and O₂ gases have to be mixed in alkaline fuel cells to generate electricity, which can be used in the absence of sunlight as and when required on a demand basis, or methanol has to be produced from H₂ and CO gases. Thus obtained methanol can be converted into gasoline (i.e., petrol) and diesel by following well-proven and practiced technologies in the industry. This latter process is referred to as the *Practicable Artificial Photosynthesis (PAP)* [9, 44, 45, 70, 71]. Only by following this method, all the CO₂ gas generated today as a waste across the globe by burning

fossil fuels to meet the energy needs of the society can be consumed, thereby, the CO₂ associated global warming, climate change, and social cost of carbon problems can be solved. In the following sections, the status on i) electricity generation from sunlight by using safe solar panels such as, SLAPE solar panels, and SLAPE-SPVC hybrid solar panels, etc., ii) storing electricity derived from sunlight in the form of chemical energy by using CO₂ and water as energy storage materials (i.e., the status of alkaline electrolyzers, electrochemical CO₂ reduction (ECR) process), and iii) the processes that convert H₂ and O₂ gases into electricity by using alkaline fuel cells, has been described and summarized.

3. Development of SLAPE Solar Panels

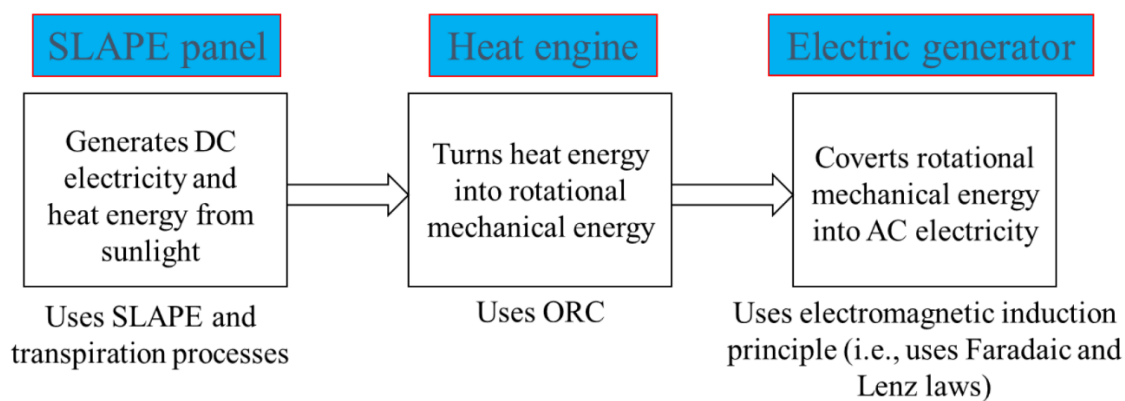
As mentioned in the previous sections, the present deployed SPVC solar panels across the globe are causing a million times higher global warming in comparison to the one caused by the equivalent CO₂ gas present in the atmosphere, and as it is not possible to achieve 10% efficiency in the eventual conversion of sunlight into any stored chemical energy to use it to meet the energy needs of the society while producing commercially with economic viability when SPVC solar panels with ~20% conversion efficiency are involved [44-51]. This is due to the fact that the efficiencies of subsequent processes that turn electrical energy into chemical energy (i.e., for example, to split water into H₂ and O₂ gases by using alkaline electrolyzers, and to reduce CO₂ gas into CO in electrochemical cells using electricity derived from sunlight) are also limited. To avoid these problems, it is necessary to develop alternative safe solar panels while improving the efficiency of electricity generation from sunlight, and to completely stop the global warming effect caused by the heat released by the SPVC solar panels deployed today. For this purpose, a new type of solar panels called "*Semiconductor and Liquid Assisted Photothermal Effect (SLAPE)*" solar panels have been introduced recently [46]. A digital photograph and its schematic representation of a custom-manufactured SLAPE solar panel are shown in Figure 1 (a) & (b), respectively, and a flow diagram showing the electricity generation from SLAPE solar panels with the help of a heat engine and electric generator is shown in Figure 2 [46]. In these later SLAPE solar panels, a semiconductor material such as, *silicon photovoltaic (SPV)* cell along with a stable organic solvent (i.e., non-working fluid (NWF)) such as, γ -butyrolactone, with an electrochemical stability window of about 7 volts are employed to capture the sunlight, and to convert it into both AC and DC electricity while producing hot-water with the help of a heat exchanger. When SPV cells are connected in series, sealed in between two layers of EVA sheets, employed in the top-chamber of an SLAPE solar panel by fully immersing inside NWF (γ -butyrolactone), and exposed to the sunlight, these SPV cells generate about 20% DC electricity exactly similar to the one generated by the conventional SPVC solar panels along with 30% heat energy out of the absorbed sunlight [46]. In the case of conventional SPVC solar panels, this 30% heat energy is released into the atmosphere, which causes a million times higher global warming when compared with the one that could be caused by the equivalent CO₂ gas present in the atmosphere. In the case of SLAPE solar panels, this 30% heat energy is not released into the atmosphere but captured into NWF (γ -butyrolactone). This *in situ*-generated heat energy is then collected into another low-boiling-point organic solvent termed the working fluid (WF). The chosen WF to establish the Proof of Concept (PoC) was dichloromethane (DCM), whose boiling point is 40°C. The heat present in NWF (γ -butyrolactone) is transferred to WF (DCM) present in a copper tube conduit made of 3/8 inch diameter (ϕ) tube

through a thin copper sheet (~ 0.2 mm, i.e., 200 microns) that separates the top-chamber from the bottom chamber, as shown in Figure 1 (b) [46]. Once the required amount of pressure is generated in WF (DCM) (Video S2) as it can be monitored by seeing at the pressure raised in the pressure gauge (Figure 3) attached to the copper tube conduit, it is then passed on to an heat engine such as, a reciprocally moved steam engine (RMSE) (Figure 4) to turn the heat energy into a rotational mechanical energy [46]. Then, the generated rotational mechanical energy can be turned into electricity with the help of any alternator (Figure 5) attached to the RMSE that works according to the principle of *electromagnetic induction* (i.e., by using *Faraday* and *Lenz* laws) [46].



- (1) Flat glass vacuum chamber to transmit sunlight but to avoid heat loss as Dewar flask
- (2) γ -Butyrolactone to capture sunlight and turn it into heat energy (non-working fluid)
- (3) Silicon photovoltaic (SPV) cell (semiconductor)
- (4) 0.2 mm Cu sheet for high heat transfer from top chamber to WF in Cu tube conduit
- (5) Working fluid (WF) in Cu tube conduit present in bottom chamber
- (6) PUF thermal insulation to completely avoid heat loss from bottom chamber
- (7) Working fluid (WF) inlet
- (8) Working fluid (WF) vapor outlet with require pressure to rotate steam engine (ORC)

Figure 1 (a) A custom-manufactured SLAPE solar panel with about one square meter area, and (b) its schematic representation [46].



* SLAPE – Semiconductor and liquid assisted photothermal effect
ORC – organic Rankine cycle

Figure 2 Generation of both DC and AC electricity by using SLAPE solar panels with construction shown in Figure 1, with the help of a heat engine and an electric generator [46].



Figure 3 A pressure gauge connected to a manifold of a copper tube conduit attached to the SLAPE solar panel showing *in situ* generated pressure out of dichloromethane working fluid (WF) upon exposure to the natural sunlight between 9 am and 1 pm on 29th March 2022 [46].



Figure 4 A reciprocally moved steam engine (i.e., a heat engine) along with a pressure gauge, electric generator (DC electricity generating device), and an LED bulb attached to an SLAPE solar panel exposed to natural sunlight [46].

