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SOLAR-POWERED VEHICLES: HARNESSING SUSTAINABLE ENERGY FOR TRANSPORTATION.

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Abstract

Solar-powered vehicles have emerged as a promising solution to address the challenges of climate change and fossil fuel dependency in the transportation sector. This research paper explores the development, benefits, and challenges associated with solar-powered vehicles. It investigates various technological advancements, design considerations, and integration strategies employed to harness solar energy for vehicle propulsion. The paper also analyzes the environmental, economic, and social implications of solar-powered vehicles, along with their potential role in shaping a sustainable transportation future. By examining current research, industry trends, and policy initiatives, this paper provides valuable insights into the progress and potential of solar-powered vehicles.

Keywords: solar energy; electrical array; photovoltaic array; photovoltaic panels; solar cells; solar energy; solar cells.

1. Introduction

In response to increasing gas emissions, air pollution, and global warming, a new and reliable renewable energy source is needed to alleviate major environmental concerns and become a sustainable alternative to burning fossil fuels. Solar energy is the fastest growing renewable energy source in the US and is projected to overtake the current, most utilized renewable energy source, hydropower, by 2030 [1]. Solar energy refers to the conversion of heat and light energy from the sun into electricity. It is considered the “cheapest electricity in history with technology cheaper than coal and gas” [2] since the sun is a free resource and converting light energy into electrical energy takes the least amount of time and power [2]. Due to the pressing needs for a renewable, carbon-free energy source, the diffusion of photovoltaic (PV) panel applications has been growing exponentially in recent years.

Although the primary use of solar power has been for producing electricity for the grid, many new applications have been emerging. These applications can range from its uses in satellites, rural electrification, solar roadways, buildings, and transportation [2]. Although solar power has its issues, such as potential environmental degradation, habitat loss, excess water use, and limited storage sites for sun energy, new advances in technology are showing promise in overcoming these challenges.

Solar-powered vehicles (SPVs) are vehicles that are powered by energy derived from solar panels that convert sunlight into electrical energy. The use of SPVs is gaining increasing attention due to their potential to reduce the dependence on fossil fuels and the negative impacts of transportation on the environment. This literature review summarizes recent research on solar-powered vehicles.

One of the primary benefits of SPVs is their potential to reduce greenhouse gas emissions. The transportation sector is responsible for a significant portion of global greenhouse gas emissions, and SPVs have the potential to mitigate these emissions by providing a clean and renewable source of energy. A study conducted by Khatib et al. (2021) compared the environmental impact of electric vehicles (EVs) and SPVs and found that SPVs had a lower environmental impact than EVs.

The efficiency of solar panels is a key factor that determines the performance of SPVs. Recent research has focused on improving the efficiency of solar panels to increase the range and speed of SPVs. A study by Rathi et al. (2021) proposed a new design for solar panels that used micro-optical structures to increase the efficiency of the panels. The results of the study showed that the proposed design could increase the efficiency of solar panels by up to 40%.

The integration of solar panels into the design of vehicles is another area of active research. One approach is to use flexible solar panels that can be integrated into the body of the vehicle. A study by Islam et al. (2021) proposed a design for a solar-powered electric car that used flexible solar panels on the roof and sides of the car. The results of the study showed that the car could travel up to 35 km per day on solar power alone.

Another approach is to use solar panels to charge the batteries of hybrid electric vehicles (HEVs). A study by Alquthami et al. (2021) proposed a design for an HEV that used a combination of solar panels and a gasoline engine to charge the batteries. The results of the study showed that the HEV had a higher fuel efficiency and lower emissions than a conventional gasoline-powered vehicle.

The use of SPVs in public transportation is another area of active research. A study by Sahu et al. (2021) proposed a design for a solar-powered electric bus that used a combination of solar panels and a battery system to power the bus. The results of the study showed that the bus had a range of up to 200 km on a single charge and could reduce emissions by up to 80% compared to a conventional diesel-powered bus.

