What can engineers do to mitigate climate change? – Harnessing the power of the Sun

Introduction

The topic of climate change is one discussed in all corners of society, among conversing school students to prominent figures in intergovernmental conferences. All have the same aim: to take urgent action to combat climate change and its impacts – number 13 of the 17 UN Sustainable Development Goals [1]. Establishing the human contribution to global warming and embracing our responsibility to do something about it is the first step in achieving this goal. Then as engineers, we must develop and innovate, harnessing the power of nature to provide hope for a more sustainable future. As told so fittingly by President Obama during the COP21 Climate Change Conference: 'We are the first generation to feel the impact of climate change, and the last generation that can do something about it' [2].

Getting to the root of the problem

Consider the ephemeral nature of human existence on Earth. The environment has far outlived us and is the vital foundation upon which all of life stands. We ought to be 'good guests' and live in harmony and collaboration with the environment.

Yet we are far from such a symphony.

Earth's climate has changed throughout history; periodic fluctuations in temperature mean that there have been four regular glacial-interglacial cycles over the past 450,000 years, as shown in *Figure 1*. Presently, we are experiencing an abnormally long interglacial period called the Holocene that has lasted close to 11,000 years. A new glaciation has been expected to begin but is not arriving due to anthropogenic climate change [3]. The warming of the climate system is unequivocal, and since the 1950s, there have been many unprecedented changes observed over decades to millennia [4].

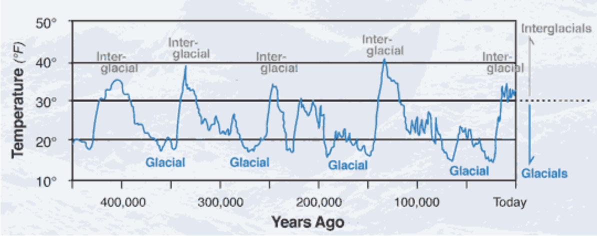

Figure 1 – Glacial-interglacial cycles over the past 450,000 years [3]

At first, you might expect that this is attributed to natural phenomena, for instance, the Sun's energy. With the Sun providing such a vast amount of the Earth's energy to power life's systems, it is natural for our first assumption to be that solar variability could be the driving force behind our warming climate. Nevertheless, the total solar energy received by the Earth fluctuates only slightly across several 11-year cycles. For decades, the variation in global surface temperature was due to changes in the average energy output from the Sun. But looking at *Figure 2*, we come across a critical moment in 1960 where the two lines abruptly diverge; the global temperature escalates dramatically, seemingly without reason and certainly with no input from increased solar irradiance. Evidently, solar irradiance is not the cause of increasing global temperatures. When we look beyond this, the true culprit of global warming becomes clear – fossil fuels. There has been an exponential growth in fossil fuel

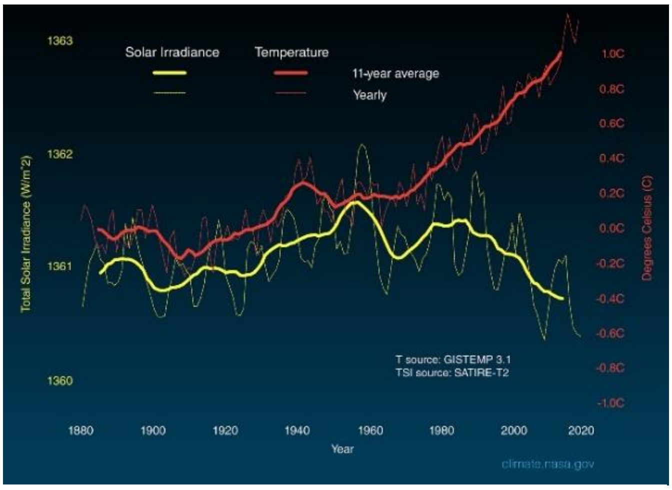

Figure 2 – A comparison of global surface temperature and solar irradiance from 1880 to 2020 [5]

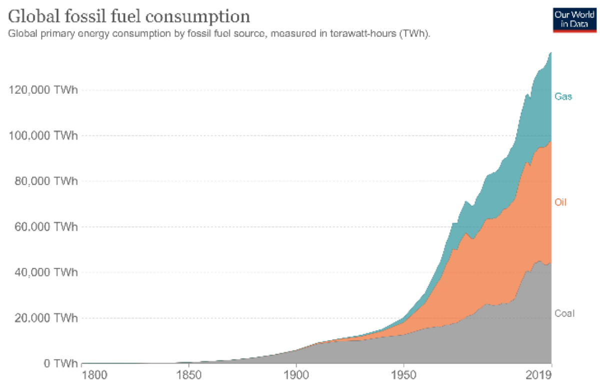

Figure 3 – Global fossil fuel consumption by source, measured in terawatt-hours (TWh) [6]

consumption since 1950, as seen in *Figure 3*. Upon comparing this data with the above evidence of increasing global temperatures, it becomes clear that our consumption of vast amounts of non-renewable energy is the driving force behind global warming.