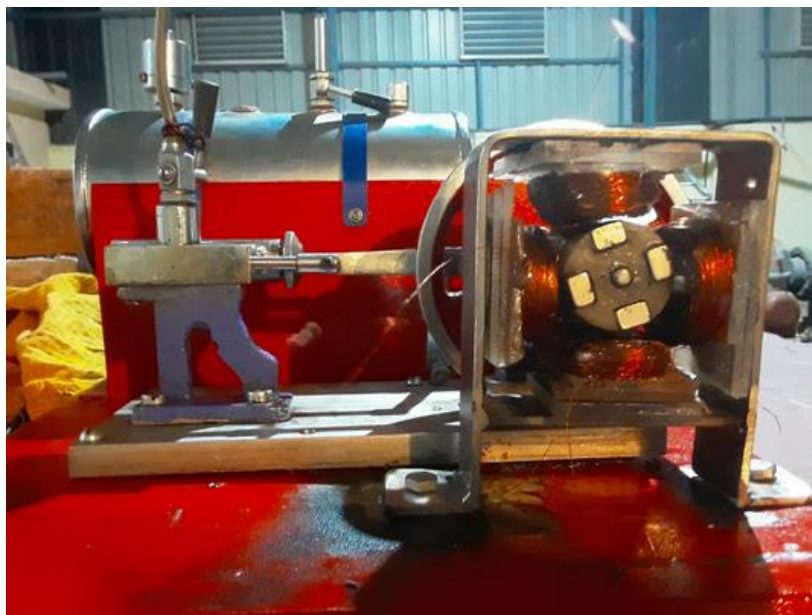


Figure 5 A custom-manufactured electric generator with four numbers of copper coils and four numbers of $\text{Nd}_2\text{Fe}_{14}\text{B}$ super-strong magnets with dimensions of $50 \times 10 \times 7$ mm fixed onto a nylon rod that sat on a shaft of the reciprocally moved steam engine (RMSE) [46].

It is a known fact that Si semiconductor present in SPV cells captures sunlight with wavelengths only in the range of 290 nm to 1137 nm (i.e., about 70% of the sunlight reaching the earth's surface). It does not capture the sunlight with wavelengths in the range of 1137 nm to 2400 nm (i.e., about 30% of the sunlight) owing to its band-gap energy of ~ 1.1 eV [46]. Out of the absorbed 70% sunlight, $\sim 20\%$ sunlight is converted into DC electricity due to the *photoelectric* (i.e., *photovoltaic*) effect, and $>30\%$ sunlight is converted into heat energy due to the *photothermal effect* and according to the *Joule heating effect*. When the SPV cells are connected in series, sealed between two layers of EVA sheet, and placed inside the top chamber of the SLAPE solar panel by fully immersing them in NWF (γ -butyrolactone) (Figure 1 (a)), the 30% heat energy generated by them is captured by this γ -butyrolactone [46]. Not only the 30% heat energy *in situ* generated by SPV cells out of the absorbed sunlight, but also 30% sunlight reaching the earth's surface in the wavelength range of 1137 nm to 2400 nm with energy lower than the band-gap energy of Si semiconductor (<1.1 eV) is also captured by this γ -butyrolactone. That means this NWF (γ -butyrolactone) present in the top chamber of the SLAPE solar panel holds heat energy formed out of $\sim 60\%$ sunlight that falls on the top surface of the SLAPE solar panel. This heat energy is then collected into a WF (DCM), thereby generating enough pressure inside the copper tube conduit to rotate an attached heat engine, such as RMSE, Oscillating steam engine, or micro-turbine, etc., to generate AC electricity with the help of an alternator (Figure 2) [46]. The WF coming out of the heat engine passes through a heat exchanger to generate hot water, which can be used for any practical purposes, while cooling itself.

Although, at present, the cost of SLAPE solar panels will be higher than that of conventional SPVC solar panels to generate a unit amount of electricity, this higher cost is compensated by nullifying the complete social cost of silicon caused by today deployed SPVC solar panels, which is a million times higher than that of the social cost of carbon (~ 185 US\$ today). Furthermore, today, the amount of sunlight converted into beneficial electricity by conventional SPVC solar panels is only about 20%. When it is a bifacial SPVC solar panel, then its efficiency will increase to a maximum of about 25%. On the other hand, the SLAPE solar panels not only arrest the increase of global warming by the heat generated by SPVC solar panels but also provide electricity up to 30% efficiency in terms of both AC and DC, and about 30-40% efficiency in terms of hot water. That means SLAPE solar panels can turn $\sim 70\%$ of the sunlight reaching the earth's surface into beneficial electricity and hot water. In contrast, conventional SPVC solar panels can convert only a maximum of $\sim 25\%$.

To establish the Proof of Concept (PoC) of SLAPE, about a one square meter area solar panel was fabricated by using 21 SPV cells ($15.7 \text{ cm} \times 15.7 \text{ cm} \times <0.25 \text{ mm}$) (Figure 1 (a)), whose fabrication details are reported elsewhere [46]. By employing this custom-manufactured SLAPE solar panel, about 17 V electricity was generated by exposing it to the natural sunlight having a power density of about 80 mW/cm^2 and an RT of about $28\text{--}32^\circ\text{C}$ on that day while experimenting by using a laboratory model RMSE (purchased in the open market in India), and a custom-manufactured electric generator. The whole system working can be seen in Video S3 [46].

The experiments needed to fully develop the SLAPE solar panels to deploy them in place of the conventional SPVC solar panels are as follows: i) Development a perfect and adiabatic insulation to altogether avoid the *in situ* generated heat loss into the atmosphere as at present there is a lot of heat loss occurring continuously into the atmosphere from all side of the SLAPE solar panel (Video S1) [46]. The heat loss from the top surface of the SLAPE solar panel can be arrested by employing

a suitably designed and fabricated flat glass vacuum chamber made of solar glass sheets, and the bottom side heat loss can be reduced by placing a heat insulation made of polyurethane foam (PUF) with a thickness of about three inches. These two chambers are separated by a copper sheet 0.2 mm thick. ii) Modification of RMSE, an oscillating steam engine or a mini turbine to increase the efficiency of the process that turns heat energy into rotational mechanical energy, and iii) Design and choosing of a proper alternator for achieving higher efficiency to turn rotational mechanical energy into electricity. Apart from these, i) the collection of DC electricity generated by SPV cells connected in series and encapsulated between the two layers of EVA sheets, ii) proper design of a heat exchanger connected between the outlet of the heat engine and the inlet of the copper tube conduit to collect maximum heat energy in the form of hot water. By making these improvements, the best efficiency of SLAPE solar panels in terms of both DC and AC electricity, along with hot-water generation, can be achieved while completely stopping the global warming effect caused by the heat released by the conventional SPVC solar panels deployed today across the globe.

In fact, the properly developed SLAPE solar panels not only solve the problems related to the million times higher global warming effect caused by heat generated by SPVC solar panels, but also problems related to the *Urban Heat Island (UHI)* effect. The various contributions to the occurrence of UHI and its impact on the top ten cities in today's world are presented in Figure 6 and Table 2, respectively [72]. As can be seen from the data of this latter table, UHI is showing a very severe adverse effects on the lives of human society, hence, it shall be avoided by developing suitable technologies such as, by deploying SLAPE solar panels on the roof top of every home thereby this UHI effect can be reduced mainly by producing required electricity and hot water that can be used for many purposes [44-48]. The main difference between an urban area (Figure 7 showing a satellite image of how densely the Delhi city area in India is covered with concrete buildings [73]) and a forest area is the conversion of the percentage of received sunlight heat energy. Since most of the land in urban areas is covered by concrete buildings and roads, they do not store any sunlight in the form of carbohydrates by using CO₂ and water as energy storage materials at a rate of 0.2% efficiency. But this sunlight storage in the form of carbohydrates occurs in the forest areas due to the presence of trees. The equivalent sunlight stored in the form of carbohydrates by trees in forest areas actually causes a UHI effect in urban areas, as there is no sunlight storage due to the absence of NP. Whereas, in the case of the infrared portion of the sunlight in both areas, it causes only evaporation of the water. In the case of forests, the infrared portion of the sunlight causes evaporation of water by a process called "*transpiration*", in which the roots of the trees suck water from the ground and evaporate through pores present in the leaves. Since this process is absent in the case of concrete buildings and roads, the infrared portion of the sunlight causes an increase in ambient temperature, which travels in the form of heat waves to places where water bodies, such as ponds, lakes, rivers, oceans, forests, etc., are present to cause water evaporation. By deploying properly developed SLAPE solar panels on every building in urban areas, 50 times more sunlight can be captured than the sunlight captured by the trees present in forest areas. That captured sunlight can be converted into electricity. That means SLAPE solar panels turn 50 times lower sunlight into waste heat energy that is released into the atmosphere than the one turned by trees present in forest areas [44-48]. Since SLAPE solar panels work exactly like trees in terms of sunlight absorption and their utilization, by deploying them on the rooftop of each and every house, the entire city or urban area can be turned into an artificial

forest that works exactly like a natural forest. As of now, it is the only way available to arrest the UHI effect. In view of this, the complete development of SLAPE solar panels to replace entire SPVC solar panels as well as to stop the UHI effect is urgently needed to save billions of dollars in wealth loss and to stop the complete depletion of important crude oil resources as they are burning today to meet energy needs [44-48].