In conclusion, SPVs have the potential to provide a clean and renewable source of energy for transportation. Recent research has focused on improving the efficiency of solar panels, integrating solar panels into the design of vehicles, and using SPVs in public transportation. However, there are still challenges that need to be addressed, such as the high cost of solar panels and the limited range of SPVs. Further research is needed to overcome these challenges and fully realize the potential of SPVs. Solar-powered vehicles (SPVs) are electric vehicles that are powered by energy obtained from the sun through solar panels. They have gained a lot of attention in recent years due to their potential to reduce carbon emissions and dependence on fossil fuels. This review article aims to discuss the various aspects of solar-powered vehicles, including their history, design, efficiency, and future prospects.

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2. Solar Energy Conversion Technologies

The energy that is naturally available from the solar source is quite enormous. The sun delivers 1.2 x 105 TW of radiative power onto the Earth, the amount that surpasses any other energy resource by capacity and availability. That would convert to 3.78 x 1012 TJ of energy per year. For comparison, according to Crabtree and Lewis (2007), all recoverable Earth's oil reserves (~3 trillion barrels) account for 1.7 x 1010 TJ of energy. Thus, the sun supplies this amount of energy to the Earth in only ~1.6 days!

A few more stats:

According to reviews of the University of Oxford, the current global energy utilization is close to 1.6 x 105 TWh per year (i.e. 5.76 x 108 TJ/year). If we again compare this amount to the global solar energy flux, the Sun is able to cover this demand in only 1 hour and 20 min! It is sort of mind blowing.

However, to be utilized, solar radiation needs to be converted into other forms of energy, such as electricity or usable heat. The question is: can we effectively do that at the scale of our demands?

Apparently, the solar resource contains enough energy to cover those demands. However, the critical limitations in solar energy conversion will be the efficiency of existing technologies and their overall capacity to produce power sustainably.

Before considering various types of conversion of solar energy, let us briefly review what solar radiation actually is. Here are a few main things we know from physics:

- Solar energy is electromagnetic radiation.
- Main components of solar radiation reaching the Earth (wavelength, λ, range given in parenthesis):
  - Infrared (52 – 55% $\lambda > 700$ nm)
  - Visible (42-43% $400 < \lambda < 700$ nm)
  - Ultraviolet (3-5% $100 < \lambda < 400$ nm) – (see Figure 1)
- Solar radiation near the earth surface is essentially in the range λ 290 – 2500 nm.
- Quantum (unit energy) of electromagnetic radiation - photon ($E = hv$) - is often a more convenient term in the mechanism of solar conversion.

The solar radiation reaching the earth's surface predominantly consists of infrared (52-55%), visible (42-43%), and ultraviolet (3-5%) radiation (see Figure 1), covering the wavelength range from ~ 290 nm to 2.5 μm [2], as shown with the orange shaded area in the diagram.

