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To What Extent are Solar Cells Efficient?

As we technologically progress in the modern era, and awareness for global warming and environmental dangers is increasing, we find different ways to move towards green energy and lower the use of non reusable , environmentally harmful, energy sources. One of the most common solutions to this problem, is the use of solar cells and panels, to convert unused energy from light to electricity for the use of our human needs. As of today, the average solar cell only puts out approximately one half of a watt (Komp). With approximately a dozen of those, a mobile phone can be charged (Komp). The question remains: is the solar energy converted to electricity efficiently? Are solar panels truly efficient? Moreover, to what extent? Solar cells and the solar energy face today a battle of efficiency versus cost, as there are various designs of solar cells, with different rates of efficiency, as well as various methods and mechanisms to increase the efficiency and electricity produced by photovoltaic (solar) cells. To consider these various methods, and determine if they are truly worth the work, sources, time and money, we must first understand what light is, how solar cells work, and how electricity is produced from light by solar panels.

Light, as most of us are familiar with, is absorbed by the Earth from the sun. the sun emits light in the form of waves (rays) to our planet. These light waves are part of the spectrum of electromagnetic waves - where electric and magnetic fields co - exist at the same time, in the same region of space, where either is moving through space while changing over time.

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Originating from the sun these electromagnetic waves are mostly in the form of visible light. Since energy is held in the electric and magnetic fields, power is transferred through these waves at a certain rate and intensity. From electromagnetic theory: if light carries energy, it also has momentum. (Harpell). As examined light has momentum and, if something has momentum, and is moving in a non zero velocity, by the mathematical definition $p = m v$ (mass times velocity), it has mass as well. However, this is not quite correct to claim that light has mass. According to the formula $p = \frac{U}{c}$ where $U = 2 m c$,momentum can be considered such that $p = \frac{2 m c}{c} = 2 m$. This mass, which mathematically defines the magnitude of momentum is considered to be the "equivalent mass" (Harpell). This makes us question: is light a wave, or a particle? When two light beams cross paths, they do not interact with each other at all; if light were made out of particles, when two beams of light would cross paths, particles would bounce off in random directions. (Kelleher). Furthermore, light makes interference patterns, when two beams or rays cross paths, which is a property of waves (Kelleher). However, when light is shined on a metal, energy is transferred from the light to the atoms in the metal in discrete packets, called quanta (Kelleher). The fact that light has both properties of a particle, as well as a wave, leads us to the conclusion it is simultaneously both a particle and a wave, but not exactly like either. Energy is transferred through light by photons, Light waves transfer energy through "massless" photons that hold energy. This energy, emitted by the most abundant energy source available to us, our greatest light source - the sun ("How do Solar Cells Work?", Learn

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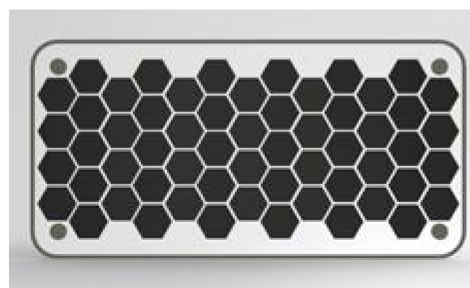
Engineering) - is absorbed by the solar cells, and converted to electricity (Glenn, "How are Solar Panels Manufactured?").

Efficiency is defined as the ratio between the work out (the work being done by the device) and the work in (the work being done to activate and power the device) as a percentage ("Efficiency of Solar Cells - Measurements"). To consider the different ways, methods and mechanisms we can use to increase the efficiency of converting electromagnetic (light) energy to electricity, we must also understand how solar cells are built, and how they operate. To build a solar cell, we use the second most abundant element of Earth: sand (Komp) and convert to a nearly 100% (one hundred percent) pure silicon ("How do Solar Cells Work?", Learn Engineering). As we add sand and carbon and heat it in a very high temperature (2000° C), we get raw silicon which is later combined with hydrogen ($SiHcI_3$) which results in polycrystalline silicon ("How do Solar Cells Work?", Learn Engineering). These Silicon cylindrical crystals, are "sliced into paper - thin disks or wafers, then trimmed into rectangles or hexagons," so they can fit together to form a solar panel of many solar cells and maximize the area (Glenn, "How are Solar Panels Manufactured?"). As shown in the figure[1]. The solar panel is made out of two main layers - both made of Silicon. Each one of these layers is "injected" with a different matter (most