Table 2 Top ten cities in present world facing severe Urban Heat Island (UHI) effect and their consequences.

Rank	City	Country	City population (in millions)	Current UHI intensity (°C)	UHI risk areas by population
1.	Delhi	India	~33	+6–10	Lethal wet bulb temperature; 30% lack AC; water shortages
2.	Mumbai	India	~25	+4–8	Slums (60% population); blackouts; humidity
3.	Cairo	Egypt	~22	+6–10	90% concrete; no nighttime cooling
4.	Jakarta	Indonesia	~11	+4–7	Sinking city; green space loss
5.	Karachi	Pakistan	~10	+5–9	Recurrent heat deaths; weak grids
6.	Lagos	Nigeria	~9	+5–9	Costal humidity; slums; no cooling access
7.	Houston	USA	~7.5	+5–9	Sprawl; industrial zones; humidity
8.	Bagdad	Iraq	~7	+7–11	Power outages; 50°C summer
9.	Riyadh	Saudi Arabia	~7	+6–10	100% AC dependency; desert heat
10.	Phoenix	USA	~5	+8–12	Extreme dry heat; grid failures

Figure 6 Various sources of urban heating that are causing Urban Heat Island (UHI) effect.

Figure 7 A satellite image of Delhi city, India, showing the area covered with concrete buildings [73].

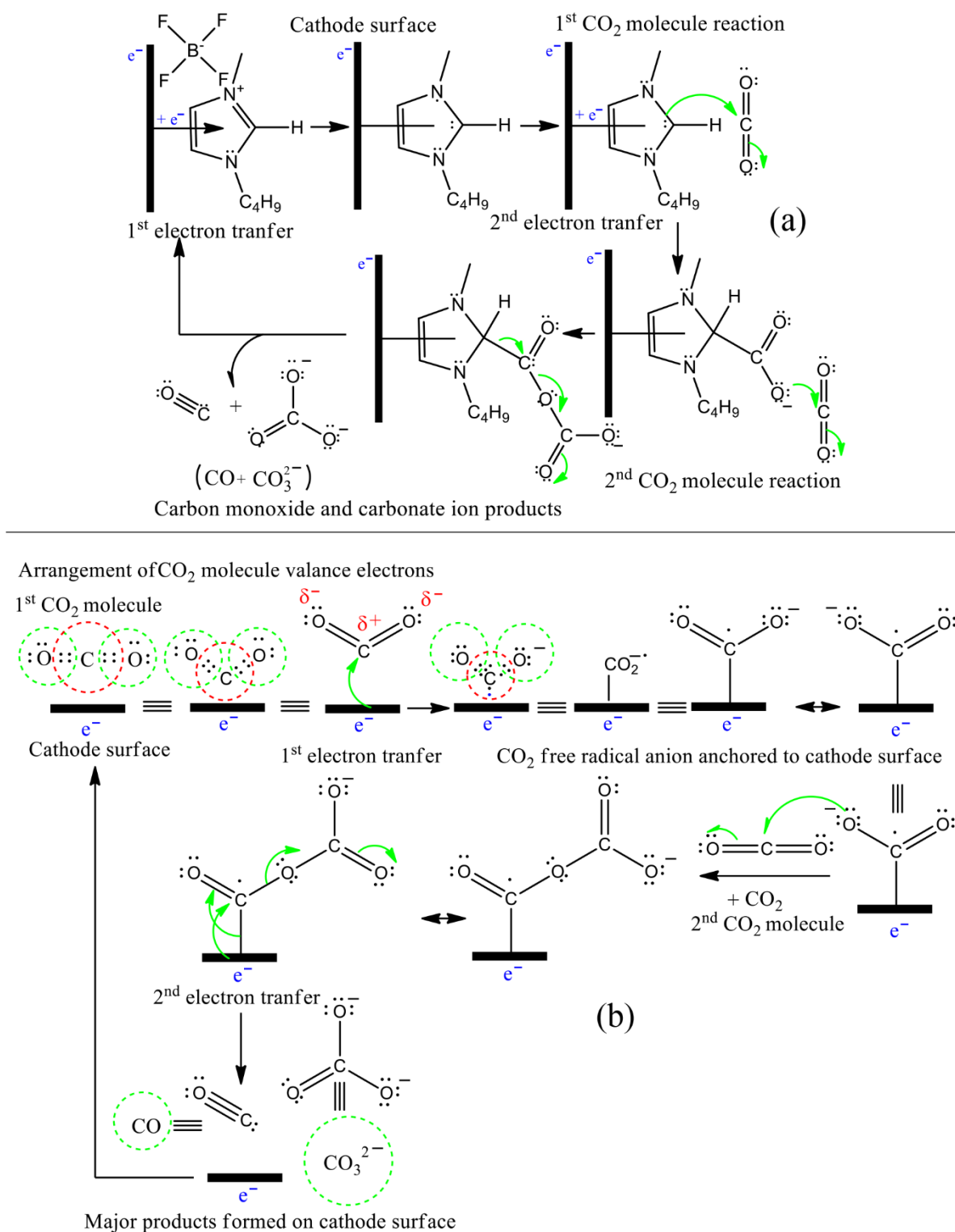
Today, one of the best and safest ways of storing large-scale electricity derived from sunlight by using solar panels can be an electrochemical CO₂ reduction (ECR) to CO while beneficially

contributing to the environment [44, 45, 70, 71]. Although, there are several routes available today to reduce CO₂ to fuel chemicals such as, thermochemical, photochemical, photoelectrochemical (PEC), photocatalysis, plasma-chemical, bio-chemical, electrochemical, etc., out of all these methods, only electrochemical routes have been found to be best in providing required rates of reaction (i.e., attaining desired current densities), product yield and selectivity (i.e., energy efficiency (EE) and Faradaic efficiency (FE)), etc., suitable for practicing at industry with economic viability [44, 45, 70, 71]. In this electrochemical route, either CO₂ gas alone or in combination with water can be utilized to store electricity in the form of fuel chemicals. In fact, this is the route suggested by Mother Nature to store any amount of energy in the form of easily dispatchable and easily storable chemical fuels with required energy densities while beneficially contributing to the environment [44, 45, 70, 71]. In fact, when solar fuels (i.e., methanol, ethanol, formic acid, diesel, gasoline, etc.,) are produced by using CO₂ and water and electricity derived from sunlight to drive this energy consuming reaction (i.e., a non-spontaneous thermodynamically up-hill reaction for which the Gibbs energy (ΔG) is positive), they can be employed in the present existing energy distribution infrastructure (i.e., in internal combustion (IC) engines) in place of petrol and diesel so that there would not be any severe economic consequences while transforming from fossil fuel energy dependency to non-fossil fuel, renewable or solar energy dependency [44, 45, 70, 71]. The CO gas produced out of CO₂ gas by using electricity derived from sunlight can be made to react with H₂ gas formed out of water in an alkaline electrolyzer to form methanol by following a well-established industrial process, and this methanol can be converted into gasoline (i.e., petrol) by following the MTG (methanol-to-gasoline) route, which is also a well-established process at the thermochemical industry. Methanol can also be turned into diesel in a relatively easy process [44, 45, 70, 71].