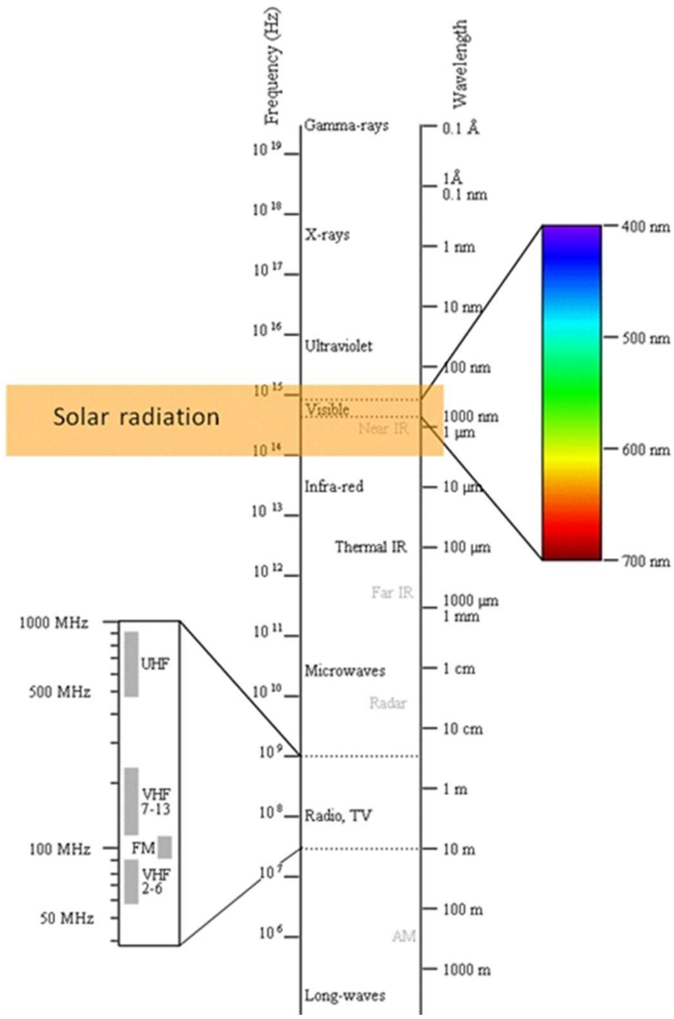

Figure 1. Electromagnetic spectrum showing different types of radiation versus wavelength and frequency scales.

This mix of various types of electromagnetic radiation allows the sunlight to be converted through a variety of physical mechanisms, which are:

- Direct conversion to electricity (through photovoltaic effect).
- Conversion to usable heat (for example, via thermal collectors).
- Conversion to matter / fuel (for example, production of biomass through photosynthesis).

3. Integration of Solar Power in Vehicles

Vehicle-integrated Photovoltaics (VIPV) designates the mechanical (see Figure 2), electrical, and design-technical integration of photovoltaic modules into vehicles. The PV modules blend seamlessly into the vehicle exterior and are connected to electric loads or the drive battery in electric vehicles. Simultaneously, the PV modules replace other components of the vehicle, e.g., the roof or the bonnet. VIPV increases the mileage of electrically powered vehicles and improves their CO_2 balance (see Figure 3). The aesthetic expectations on integration into the vehicle design are especially high for cars. For utility vehicles (e.g., trucks and buses), particularly lightweight

PV modules are needed to avoid restricting the load capacity. Further application areas include caravans and mobile homes, delivery bicycles, trams, trains, ships, aircraft, and drones.

Figure 2. Vehicle-integrated Photovoltaics (VIPV)