Of course, we know that correlation does not always mean causation, but in this instance – it does. The burning of fossil fuels like coal and oil increases the concentration of atmospheric carbon dioxide, CO_2, which traps infrared radiation from the Earth and re-emits it, leading to an accumulation of heat on Earth. Rapidly increasing global temperatures caused by this greenhouse effect can and will have a devastating impact on Earth and has already had observable effects on the environment [7].

We can only mitigate climate change and stabilise global temperature once we limit the total amount of CO_2 emitted and once emissions eventually approach zero [8]. To achieve this goal, we must significantly reduce our global usage of fossil fuels and change our primary energy source from fossil fuels to renewables.

The power of the Sun

In total, 173,000TW of solar energy continuously strikes the Earth's surface [9]. This energy is more than 10,000 times the world's total energy use; the power provided by the Sun in just 90 minutes is enough to manage the entire world's energy consumption for a year [9],[10]. Thus, the potential held by renewable energy sources is clear, with solar power being just one example of the many ways in which we can sustainably source our energy.

Our use of solar power is not a recent phenomenon; humans used sunlight as early as the seventh century BCE to light fires. Later, in the third century BCE, Greeks and Romans harnessed solar power to light torches for religious ceremonies [11]. 'One must not believe, despite the silence of modern writings, that the idea of using solar heat for mechanical operations is recent. On the contrary, one must recognise that this idea is very ancient and its slow development across the centuries has given birth to various curious devices' [12]. The words of Augustin Bernard Mouchot from 1878 are still applicable today. Gradual technological advancements in the engineering sector are of foremost importance. Both developments of past ideas and completely new, modern innovations are vital for successful creations in the renewable energy technology sector. Now let us look at one such 'curious device' whose origin we can accredit to a discovery made in 1839 by the French physicist Edmond Becquerel.

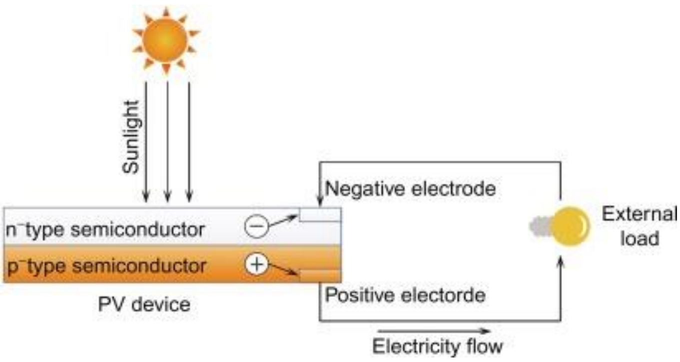

Figure 4 – The operation of a photovoltaic cell [14]

Becquerel experimented in his father's laboratory by placing metal electrodes in an electrolyte. During this experiment, he discovered that the energy in the system increased upon exposure to light [13]. This observation formed the basis of the photovoltaic (PV) effect – the principle of producing electricity from solar radiation [14]. This discovery transformed the renewable energy sector and powers so much of our lives today.

But how exactly does energy from the Sun generate an electric current in photovoltaic cells? Essentially, a photovoltaic (PV) cell consists of two semiconductor materials with a p-n junction (*Figure 4*) [14]. Within a PV cell, two layers of different semiconductor materials are placed in contact with each other to induce a built-in electric field. The first n-type layer has an abundance of electrons and hence a negative charge – the p-type layer has many holes and is positively charged. The contact of these two layers creates a p-n junction at the interface and produces an electric field [15]. When solar radiation strikes a solar cell, the semiconductor material absorbs photons, providing the energy needed to free some bound electrons from their crystals [14], [16]. Free electrons move from the n-side to the p-side of the junction; thus, upon connection to an external circuit, an electric current is formed [14].