Among various ECR reactions to form CO reported so far, only those reactions involved imidazolium-based room temperature ionic liquids (RTILs) as helper catalysts have exhibited the highest reaction rates, FE, EE, and selectivity towards CO gas [67, 68]. In fact, it is believed that ECR in the presence of imidazolium-based RTIL helper catalysts requires protons (H⁺) derived from water on the surface of the anode to reduce CO₂ to CO on the surface of cathode [67, 68]. That could be the reason why several ECR reactions performed in the presence of RTIL helper catalysts have involved aqueous anolyte solutions to facilitate water oxidation reaction (WOR) on the surface of the anode simultaneously, along with CO₂ reduction reaction that occurs on the surface of cathode. The protons (H⁺) formed out of water travel through Nafion (i.e., proton exchange membrane (PEM) or cation exchange membrane (CEM)) to reach the surface of the cathode immersed in a non-aqueous aprotic solvent-based catholyte solution to react with CO₂ gas to form CO gas. In this latter reaction, the involvement of an expensive Nafion membrane is a must, and the simultaneously occurring competitive hydrogen evolution reaction (HER) on the surface of the cathode not only reduces the EE of the reaction but also increases the cost of the process.

Of late, it was found that even in the presence of protons (H⁺), the imidazolium-based RTIL helper catalyst-mediated ECR to CO reaction does not involve protons (H⁺) in the reduction process, and this reaction takes place as per Scheme 1 [68]. The advantages of this process are not only the complete elimination of water from the ECR reaction, which in turn eliminates expensive Nafion membrane but also the competitive HER, making the process not only energetically efficient but also an economic one. This is due to the fact that this reaction avoids wastage of about 33% energy in the formation of water byproduct that occurs during methanol formation in

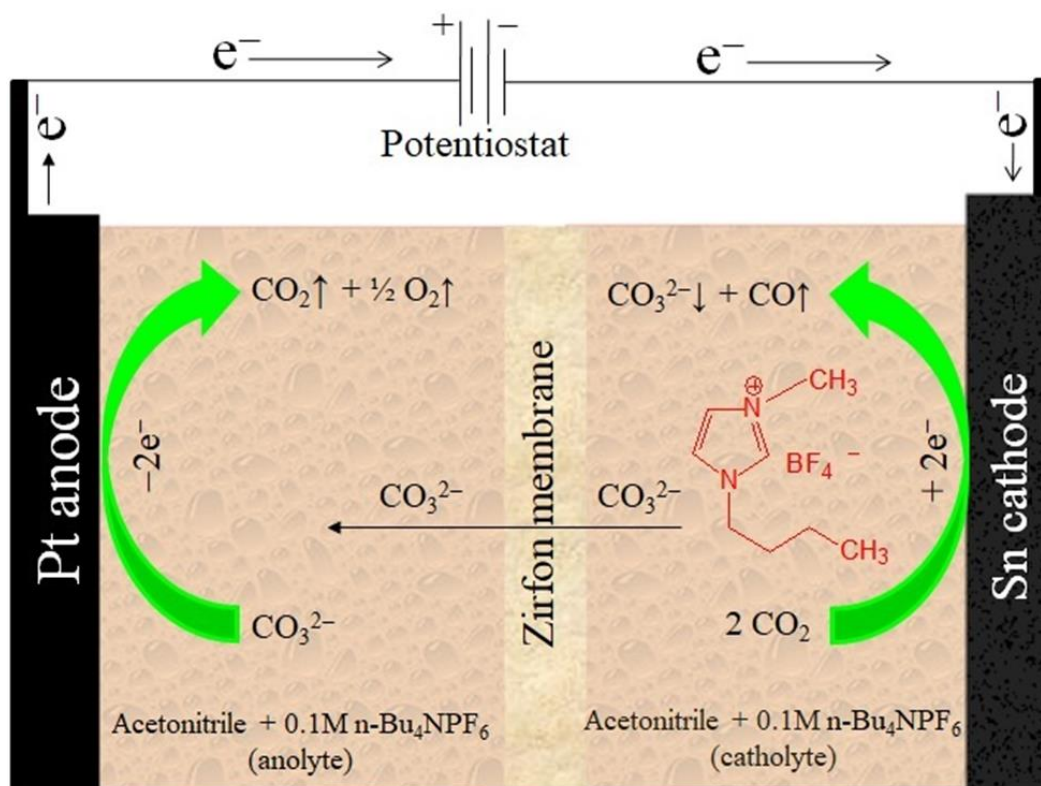
the hydrogenation CO_2 (a thermochemical reaction) ($\text{CO}_2 + 3\text{H}_2 \rightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O}$), and facilitates achieving 100% atom economy ($\text{CO}_2 \rightarrow \text{CO} + \frac{1}{2}\text{O}_2$; $2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2$; and $\text{CO} + 2\text{H}_2 \rightarrow \text{CH}_3\text{OH}$). This reaction is, in fact, a reverse reaction of CO oxidation in air (i.e., electrochemical CO_2 disproportionation reaction). When the ECR to CO reaction was performed over tin (Sn) metal cathode immersed in a catholyte solution made of acetonitrile (MeCN) plus 0.1 M tetrabutylammonium hexafluorophosphate ($n\text{-Bu}_4\text{NPF}_6$) supporting electrolyte and 1-butyl-3-methylimidazolium tetrafluoroborate (bmim-BF_4) RTIL as helper catalyst that was separated by a nafion membrane (i.e., PEM) from aqueous based anolyte solution of sodium phosphate buffer ($\text{pH} = 7.4$) containing 0.5 mM Co^{2+} ions to *in situ* form Nocera catalyst on the surface of platinum anode during controlled potential bulk electrolysis (CPBE) process as reported elsewhere [68], the formation of NaHCO_3 along with CO gas in 1:1 molar ratio was noted in the cathodic compartment. The CO gas was collected from the headspace area, whereas the NaHCO_3 white precipitate was collected from the catholyte solution. The formation of NaHCO_3 in a 1:1 molar ratio with CO gas confirms that it is indeed an electrochemical CO_2 disproportionate reaction. In fact, the carbonate ion molecule that forms on the surface of the cathode during CPBE shall travel from the cathodic compartment to the anodic compartment and shall decompose into CO_2 and $\frac{1}{2}\text{O}_2$ gases on the surface of the anode at appropriate applied reaction potentials. Since these carbonate ions cannot travel through the Nafion membrane, they reacted with Na^+ and H^+ , which travelled from the anodic compartment to the cathodic compartment to form NaHCO_3 either on the surface of the cathode or in the catholyte solution. In order to avoid the conversion of one CO_2 molecule out of every two CO_2 molecules into NaHCO_3 during ECR reaction, suitable reaction conditions and suitable anodic materials have to be established.



Scheme 1 A schematic diagram showing the mechanism of CO formation in electrochemical CO₂ reduction (ECR) reaction in the absence of any protons (H⁺) with (a) and without (b) the presence of imidazolium-based RTIL helper catalyst [68].

Furthermore, to confirm this reaction mechanism, an electrolysis experiment was also conducted by using a system that does not contain any moisture, hence, an expensive Nafion membrane as per the reaction mechanism shown in Scheme 2 [68]. In this latter experiment, a porous Zirfon membrane available in the market was employed to separate the anodic

compartment from the cathodic compartment containing both anolyte and catholyte solutions made of only non-aqueous aprotic solvent, MeCN. In this latter experiment, the CO_2 gas was reduced to CO with >98% selectivity (confirmed by conducting an experiment with $^{13}\text{CO}_2$ isotopic gas) at a current density of $\sim 120 \text{ mA/cm}^2$ over Sn cathode at a reduction potential of -1.452 V vs. NHE (i.e., at a overpotential of only 120 mV) when the catholyte solution containing $\sim 50 \text{ mM}$ bmim- BF_4 but no protons (H^+) derived from water was saturated and purged continuously with CO_2 [68]. However, no formation of traceable O_2 gas in the headspace area of the anodic compartment was noted. It raises doubt about the decomposition of carbonate ions (CO_3^{2-}) on the surface of the anode. Furthermore, a gradual formation of imidazolium cations attached to a carbonate solid complex was also noted in the catholyte solution with the progress of the CPBE process (confirmed by NMR spectral analysis). In addition to these, the zirfon porous membrane was also found to be not stable in MeCN-based electrolyte solution for more than 7-hour period during CPBE, as it became very soft and lost its strength. That means not only suitable reaction conditions for anodic reaction to be established, but also a suitable membrane to perform ECR to CO formation in completely water-free conditions over a Sn cathode in the presence of imidazolium-based RTILs also needs to be developed.