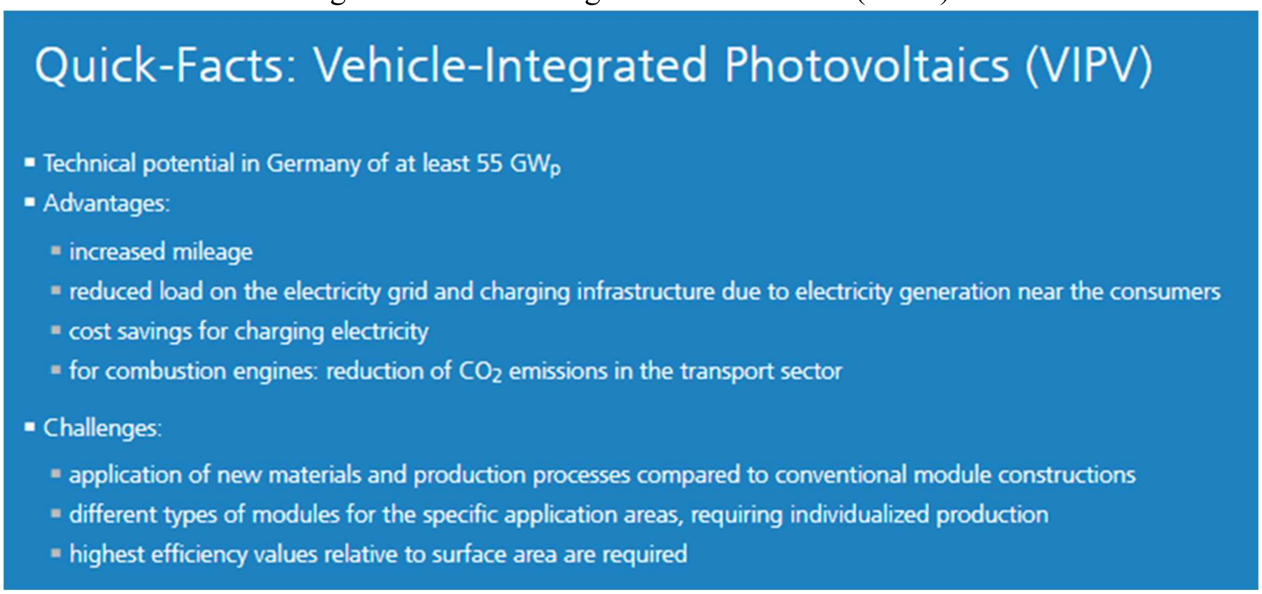

Figure 3. Vehicle-integrated Photovoltaics (VIPV): Quick-Facts.

Application options

An application example is given by electric cars which are additionally equipped with PV modules. The applied PV modules usually meet additional aesthetic requirements, e.g., special designs and curvature are possible. The additional electricity generated by the vehicle can increase the mileage by several kilometers per day. In refrigerated vans, the PV electricity can be used for electric Peltier cooling of the load. In this way, the same cooling power can be generated with less usage of the refrigeration unit and the diesel consumption can be reduced. The integration of PV modules onto the refrigerated compartment requires particularly lightweight modules which do not compromise the thermal insulation.

4. Solar-powered automobiles

Currently, the transportation sector is a leading contributor to greenhouse gas emissions. While many countries are leveraging purely electric vehicles that are recharged from renewable energy from the grid, some countries do not have access to renewable grid energy. Moreover, in many regions, accessibility to the grid is limited to those in urban areas. As such, solar-powered automobiles provide an opportunity to move away from fossil fuels for these people.

Currently, a high-efficiency car company, Aperta Motors, is conducting test drives and safety tests on a new design of cars called Aperta. These Aperta are three-wheelers, covered by 34 square feet of solar panels, which provide enough energy to drive up to 40 miles on a sunny day [3]. However, overcast, or nighttime conditions would significantly decrease potential driving ranges due to reduced levels of solar energy available. Additionally, the state-of-the-art nature of this technology and its relatively recent development hinders its intranational, and commercial success, as further improvements and safety features must be implemented.

The co-founders of Aperta Motors, Steve Fambro and Chris Anthony, wanted to create a new, more efficient vehicle that could run on solar energy instead of conventional internal combustion engines, which burn gasoline to fuel regular and hybrid cars. During the combustion of gasoline, up to 80% of the energy produced is lost as heat, wind resistance, braking, and rolling resistance, while only about 20% of the energy generated is used to move the vehicle [3]. Even hybrids waste an average of 70% of fuel to these losses. But electric vehicles can range from 60 to 70% efficient, depending on the technology, time of day, and location of the car [3]. Most electric vehicles waste about 30% of their full potential energy due to resistance and converting currents [3]. However, the novel design of the Aperta allows it to use 90% of its full capacitance on moving the vehicle [3].

There are many benefits that the Aptera brings as a new car design. Its aerodynamic shape, unlike most vehicles, reduces friction, drag, and resistance, and due to its slippery texture, can even make small, light objects slide off the mirror or itself. Additionally, it has a lighter frame requiring less energy to move the car; can automatically remove heat from both the exterior and interior of the car when parked; can be fully charged 10 times quicker than the average electric vehicle; and only a small number of solar panels are required to power it.