Although the process is seemingly simple, it took 115 years to make the first efficient solar cell after Becquerel discovered the PV effect in 1839 [17]. The first key turning point came in 1870 with the discovery that selenium was a semiconductor; this paved the way for the invention of the first selenium solar cell by American scientist Charles Fritts in 1883 [18]. However, the power efficiency of solid selenium is only 1-2%, meaning it was far from being practical or cost-effective for commercial use. Scientists continued to work on developing efficient solar cells, and upon the discovery of the semi-conductive properties of silicon, it seems this work paid off. In Bell's labs in 1954, we saw the creation of the first silicon solar cell with an efficiency that would later reach 11% [14]. These discoveries made the new era of solar power generation. After decades of tireless work by physicists and engineers alike, 50 years later, 3GW of production capacity was deployed worldwide, and in 2016, we reached 300GW [17].

Yet globally, engineers still strive to make discoveries in this field and endeavour to revolutionise our use of solar power. Perseverance remains the key to fighting the damaging effects of climate change on Earth.

The bright future of solar power

Presently, engineers are making exciting innovations in the solar power industry. From the development of concentrated solar photovoltaics (CSP) to solar heating and cooling (SHC) systems, the progress of solar power technology is looking promising [19]. Among these innovations, one evolving area stands out – silicon solar cells. Of course, we have already covered the topic of silicon solar cells and how they power our lives today. But often, the best progress is made by building upon a foundation that is already in place. Thus, our next topic of discussion will be solar power's new star material – perovskite.

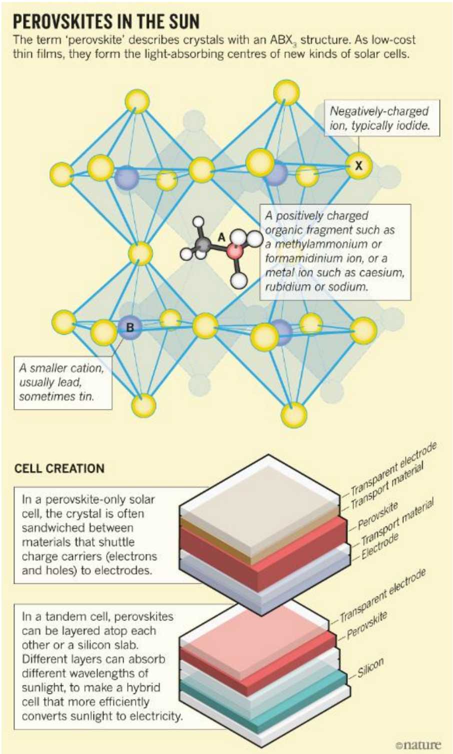

Figure 5 – The structure of perovskite [25]

Silicon is the most common semiconductor material used in solar cells, representing approximately 95% of modules sold today [20]. A 50μm thin layer of high-quality crystalline silicon together with efficient light trapping and well-passivated surfaces is, in principle, all that is required to achieve stable solar cell efficiencies [21]. The success of solar cells has been due to high efficiency, low cost, and long lifetime [20]. Nevertheless, this mainstream solar technology is close to reaching its practical and economic photovoltaic efficiency limit [22]. The ground-breaking perovskite cell produced by Oxford PV can convert 29.52% of solar energy into electricity; this greatly exceeds the average conversion rate of just 15 – 20% that is achieved by silicon solar cells [23]. Thus, the perovskite solar cell technology will allow silicon solar cell and module manufacturers to break through the performance barrier. Improving the performance of silicon photovoltaics will accelerate the growth of solar energy globally [22].

Perovskites are synthetic materials, inexpensive and relatively simple to produce even in large quantities. In *Figure 5*, we see the details of the structure of perovskite [24]. The technology used in Oxford PV's cell involves coating ordinary silicon solar cells with a thin film of perovskite to better utilise photons across the solar spectrum [23]. Perovskites can be tuned to respond to different colours in the solar spectrum by changing the material composition, and a variety of formulations have demonstrated high performance [26]. The development of multi-junction (tandem) solar cells consisting of multiple light absorbers shows much potential in breaking the efficiency limit of a single junction solar cell by absorbing light in a range of wavelengths (*Figure 5*) [27]. With developments such as these, engineers are working relentlessly to promote a revolution in the solar power industry and play a vital role in decarbonising the world's energy supply.