Scheme 2 A schematic diagram showing electrochemical CO_2 reduction (ECR) to CO formation in aqueous free environment [68].

5. Development of Inexpensive Alkaline Electrolyzers

Development of very inexpensive and highly efficient alkaline electrolyzers to split water into H_2 and O_2 gases is very important to harvest sunlight at every home to meet all the energy needs of society without depending on fossil fuels that generate greenhouse CO_2 gas as byproduct [58-

60, 71]. Water is also one of the best energy storage materials, as suggested by Mother Nature, to store any amount of energy, precisely similar to the one stored by using CO_2 gas. Among the different types of electrolyzers developed so far, the alkaline ones are most economical and durable. In fact, before 1970, before the invention of the *steam reforming of methane (SRM)* process, entire commercial H_2 gas used to be obtained from water electrolysis in alkaline electrolyzers only, which used to be operated continuously for periods up to 10 years (i.e., from 60,000 to 90,000 hours) [44, 45, 58-60, 71]. Stacks employed in these alkaline electrolyzers are needed to be maintained after every 10 years of operation. However, the major problem with those commercial alkaline electrolyzers was the usage of asbestos porous membrane, which is carcinogenic in nature, employed to separate the anodic compartment from the cathodic compartment to avoid intermixing of H_2 and O_2 gases on the surfaces of electrodes, where they can undergo explosion. Due to the carcinogenic nature of asbestos, it was banned from usage in subsequent years. Furthermore, the usage of alkaline electrolyzers to produce commercial hydrogen gas was also stopped after the invention of an inexpensive alternative SRM process. Even now, there is little demand for hydrogen gas in society. At present, the major usage of H_2 gas is for the synthesis of ammonia, which is a starting material to synthesize urea, one of the most important fertilizers employed today. When quite inexpensive and durable alkaline electrolyzers are realized, then all the H_2 utilized for ammonia synthesis can be obtained from water electrolysis using electricity derived from sunlight using solar panels, since the SRM process generates about 11 tons of CO_2 gas for every ton of H_2 gas produced [44, 45, 58-60, 71]. This latter CO_2 gas generation can be avoided by generating H_2 gas from water in alkaline electrolyzers. The real boom for the H_2 production from water by using the alkaline electrolyzers comes to store large-scale electricity generated from sunlight by using solar panels, only when ultra-low cost alkaline fuel cells (AFCs) are also developed [74-76]. In that case, at every home, solar panels can be deployed to generate the required amount of electricity to meet all the energy needs of society as well as of every home, as it can be stored economically by using inexpensive alkaline electrolyzers, and regenerated as and when required on a demand basis to get electricity RTC without any interruption by using AFCs. Otherwise, storing electricity by using water splitting into green or yellow hydrogen is of not much useful.

A substitute porous membrane, namely, Zirfon[®] (a composite of zirconia powder and polysulfone organic polymer), manufactured by M/s. Agfa, Belgium, has been developed to replace asbestos in alkaline electrolyzers [58-60, 71]. However, the cost of this commercial zircon porous membrane is about 200 US\$ per square meter today [71]. The alkaline electrolyzers involve inexpensive base metals such as nickel (as both electrode as well as bipolar plate), iron (steel) and cobalt as electrodes, whose cost is about a thousand times lower than that of precious metals; platinum and palladium electrodes/catalysts, which are employed in PEM based electrolyzers [44, 45, 58-60, 71]. Nickel is a preferred bipolar plate metal for alkaline electrolyzers as it is electrically more conductive and quite stable against alkaline electrolytes containing KOH or NaOH. The precious metal-based catalysts and electrodes are compulsory to be employed in PEM-based electrolyzers as these electrolyzers use acidic electrolyte in which base metal-based electrodes and catalysts cannot survive. Although the efficiency of PEM-based electrolyzers is higher than that of alkaline electrolyzers, their cost is very high when compared with the latter ones, as they involve platinum and palladium as electrodes and catalysts [44, 45, 58-60, 71]. Furthermore, PEM electrolyzers involve quite expensive Nafion as a membrane to separate anodic

and cathodic compartments, whose cost is about 500 US\$ per square meter. However, the bipolar plates made of highly electrically conductive dense graphite employed in PEM electrolyzers are less expensive than those of nickel bipolar plates employed in alkaline electrolyzers. However, when compared with nickel metal, whose manufacturing process cost is a bit expensive, the corrosion resistance of graphite in an acidic environment is poor, and it is quite brittle in nature. Since, at present, the major cost is decided by the cost of expensive zircon membrane, an inexpensive alternative porous membrane to replace these zircon porous membranes is needed [44, 45, 58-60, 71].

Recently, ultra-low cost polypropylene (PP) web-reinforced EPDM rubber-ZrO₂ composite porous membranes were introduced to replace the expensive zircon (ZrO₂ + polysulfone composite) membranes for alkaline electrolyzers [44, 45, 71]. The difference between these two porous membranes is the organic polymer material that holds ZrO₂ powder particles in the porous membranes. In the case of zircon membrane, polysulfone holds the ZrO₂ particles, whereas, in EPDM rubber based porous membrane, EPDM rubber holds the ZrO₂ powder particles. In the case of the Zircon membrane, the strength is provided by the polysulfone cloth, whereas in the case of the EPDM rubber-based membrane, the PP cloth provides the strength against tearing due to the very thin porous membranes. Without the polymer cloth web reinforcement, these porous membranes cannot withstand the pressure generated inside the alkaline electrolyzer stack during operation. The remaining chemical composition is the same in both membranes. In these porous membranes, the role of both polysulfone polymer and EPDM rubber is to hold ZrO₂ particles together in the membrane composition so that these ZrO₂ particles confer hydrophilicity to these membranes. Nevertheless, the porous creation methods in these two membranes are different. In the case of zircon, a phase inversion method is employed that confers more uniform pore diameters and pore size distribution in entire zircon membrane with relatively quite high porosity, whereas, in the case of EPDM rubber based porous membrane, porosity is created by burning out of an organic ammonium salt namely "dinitrosopentamethylenetetramine (DNPT)" blowing agent that is mixed to the rubber compound in the weight ratio of 2.66-4%, which decomposes into gases to escape from the semisolid rubber compound during vulcanization process at elevated temperatures and pressures leaving behind porosity [71]. The fabrication procedure of EPDM rubber-based porous membranes is reported previously [71]. The proto-type custom manufactured PP cloth web-reinforced EPDM rubber-ZrO₂ composite porous membranes fabricated by following usual procedure employed in the rubber industry, were evaluated for water electrolysis reaction in cyclic voltammetry (CV) experiments (Figure 8 (a) & (b)) over a Ni working electrode (WE) and a Ni counter electrode (CE) dipped in an aqueous 30 wt.% KOH solution vis-à-vis a commercial zircon membrane under identical reaction conditions, and thus obtained results are presented in Figure 9 [71]. As can be seen from these CV profiles, the obtained results in the presence of both porous membranes are absolutely similar. The microstructural characteristics of the PP cloth web-reinforced EPDM rubber-ZrO₂ porous membranes are revealed through their SEM micrographs (Figure 10) [44, 45]. However, the performance of these EPDM rubber-based porous membranes in the CPBE experiment with the required current density (>100 mA/cm²) is yet to be tested. Nevertheless, this EPDM rubber-based membrane was found to be quite stable for a six-month duration when placed inside an aqueous 30 wt.% KOH solution with respect to both physical properties and chemical stability. Furthermore, these membranes do not allow leakage of any electrolyte when they are placed in a two-

compartment electrochemical cell (Figure 8 (b)). In fact, none of the materials present in the EPDM rubber-based membrane can react with aqueous 30 wt.% KOH solution to undergo any degradation. However, the porosity characteristics and their formation in these PP cloth web-reinforced EPDM rubber-ZrO₂ porous membranes required for performing water electrolysis in aqueous 30 wt.% KOH solution with current density reaching up to a value of 300 mA/cm² are yet to be optimized by varying the amount of DNPT, and the vulcanization temperature, pressure, and duration of heat treatment so that this EPDM rubber based membrane exhibits performance exactly similar to those exhibited by zircon membrane.