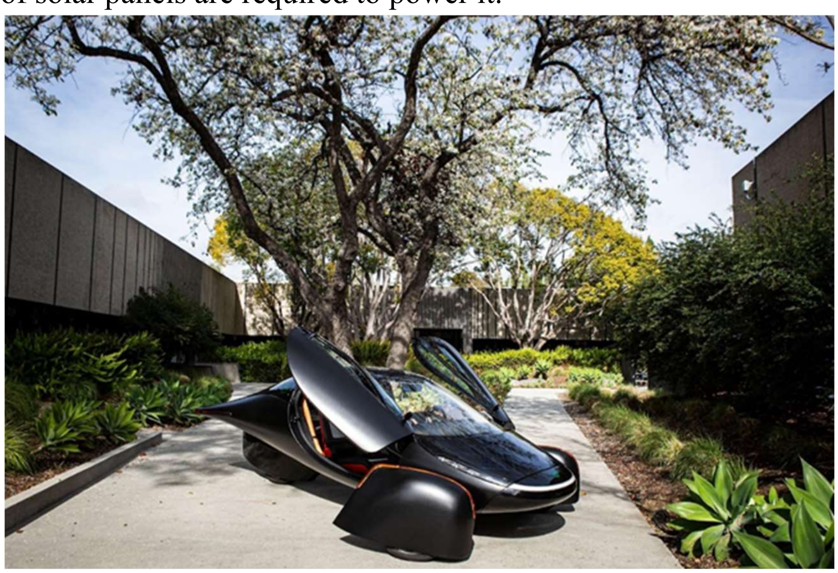

Figure 4. Aperta: There are three wheels in total and a very sharp curved end to minimize friction and is shaped like an egg to provide robustness and keep it strong like a shield [3].

The integration of photovoltaic panels on cars is becoming more feasible and in demand due to new advancements in PV technology, and in response to rising fuel prices [4]. These vehicles will be efficient solutions to environmental issues and saving energy.

Solar Skins, Wearable Solar, Solar water purifiers, and increase in solar panel efficiency.

For much of the history of solar panels, they have been heavy, rigid, and inefficient. As such, their use was very limited to larger applications, such as powering a house or a vehicle. However, advances in solar panel technology have allowed solar power to be a viable solution for a range of consumer products as well.

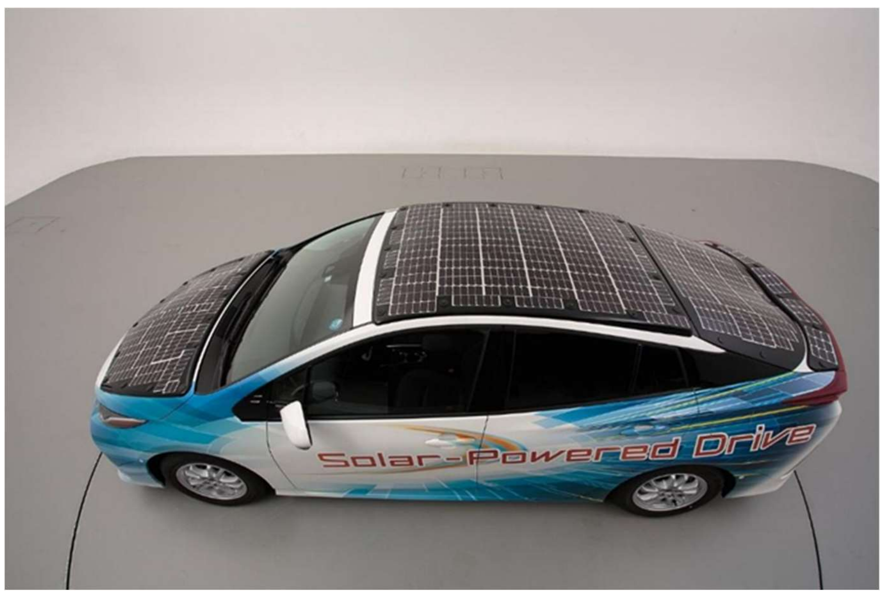

Figure 5. Installed solar skins on a hybrid car. These skins allow for cosmetic customization and cost less than installing regular solar panels on cars [5].