Unfortunately, there are still hurdles to be overcome. The main challenge of perovskites is undoubtedly their low durability. The latest silicon solar panel models have an expected lifespan of 40-50 years and generally come with a warranty of at least 20 years [28]. Perovskites are sensitive to air and moisture; their durability may be affected by environmental factors. However, commercial solar panels encapsulate their photovoltaic materials in plastic and glass for protection, meaning gradual material degradation presents few problems [25]. The real issue lies in the perovskite crystals themselves. In some cases, the structures shift as the perovskite warms up; this change is reversible, but performance is affected [25].

Another area of concern is material toxicity. While attempting to mitigate climate change, it would be ironic to harm the environment through chemical pollution. Thus, we must resolve the issue of the lead toxicity of perovskites. In *Figure 5*, we see that a component of the small cation in perovskites is lead; this means that environmental pollution by the toxic metal becomes an issue. Of course, looking at *Figure* 5, you might have noticed that an alternative to the use of lead is tin; however, when researchers tested the efficiency of this material, they discovered that the performance of the photovoltaic cells decreased [25]. So, lead remains the best material for use in perovskite solar cells, meaning there has not yet been a success in finding a replacement for its use. Although this seems a pressing issue, a life-cycle analysis of Oxford PV's tandem cells suggests that the small amount of lead that perovskites contain would not considerably impact environmental toxicity if leaked [25]. Despite this argument, engineers need to continue ongoing efforts to find a replacement for this potentially toxic material to prevent even the slightest chance of damaging our sensitive environment.

Conclusion

As we finally accept the impacts of the human-generated greenhouse effect and our contribution to climate change, it becomes more crucial for engineers globally to create technologies to combat it. In the solar technology industry, this has seen remarkable success over the centuries from the discovery of the photovoltaic effect in 1839 to the worldwide distribution of solar panels today. Yet as we have seen, there is still so much room for development and innovation to boost the performance of solar power technology and accelerate our use of renewable energy technologies. In this way, the work of engineers – past, present, and future – is our key to achieving a more sustainable future.

References

1. United Nations (n.d.). *The 17 Goals* [Online]. Available: https://sdgs.un.org/goals. [Accessed: February 15, 2022].
2. United Nations Climate Change (n.d.). *Remarks By President Obama at the First Session of COP21* [Online]. Available: https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/cop21cmp11_leaders_event_usa.pdf. [Accessed February 15, 2022].
3. Afework, B., Amin, S., Pomerantz, C. & Donev, J. (2018). *Energy Education - Glacial and interglacial periods* [Online]. Available: https://energyeducation.ca/encyclopedia/Glacial_and_interglacial_periods. [Accessed: February 14, 2022].
4. Stocker, T.F., Dahe, Q., Plattner, G-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Midgley, B & Midgley, P.M. (2013). *Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Online]. Cambridge University Press. Available: https://www.ipcc.ch/report/ar5/wg1/. [Accessed February 15, 2022].
5. National Aeronautics and Space Administration (n.d.). *The Causes of Climate Change* [Online]. Available: https://climate.nasa.gov/causes/. [Accessed: February 15, 2022].
6. Ritchie, H. & Roser, M. (2020). *Fossil Fuels* [Online]. Our World in Data. Available: https://ourworldindata.org/fossil-fuels. [Accessed February 15, 2022].
7. National Aeronautics and Space Administration (n.d.). *The Effects of Climate Change* [Online]. Available: https://climate.nasa.gov/effects/. [Accessed February 15, 2022].
8. Bruckner T., Bashmakov, I.A., Mulugetta, Y., Chum, H., De la Vega Navarro, A., Edmonds, J., Faaij, A., Fungtammasan, B., Garg, A., Hertwich, E., Honnery, D., Infield, D., Kainuma, M., Khennas, S., Kim, S., Nimir, H.B., Riahi, K., Strachan, N., Wiser, R. & Zhang, X. (2014). *Climate Change 2014: Mitigation of Climate Change.* Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Online]. Cambridge University Press. Available: https://www.ipcc.ch/report/ar5/wg3/. [Accessed: February 15, 2022]
9. Chandler, D.L. (2011). *Shining Brightly* [Online]. MIT News | Massachusetts Institute of Technology. Available: https://news.mit.edu/2011/energy-scale-part3-1026. [Accessed February 15, 2022].
10. Solar Energy Technologies Office (n.d.). *How Does Solar Work?* [Online]. Office of Energy Efficiency & Renewable Energy. Available: https://www.energy.gov/eere/office-energy-efficiency-renewable-energy. [Accessed February 15, 2022].
11. Richardson, L. (2020). *The History of Solar Energy* [Online]. Energy Sage. Available: https://news.energysage.com/the-history-and-invention-of-solar-panel-technology/. [Accessed February 15, 2022].
12. Project Solar UK (2018). *The History of Renewable Energy: Where It All Began* [Online]. Available: https://www.projectsolaruk.com/blog/history-renewable-energy-began/. [Accessed: February 15, 2022].
13. The Renewable Energy Hub (2020). *History of Solar PV* [Online]. Available: https://www.renewableenergyhub.co.uk/main/solar-panels/the-history-of-solar-power/. [Accessed February 17, 2022].
14. Asdrubali, F. & Desideri, U (2018). *Handbook of Energy Efficiency in Buildings: A Life Cycle Approach* (1st ed.). Butterworth-Heinemann. https://doi.org/10.1016/C2016-0-02638-4. [Online]. Available: https://www.sciencedirect.com/topics/engineering/photovoltaic-effect. [Accessed: February 17, 2022].
15. Rashid, M.H. (2017). *Power Electronics Handbook* (4th ed.). Butterworth-Heinemann. https://doi.org/10.1016/C2016-0-00847-1. [Online]. Available:

https://www.sciencedirect.com/topics/engineering/photovoltaic-effect. [Accessed February 17, 2022].
16. Encyclopedia Britannica (1998). *Photovoltaic effect* [Online]. Available: https://www.britannica.com/science/photovoltaic-effect. [Accessed February 18, 2022].
17. Lincot, D. (2017). *The new paradigm of photovoltaics: From powering satellites to powering humanity*. Comptes Rendus Physique, 18(7–8), 381–390. https://doi.org/10.1016/j.crhy.2017.09.003. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1631070517300555. [Accessed February 18, 2022].
18. Government of Alberta (n.d.). *The Photovoltaic Effect and the Development of Solar Technology – Electricity & Alternative Energy* [Online]. Alberta Culture and Tourism. Available: http://history.alberta.ca/energyheritage/energy/solar-power/the-photovoltaic-effect-and-the-development-of-solar-technology.aspx. [Accessed: February 19, 2022].
19. Solar Energy Industries Association (n.d.). *Solar Technologies*. [Online]. SEIA. Available: https://www.seia.org/initiatives/solar-technologies. [Accessed: February 19, 2022].
20. Solar Technologies Office (n.d.). *Solar Photovoltaic Cell Basics* [Online]. Available: https://www.energy.gov/eere/solar/solar-photovoltaic-cell-basics. [Accessed: February 19, 2022].
21. Willeke, G. (2002). *Thin Crystalline Silicon Solar Cells*. Solar Energy Materials and Solar Cells, 72(1–4), 191–200. https://doi.org/10.1016/s0927-0248(01)00164-7. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0927024801001647. [Accessed: February 19, 2022].
22. Oxford PV (n.d.). *Why Perovskite Photovoltaics?* [Online]. Available: https://www.oxfordpv.com/perovskite-pv-transform-global-solar-market. [Accessed: February 19, 2022].
23. Oxford PV (2020). *Oxford PV hits new world record for solar cell* [Online]. Available: https://www.oxfordpv.com/news/oxford-pv-hits-new-world-record-solar-cell. [Accessed: February 20, 2022].
24. Crownhart, C. (2021). *Can the most exciting new solar material live up to its hype?* [Online]. MIT Technology Review. Available: https://www.technologyreview.com/2021/06/29/1027451/perovskite-solar-panels-hype-commercial-debut/. [Accessed: February 20, 2022].
25. Extance, A. (2019). *The reality behind solar power's next star material* [Online]. Nature. Available: https://www.nature.com/articles/d41586-019-01985-y. [Accessed February 19, 2022].
26. Solar Energy Technologies Office (n.d.). *Perovskite Solar Cells* [Online]. Available: https://www.energy.gov/eere/solar/perovskite-solar-cells. [Accessed February 19, 2022].
27. Li, H. & Zhang, W. (2020). *Perovskite Tandem Solar Cells: From Fundamentals to Commercial Deployment*. American Chemical Society. https://doi.org/10.1021/acs.chemrev.9b00780. [Online]. Available: https://pubs.acs.org/doi/10.1021/acs.chemrev.9b00780. [Accessed: February 19, 2022].
28. The Renewable Energy Hub (2020). *How long do Solar Panels last* [Online]. Available: https://www.renewableenergyhub.co.uk/main/solar-panels/how-long-do-solar-panels-last/. [Accessed: February 19, 2022].