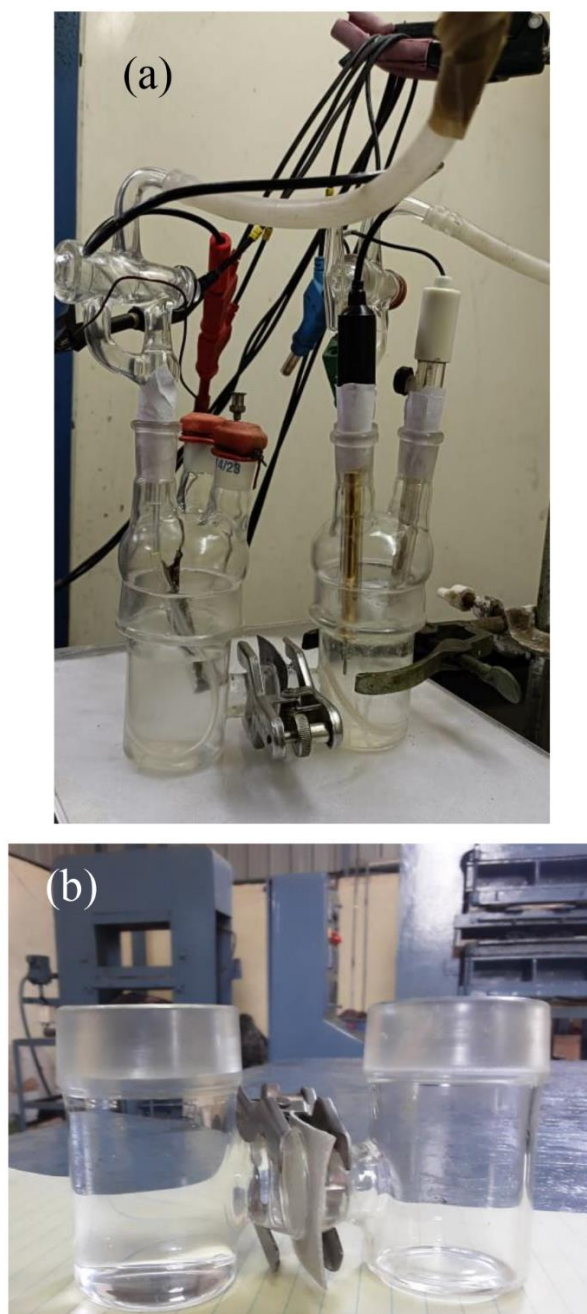


Figure 8 Digital photographs showing experimental set-up employed for conducting controlled potential bulk electrolysis (CPBE) (a) and cyclic voltammetry (CV) (b) by using the PP-cloth web-reinforced EPDM rubber-ZrO₂ composite porous membrane to split water into H₂ and O₂ gases over Ni electrodes in 30 wt.% aqueous KOH electrolyte.

(b) also revealing that the PP-cloth web-reinforced EPDM rubber-ZrO₂ composite porous membrane does not allow leakage of electrolyte from an all-glass custom-made two-compartment electrochemical cell in which one compartment was filled with 30 wt.% aqueous KOH electrolyte and the other compartment kept empty [71].

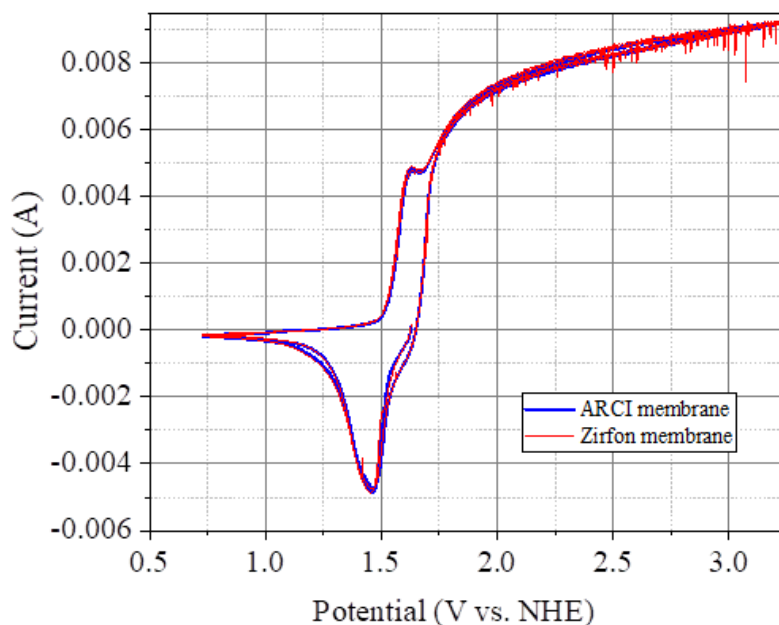


Figure 9 CV profiles recorded at a rate of 100 mV/s over Ni WE (<1 mm² area) vs. Ni CE in an all-glass gas-tight custom-made two-compartment electrochemical cell separated by either a PP cloth web-reinforced EPDM rubber-ZrO₂ composite porous membrane (~570 microns thickness) or by a commercial zirfon porous membrane in argon gas degassed 30 wt.% aqueous KOH solution (pH = 14) [71].