In recent years, researchers and developers of solar energy applications have been striving to conceive higher efficiency solar panels. Through the contributions of Swiss and American researchers, perovskite solar panels have had major breakthroughs. Currently, perovskite solar panels can achieve more than 20 % efficiency while still being one of the lowest cost options available on the market. MIT researchers are currently working on developing a new technology that can double the energy production of overall solar cells by capturing wasted heat. If the trial tests and results are as expected, costs of solar panels could plummet in the market [6].Additionally, solar panels are no longer required to be heavy, rigid surfaces. Solar skins are custom designed solar panels that allow for the solar cell to conform to almost any surface. It can be beneficial for businesses, homes, and government offices because these solar skins can display custom images on surfaces and provide an equal amount of solar energy as regular solar panels [7]. Although wearable solar devices are not exactly new, there has been new textile developments.

Solar devices before this were made strictly of hard plastic material or even metal, but now can expand into chairs, seats, and cotton [6].

As solar power continues to improve, it can be used on a number of new applications. For example, last year, Stanford University collaborated with the Department of Energy to develop solar water purifiers. These purifiers are solar devices that can purify water with exposure to sunlight, and they are capable of filtering water more quickly and efficiently. Prior designs required days of exposure to radiation to fully purify water, but the newer designs can access visible light and purify the same amount of water within minutes (about 4000 times quicker) [6].

5. Future Innovations Worldwide: Solar Roads, Solar Paint, Solar Windows, and more solar cars

5.1. Solar Roads

Solar paint can capture energy from the Sun and convert it into electricity. The advantages associated with these paints revolves around the wide range of applications, but they currently lack the efficiency of traditional solar panels. Despite this, solar paints are likely to be commercialized within the next five years [9]. There are three types of solar paints: hydrogen-extracting solar paint (solar paint hydrogens), quantum dot solar cells (photovoltaic paint), and perovskite solar paint, which can all be applied in a variety of situations. Hydrogen-extracting solar paints absorb moisture from the atmosphere and absorbs light energy shining on the paint with its titanium oxide composition materials. This light energy provides energy (in the form of heat) to break the H2O molecule into two elements hydrogen and oxygen; they hydrogen can then be captured for providing power through a fuel cell. A lead researcher states that they do not need filtered water to power the system because their development of solar paint can produce hydrogen from even a little water vapor present in the air. Solar paint hydrogens are a cheap and environmentally friendly way to produce energy from only surrounding H2O molecules [9].

The photovoltaic paint, developed by the University of Toronto, consist of quantum dots, which are nanoscale conductors that turn light into electrical currents. They are cheaper and more efficient than regular solar panels. Additionally, by increasing the quantum solar paint dot size, the amount of light absorption can increase at a larger scale which causes an exponentially increase in conversion of light energy to electricity. Researchers say at some time in the future, photovoltaic paints will be mainstreamed once they finish testing that solar paints actually work on every surface (Currently can't be applied to solar panels because it decreases the overall efficiency and can only be applied on wooden surfaces) [9].

The last paint innovation are perovskite solar paints, which consist of one type of titanium oxide mineral and are the components of solar cells [9]. Additionally, although all three solar paints are in liquid form, perovskite solar paints have the lowest viscosity. This allows perovskite solar paints to be sprayed on surfaces to form a sun-harnessing layer. Solar paint can enhance solar systems already built in whether it be on your roofs, door, or cars. Additionally, with increased efficiency levels and cheaper production costs or market prices, solar paints can serve as a primary energy source for homes and businesses and can completely revolutionize the energy industry.