[1] Efficient structure of solar cells in a solar panel; Taken from the website GreenByDesign

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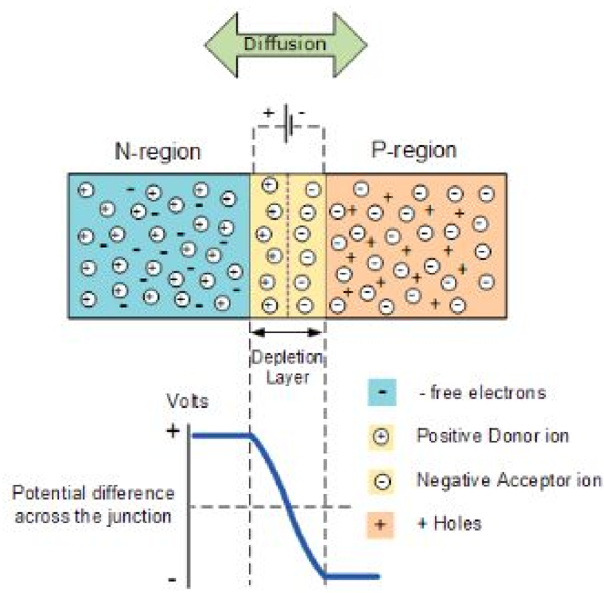
commonly, one with boron and the other with phosphorus), which due to their chemical structure, creates a Negative Silicon - Boron layer at the top, and positive Phosphorus - Silicon layer at the bottom; these layers, are silicon cells that are now little semiconductors. A system of two layers (P layer and N layer) is created, where the layer (or boundary) where both layers touch, is called the PN Junction (Positive - Negative Intersection). The positive layer (Silicon - Boron) more holes than electrons, which creates a system where the atoms would share orbiting



electrons, and there is room for more electrons in the system and a positive charge in the layer (Komp). Comparatively, the negative layer (silicon phosphorus) has an excess of electrons; these extra electrons float in the top, N layer, which causes the layer to have a negative charge (Komp). The charged system in the depletion zone (around the PN Junction region), creates an electric field at the PN Junction, due to the charge of extra electrons ("How do Solar Cells Work?", Learn Engineering) as seen in the image[2]. In addition, due to the electric field created in the system, if both layers are connected through a wire (a conductor), and electrons are free to move

[2] The potential difference and charge distribution in a solar cell - taken from the article "Multi-junction Solar Cells: What You Need to Know" from the website EnergySage.

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from the negative layer to the positive layer through the wire due to the potential difference created as a result of the increasing difference in charges (the holes are moving towards the P region and the electrons are moving towards the positive N layer) in the PN junction. The cells are then “coated with an anti - reflective substance so they do not simply reflect sunlight, but capture it (Glenn, “How are Solar Panels Manufactured?”). Such methods and mechanisms are used creatively to increase the efficiency of solar panels.

As explained, light is the flow of tiny particles called photons (Komp) shooting out from the sun. When a photon hits the negative layer with enough energy, it can knock out an electron from its bond with the atom (Komp), creating a hole (a place where there is supposed to be an electron, but there is not one). Because the silicon atoms in the system can share electrons , the holes created as a result of photon energy, can move around freely, as well as the electron released from its place. However, because of the electric field in the PN Junction, the electrons will move upwards towards the N layer, and the holes will move to the bottom, into the P - layer (Komp). The mobile electron at the top of the N region, are collected by thin metal fingers on the top of the photovoltaic cell (Komp). Due to the potential difference in the systems, electrons will move from these metal fingers, to a conductive aluminum sheet in the back, that (brings them to the P layer) through a conductor, which is connected to a circuit element (bulb, capacitor, etc.), would have electrons flowing through it and activating it, doing an electrical work and powering the device (Komp). The flowing electrons go to the bottom P - layer, filling up the holes. This

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cycle continues and the electrons remain in the system. Photovoltaic cells can last theoretically forever, and in reality for a long duration of time, due to this fact.