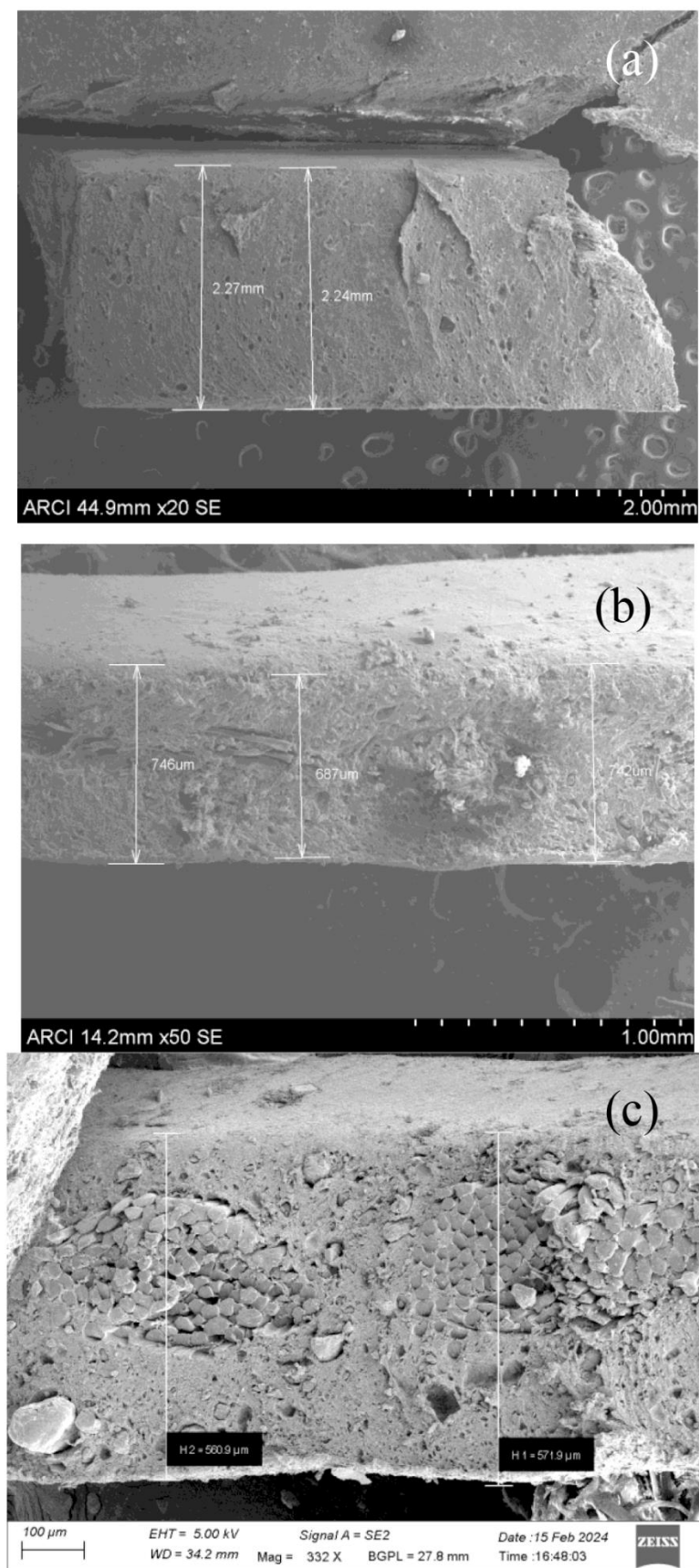


Figure 10 The SEM micrographs of the cross-sections of the PP web-reinforced EPDM rubber-ZrO₂ composite porous membranes with different thicknesses: (a) with ~2.27 mm; (b) with ~745 μm, and (c) with ~570 μm [44, 45].

6. Development of Inexpensive Alkaline Fuel Cells

Storing electricity generated from sunlight by following relatively inexpensive methods is of great importance so that electricity generated from sunlight by using solar panels can be used in the absence of sunlight (i.e., RTC) as well without any back-up from fossil fuels. At present, electricity generated by solar panels is stored either i) by pumping water into dams, ii) by using lithium-ion batteries (LIBs) such as Tesla's Powerpacks, Powerwalls, Megapacks, etc., or iii) given to the grid system. As mentioned in previous sections, these three methods are expensive. According to Mother Nature's teachings, any amount of energy can be stored by splitting water into H_2 and O_2 gases by following inexpensive alkaline electrolyzers. This electricity storage in the form of H_2 gas is more valid only when inexpensive alkaline fuel cells (AFCs) are also available [74-76]. That means without AFCs, alkaline electrolyzers are not of much useful to store electricity generated from sunlight in the form of H_2 gas by splitting water because of without AFCs, the huge amount of H_2 gas generated cannot be converted back into electricity. However, since, at present, the cost of AFCs is very expensive, the relatively inexpensive other three methods mentioned above are being utilized. Furthermore, today, to store an MWh equivalent electrical energy using Tesla Megapack, it costs around 1.24 million US\$ (i.e., INR 10,82,01,121/- or 10 crores Indian rupees). In fact, storing that much energy in such a compact area can become very dangerous if any short circuit or fire accidents occur. Since electricity cannot be stored when dams are in full capacity or overflowing, reducing the cost of fuel cells can be the best option to store large-scale produced electricity from sunlight in the form of H_2 gas by splitting water, as suggested by Mother Nature. Although today, the cost of AFCs is expensive when compared with the other methods, it shall be noted that this cost can come down quite drastically when they are manufactured in quite large numbers. For example, in the year 1975, the cost of electricity generated by using SPVC solar panels was ~115.3 US\$ per kWh, whereas today, its cost is ~0.27 US\$ per kWh. That means its price is reduced by 427 times [45]. Whenever the production becomes double, the cost of a product becomes half. When the PP web-reinforced EPDM rubber- ZrO_2 composite porous membranes are employed in the AFCs, their cost can come down to a great extent. In fact, in some of the AFC studies, the commercial zircon porous membrane was employed and found quite promising results.

7. Assumptions, Limitations, and Uncertainties of the Processes Discussed in This Article

The four processes namely i) electricity generation from sunlight, ii) electrochemical CO_2 reduction (ECR) to CO, iii) electrochemical water splitting into H_2 and O_2 gases in alkaline electrolyzers, and iv) regeneration of electricity by using H_2 and O_2 gases formed in alkaline electrolyzers by using AFCs presented and discussed in above sections are either already tested on a laboratory scale or on an industrial scale. Out of these four processes, only the ECR to CO formation process is yet to be tested on an industrial scale, although it is a well-proven process on a laboratory scale. On the other hand, the electrochemical water splitting using alkaline electrolyzers was a commercially well-practiced and well-proven process prior to 1970 to generate commercial hydrogen gas. When comes to electricity generation from sunlight by using SPVC solar panels, they are harming environment quite severely by generating a million times higher heat energy than the one that could be generated by the equivalent CO_2 gas present in the atmosphere. To avoid the global warming effect caused by the heat generated by SPVC solar panels, the SLAPE-

SPVC hybrid solar panels have to be fully designed and deployed. Although these hybrid solar panels are a bit expensive when compared with the conventional SPVC solar panels, they will be compensated for as they completely reduce the social cost of silicon. Today, the social cost of silicon is a million times higher than the social cost of carbon, which is about 185 US\$ for a ton of CO₂ gas released into the atmosphere, as per the latest information on the internet. According to a study [77], during the last decade, the unpresented heavy rains and floods have been witnessed in the central Indian region. These sudden increases in rains, floods, heat waves, and frequent forest burnings during summer periods, etc., have been attributed to the rise of atmospheric temperature and climate warming due to the heat energy released by the so far installed SPVC solar panels in thousands of km² area in India and other countries. To avoid such damage to the environment and economy of the states and of the entire world, the waste heat released from SPVC solar panels has to be captured and used for the beneficial purposes of society. That means the SLAPE-SPVC hybrid solar panels have to be developed. Along with these hybrid SLAPE-SPVC solar panels development, a method to turn gravity and water buoyancy into electricity also needed to be developed because this latter electricity can be produced RTC, hence, energy storage that is needed to store electricity produced by using solar panels can be avoided.

Today, the cost to be incurred to manufacture the alkaline electrolyzers and AFCs to store a unit amount of electricity may be quite expensive when compared with the one required to store by using LIBs or other batteries, but when these AFCs and alkaline electrolyzers are manufactured in quite large numbers at an industry scale, their manufacturing cost can come down heavily so that they can be deployed at every home across the globe as a part of harvesting sunlight to meet all the energy needs of the society at an affordable cost. This is the only way available today for human society to make energy, environment, economy, and life sustainable on Earth, and to achieve the UNO's 17 SDGs.

8. Conclusions

8.1 Remarks

The following conclusions can be drawn from the above description:

1. To achieve eight of the UNO's 17 SDGs namely; SDG-1 (*no poverty*), SDG-2 (*no hunger*), SDG-7 (*affordable and clean energy*), SDG-8 (*decent work and economic growth*), SDG-10 (*reduced inequalities*), SDG-11 (*sustainable cities and communities*), SDG-13 (*climate action*) and SDG-14 (*life below water*), the development of suitable electrochemical routes for splitting water into H₂ and O₂ gases, and to reduce CO₂ to CO with required product formation rates, energy efficiencies, faradaic efficiencies and with overpotentials as minimum as possible are required.
2. In order to harvest the solar energy safely to meet all the energy needs of the society without any back-up from fossil fuels, apart from developing suitable routes for electrochemical CO₂ reduction (ECR) to CO, and electrochemical splitting of water into H₂ and O₂ gases, the development of safe, inexpensive and affordable solar panels such as SLAPE-SPVC hybrid solar panels, and AFCs are also needed.
3. In order to realize the affordable and quite inexpensive alkaline electrolyzers to store the electricity derived from sunlight at every home by using water as a safe and abundantly available energy storage material, the complete development of ultra-low cost

polypropylene (PP) web-reinforced EPDM rubber-ZrO₂ composite porous membranes is also highly essential.