5.2. Solar Glass

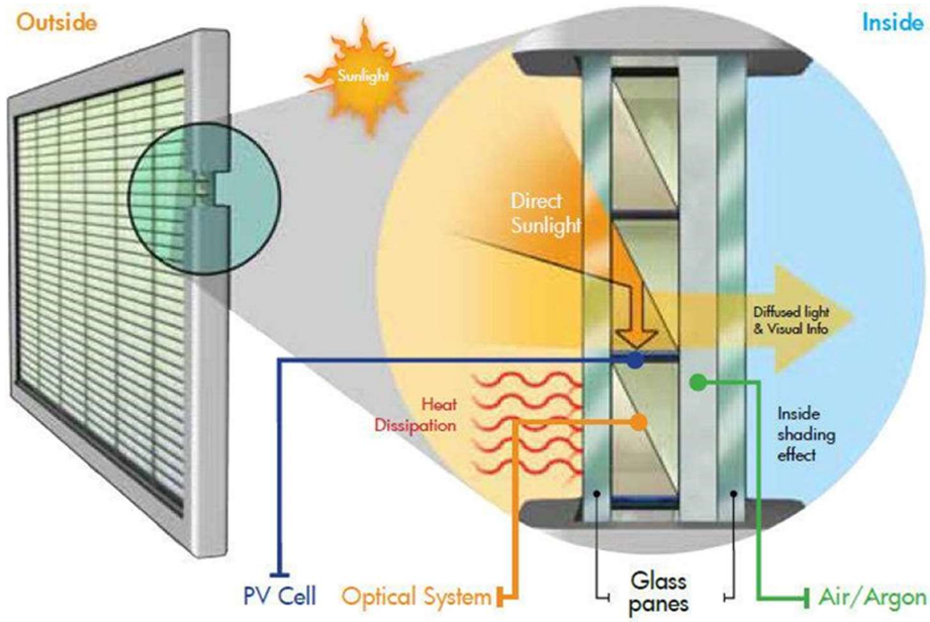

Figure 6. This image shows a solar window that acts like a regular window by the optical system allowing visible light in (creating a shading effect), but also absorbing invisible infrared light with the air/argon inside of it [10].

Solar glass along with solar windows, are transparent solar cells that can transform the way solar energy is collected and harnessed. They can turn sunlight into energy without needing the bluish-grey opaque panels, which electricity is generated, and can be harnessed on any glass surface. Solar glass is regular glass that has a coating of an organic dye on its surface which allows visible light to pass through and invisible infrared rays to be collected, captured and then converted into electricity [10]. But solar windows are relatively new and with the same shape and size, produce about two-thirds of regular solar panels. Along with this, the costs of solar windows are about an average of 20% higher than regular windows [10]. But the company that first developed this product, Ubiquitous Energy, says the more solar material installed on buildings the more energy production there will be which may equal the electricity consumed or even produce more electricity than used [11-13].

6. Conclusions

Solar-powered vehicles have come a long way since the first working prototype was created in the 1950s. While current limitations such as low efficiency and high cost hinder their widespread adoption, the future prospects of SPVs are promising. As the world moves towards cleaner energy, solar-powered vehicles are expected to play a crucial role in reducing carbon emissions and dependence on fossil fuels.

Solar-powered vehicles have come a long way since their inception, with several companies now offering hybrid solar-powered vehicles. While the technology is not yet advanced enough to replace traditional vehicles entirely, the potential for solar-powered vehicles to revolutionize transportation is enormous. With continued advancements in solar technology and increased investment in charging infrastructure, solar-powered vehicles could become a viable and environmentally friendly way to travel.

By addressing the various aspects of solar-powered vehicles, this research paper aims to contribute to the understanding of this innovative technology and its potential for revolutionizing the transportation sector. It will provide researchers, policymakers, and industry stakeholders with valuable insights to further advance the development and adoption of solar-powered vehicles, thereby promoting a cleaner and more sustainable future.
The recent innovation of solar-powered cars showcases a prominent application of solar energy technology. These vehicles are capable of harnessing solar energy through solar cells and can more efficiently use the energy for motion, compared to traditional gas-powered automobiles. In addition, the advent of solar skins introduces levels of cosmetic customization to vehicles, while incorporating solar energy technology at economically feasible costs. Advancements in calcium titanium oxide will likely further increase the efficiency of solar panels and widen the range of solar applications in the future.

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