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P2_6 Solar Leaf

J. Nixon, S. Carter, H. Lyons, R. O'Sullivan

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

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Abstract

This paper explores the reality of a gigantic photosynthetic surface with the goal of fulfilling the human species energy requirements. We determined that an area of approximately 57,000 km^2 would suffice in producing enough energy to power the planet for 1 year. Calculations are completed under a variety of assumptions which make the plan pragmatically unfeasible to implement. However, the outcome provides hope through the comparison to solar panels given their higher efficiency requiring a lower area.

Introduction

80% of the worlds biomass is composed of plant matter [1]. These plants do not generate energy from the same sources as humans, instead they use photosynthesis. Given the dominance of the plant taxa, photosynthesis could be argued through this metric to be the fittest form of energy generation on planet Earth. This paper aims to analyse this method of energy generation by considering the possibility of powering the human species through a single large photosynthetic surface (or "leaf")

Theory

Photosynthesis is the process by which energy from photons is converted into chemical energy stored in the form of sugars. This process takes place in the chloroplast of a plant and requires other molecules such as water and carbon dioxide to occur. However, for the purposes of this paper we will be making two simplifications: The first is that photosynthesis takes place across the entire area of the plant's leaf, the second is that we will ignore the underlying chemistry of the process and instead focus on the energy alone. In reality, the conversion of this chemical energy into electrical would reduce energy yield dependant on the efficiency of the microbial fuel cell used to convert. The energy of a photon is given by

$$E_p = hc/\lambda \qquad (1)$$

Where E_p is the photon energy, h is Plank's constant, and λ is the wavelength of the photon. This provides us the ability to calculate the "incoming energy" from the sun subject to the number of photons incident on the surface of our leaf. A plant appears green due to its reflection of the green part of the visual spectrum, from this we can infer that the wavelength of light absorbed and utilised (the photosynthetically active region) will be from the remaining (non-green) parts of the spectrum. Photon flux is given by

$$\Phi = N_p/At \qquad (2)$$

Where Φ is photon flux, N_p is the number of photons, A is the incident area and t is the length of time photons are incident. Photon flux from the sun varies throughout the year as we approach and recede from it in our solar system. Other variations in flux occur due to season, time of day, and location. We can control as best possible for these fluctuations by considering a year-long timescale in a set location. Even under these conditions implicit assumptions are made about the consistency of fusion in the sun. However, we believe it grants the highest level of accuracy achievable.

Calculations and Discussion

D. Hall and K. Rao [2] summarise the energy losses in the photosynthetic processes and provide the net efficiency of photosynthesis to be 5%. This value includes "loss due to photons being outside the photosynthetically active region" discussed earlier. This value of course varies from species to species, however it will suit our purposes as a general estimate. We will pick a location for analysis which grants a high year-round photon flux. The Saharan region of Africa is very large, mostly uninhabited and suits the high photon flux requirements perfectly. The solar constant G_{SC}(=1373 Wm^{-2}) describes the flux density per unit area 1 AU away from the sun. Different climates allow for different percentages of this flux density to reach Earth's surface from the atmosphere. The percentage of G_{SC} which reaches Earth's surface is usually found between 15% and 80% [3]. The Sahara desert on average causes the least reduction in this flux density due to the lack of cloud cover. Leaning to a slightly more conservative estimate (assuming 80% all year round but rounding down to a single significant figure) we find:

$$0.8 \times G_{SC} \approx 30\,\mathrm{GJ\,Year}^{-1}\,\mathrm{m}^{-2} \qquad (3)$$

This value tells us that incident photons in the Sahara provide 30 GJ Y^{-1} m^{-2}. Comparing this value with the value found in [4] (341$\mathrm{Wm}^{-2} \approx$ 11GJ Y^{-1} m^{-2}) which is a global average across all regions and climates, I believe this estimate to be reasonable as areas in the northern and southern hemisphere which are both more common and have much higher cloud cover would bring the global average down significantly. Finally we can apply the 5% efficiency value from [2] and find that our leaf placed in the Sahara could produce 1.5 GJ Y^{-1} m^{-2}. Comparing this to the annual power usage of the human species [5] 8.5×10^{19} J Y^{-1} we can see from a simple division:

$$\frac{Power\ Required}{Power\ per\ Square\ Meter} \approx 5.7 \times 10^{10}\ \mathrm{m}^2 \quad (4)$$

Conclusion

Nearly 60,000 km^2 of photosynthetic surface is required to produce enough energy to sustain the human populations requirements for 1 year. This paper neglects the importance of the form of energy produced and the chemical requirements for the reaction to take place. However, by comparing the efficiency of a leaf (5%) to a solar panel (15%-20%) it is not entirely unfeasible for us to conclude that a solar panel farm in this location of this approximate size or smaller could sustain the human greed for energy for years to come. Further research into exact specifications of solar panels as well as the environmental impacts of such constructions would be beneficial to assessing the feasibility further.

References

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