4. Among the various methods available to employ the waste-stream greenhouse CO₂ gas as energy storing material to harvest sunlight in the form of solar fuels to meet all the energy needs without any back-up from fossil fuels, ECR into CO in the presence of bmim-BF₄ RTIL helper catalyst over the surface of Sn cathode in the absence of protons (H⁺) is a must to avoid the usage of expensive nafion membrane (PEM), and to avoid the wastage of about 33% energy in the formation of water byproduct while converting CO₂ gas into methanol by following hydrogenation of CO₂ via thermochemical route on the way to produce synthetic petrol (i.e., gasoline) by following methanol-to-gasoline (MTG) process, and to achieve 100% atom economy.
5. To perform ECR reaction in the absence of protons (H⁺) derived from water to generate CO gas, ultra-low cost EPDM rubber-CaCO₃ composite porous membrane to transport carbonate ion (CO₃²⁻) from cathodic compartment to anodic compartment also needs to be developed.
6. Once all the above-mentioned methods are developed, eight of the UNO's 17 SDGs can be achieved relatively easily in the next few decades.

8.2 Recommendations

The following recommendations are made to achieve the UNO's 17 SDGs:

- i. It is a known fact that fossil fuels cannot sustain our civilization's economic growth. Hence, it is necessary to utilize renewable energy resources to meet all the energy needs of society without any backup from fossil fuels. Furthermore, fossil fuels formed over a period of geological ages out of sunlight stored at the rate of just 0.2% by using CO₂ and water as energy-storing materials to feed human beings and animals are the starting materials today for several commodity chemicals used in the day-to-day life of human society. These fossil fuels are not just to meet the energy needs of society within just a two to three-hundred-year period but to be used for several centuries to come. Hence, they need to be used very judiciously and not wasted on unnecessary purposes.
- ii. Among the seven so far identified renewable energy resources, namely; i) solar, ii) wind, iii) tide, iv) biomass, v) hydroelectricity (due to gravity), vi) geothermal and vii) nuclear energy, only sunlight has the capability to supply the required amount of energy needed by human society in the future. However, for this purpose, suitable technologies are yet to be developed. Furthermore, it is necessary to look into the practical possibilities available today to harvest sunlight to meet all the energy needs of society without any backup. Here, the things to be considered are i) available land and water bodies to deploy solar panels, ii) the efficiency at which the sunlight is turned into electricity by today available solar panels, iii) the contribution of waste heat energy generated by the present deployed SPVC solar panels to the climate change and to the global warming (i.e., negative effects of solar panels installations) occurring today, iv) methods available today to store electricity derived from sunlight to use it in the absence of sunlight (i.e., during peak hours of evenings and mornings and in the nights), etc.. Unless solar energy is stored effectively and efficiently, it is not possible to depend exclusively on it to meet all the energy needs without any backup. There are several losses associated with electricity storage in batteries.

- iii. Today, the main methods employed to store electricity derived from sunlight are i) connecting to the grid system or ii) storing in LIBs or other batteries. LIBs are quite expensive and they are yet to reach the level of storing an Exajoule (EJ) amount of energy. As far as storing electricity generated from sunlight by pumping water into dams is concerned, there are not enough dams to store the entire electricity generated today by using solar panels. For example, today, at Nagarjuna Sagar dam, Telangana state, India, by buying electricity generated using SPVC solar panel at the rate of Rs. 3/- per unit (i.e., for one kWh), water is pumped into the dam during daytime. To sell at the rate of Rs. 9/- per unit, electricity is generated again during evening and morning peak hours. With this price difference, the electrical department is running in profit in Telangana state, India. In fact, for pumping water into the dam, about 110 MW of power is consumed, and with the amount of water pumped into the dam, only 100 MW of power is generated, resulting in a net loss of 10 MW of power per turbine. Nevertheless, there is a lot of difference between the amount of electricity generated by using SPVC solar panels and the number of dams available today to store electricity in India. The number of dams available today in India cannot store all the excess electricity generated by using SPVC solar panels to use it again during the peak hours. That means without running the thermal power plants, it is not possible to depend only on electricity generated by using SPVC solar panels to meet all the energy needs. In fact, it is never going to be possible given the conditions prevalent in India. Furthermore, a dam can be used for storing electricity when it does not contain full water and when it is not overflowing. On the other hand, thermal power plants (TPPs) need to be operated 24 hours a day without any break for safety purposes. Otherwise, they cause huge losses to their operators. For example, Germany's Energiewende program has been found to be a big failure as neither of the two intended objectives could be met by investing 100 billion US\$ to deploy rooftop solar panels. The reason for failure is giving the electricity generated by using solar panels to the grid system attached to the TPPs.
- iv. Nature has stored several million gigawatt-hours of solar energy by using CO₂ and water as energy storage materials, and it suggests that any amount of energy can be stored by using CO₂ and water as energy storage materials while beneficially contributing to the environment. Hence, it is very important to realize the technologies that can use CO₂ and water as energy storage materials to store electricity derived from sunlight to meet all the energy needs of society without any backup from fossil fuels. That means suitable, safe and affordable technologies to i) convert sunlight into electricity without damaging the environment (i.e., by using safe SLAPE-SPVC hybrid solar panels, which do not add any heat into the atmosphere), ii) electrochemically reduce CO₂ gas to CO gas, iii) split water into H₂ and O₂ gases in inexpensive alkaline electrolyzers, and iv) turn the H₂ and O₂ gases formed out of water into electricity by using inexpensive AFCs to supply electricity derived from sunlight RTC without any interruption. These systems need to be developed and used in a widespread manner so that their price can reach an affordable level for the common man.
- v. If any new technology is developed to utilize gravity in conjunction with water buoyancy to generate electricity, it can supply the required amount of energy to meet all the energy needs of society without any backup from other renewable energy resources, including solar energy. Furthermore, gravity and water will be available on Earth as long as it exists.

- vi. Today, various methods being followed across the globe by almost all countries to reduce the usage of fossil fuels to meet the energy needs (i.e., by using renewable energy resources) have been found to be not sufficient to reach all the UNO's 17 SDGs. It is most unlikely that any of the UNO's 17 SDGs will be achieved before the deadline of the year 2030.
- vii. For a sustainable climate and life below water, it is required to follow the natural routes to harvest sunlight, and to deal with the excess CO₂ present in the atmosphere. Unless we find additional renewable energy resources that are omnipresent and abundantly available 24 hours a day, it is quite challenging to meet all the UNO's 17 SDGs by the end of the year 2030, even during the next few decades. Nature does not sequester CO₂ gas but the biomass.
- viii. Nature suggests using CO₂ and water as energy-storing materials instead of LIBs. LIBs are indispensable today to use in portable devices such as laptops, mobile phones, etc., but not to store an enormous amount of electrical energy generated out of sunlight to meet the energy needs of society RTC without any interruption. The usage of that much amount of LIBs will certainly damage the environment with the byproducts formed while manufacturing them and while processing lithium and other elements' ores used in LIBs. It is also not safe to keep such an amount of energy in the form of batteries in such a compact areas of Tesla Powerpacks, Powerwalls, and Megapacks.
- ix. Once, all the fossil fuels are exhausted, it will become very difficult for human society to get energy needed to meet all its energy needs as there is no way as on today to get such an amount of energy from any of the renewable energy resources available today (practically not possible). For that purpose, at every home safe solar panels have to be deployed to generate electricity from sunlight and it has to be stored in a safe and economic manner to get electricity RTC without any interruption.

Author Contribution

The author did all the research work of this study.

Competing Interests

The author has declared that no competing interests exist.

Additional Materials

The following additional materials are uploaded to the page of this paper.

1. Video S1: Video showing about 46°C temperature measured on the surface of a device containing 21 numbers of commercially available multi-crystalline SPV cells and 2 litres of γ -butyrolactone upon exposure to sunlight having a power density of $\sim 80 \text{ mW/cm}^2$ for 2-hour period at about 13:30 hours when the ambient room temperature was varied between 32°C and 34°C.

2. Video S2: Video showing the boiling of dichloromethane working fluid by absorbing the heat energy generated by SPV cells and γ -butyrolactone together out of the absorbed sunlight in a device.
3. Video S3: Video showing the generation of 16 V electricity by the heat energy generated by 21 numbers of commercially available multi-crystalline SPV cells in conjunction with 2 litres of γ -butyrolactone that was captured by dichloromethane working fluid and converted into rotational mechanical energy with the help of a reciprocally moved steam engine, and eventually electricity with the help of a custom-made electric generator containing four super strong magnets.

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