A major question remains unanswered: if producing electricity from light using photovoltaic cells is as easy as it seems, why is our modern society not relying entirely on solar energy? In other words, we ask: to what extent are solar cells truly efficient in making electricity out of light? For a solar cell, made of two layers of thin films of silicon, the measured efficiency stands on 22% (Glenn, "Solar Panel Efficiency: Key Things for Home Solar"). It lasts for an average of 20 years, and relatively cheap, with a price of seventy five dollars per 100 Watts power produced ($75 / 100W) ("How Efficient are Solar Panels?" *Green Match*). Since nothing but electrons is moving in the solar cell systems, nor running out, solar cells are considered a beneficial and handy that could last for decades (Komp). The efficiency of solar cells can be considered by two (2) major components: reflectance efficiency - how much sunlight is reflected rather than absorbed, and thermodynamic efficiency - maximum efficiency possible, optimizing and maximizing generated electricity.. (Glenn, "Solar Panel Efficiency: Key Things for Home Solar"). As the most efficient solar panel holds the record of being only twenty two percent (22%) efficient, and as Earth's surface area intercepts nearly one hundred and seventy three thousand terawatts (173,000 TW) of power from the sun's electromagnetic waves - light (Komp), the question arises: how can this efficiency percentage be increased, in such a way that more energy from the sun will be converted to electricity? Over recent decades, several methods

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to increase solar power efficiency have been attempted and developed; some are still practical and theoretical, yet to be tried.

First of all, the silicon produced to create the solar cells can be purified to almost one hundred percent (100%). Silicon is produced by combining Sand and Carbon together, and heating it to two thousand degrees Celsius (2000° C). It is resulted in the formation of Silicon Crystals, which are later cut into square films to be used as solar cells. To increase efficiency, we can use different types of silicon crystals. For example, Polycrystalline (multi crystal) Silicon, is made by putting a single silicon crystal seed and molten silicon together in a mold, and as they cool off, the outside of the mold cools quicker than the inside, which results in the creation of many different crystals (Hacker). The efficiency rates of polycrystalline cells are between 13 and 16 percent (13 - 16 %) for the average solar cell (Hacker), often even higher and is relatively cheap. On the other side, we can produce monocrystalline (a single crystal) silicon, is made by "rotating a solid silicon seed crystal while slowly extracting it from a pool of molten silicon" (Hacker). The production of monocrystalline silicon is much more complex and expensive than the production of polycrystalline silicon (Hacker); however, monocrystalline is considered to be more efficient with an average efficiency rate lying between 15 and 20 percent (15 - 20 %). Photovoltaic cells made of monocrystalline silicon, the structure of the crystal is organized and oriented, as opposed to polycrystalline where the silicon crystal structure is randomly oriented ("How do Solar Cells Work?", Learn Engineering). They are also proven to work better in higher temperatures and cloudy conditions (Hacker) and offer higher electrical conductivity ("How do

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Solar Cells Work?", Learn Engineering). It ought to be mentioned, that as the thin films of Silicon are sliced, cutting films in the shapes of hexagons or octagons appears to increase efficiency, as it covers more surface area, and reduces the amount of disposed of silicon, since more silicon from the edges of the cylindrical crystal is used. In addition, to increase efficiency in a photovoltaic cell, engineers have designed a version of a solar cell where the bottom layer (the negatively charged P region layer), is much larger and lightly doped, while the positively charged N region layer, is much thinner and smaller as is heavily doped.This creates a system where the depletion layer is much thicker, and light striking is producing free movement of electrons in a much greater area. ("How do Solar Cells Work?", Learn Engineering), resulting in more current generated by the solar cell.

Another method to increase the efficiency of photovoltaic cells and panels, that should be considered, is coloring the outside surface of the cells. Light is absorbed more by darker colors than it is by brighter colors, which reflect light. Painting solar cells' surfaces in black (or any dark color), will result in more light being absorbed by the cell, than reflected. An additional way to capture light and absorb it by the solar cell and to prevent it from being reflected, it builds a "cage around it". In such a system, the photovoltaic cells and panels will be placed inside a glass box, the light will be allowed to go inside, and prevented from being reflected outside. The glass box will reflect the solar cell light reflected from the cell, to be absorbed and converted into

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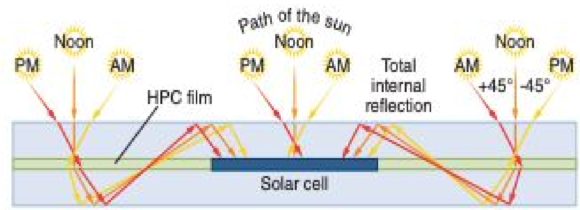
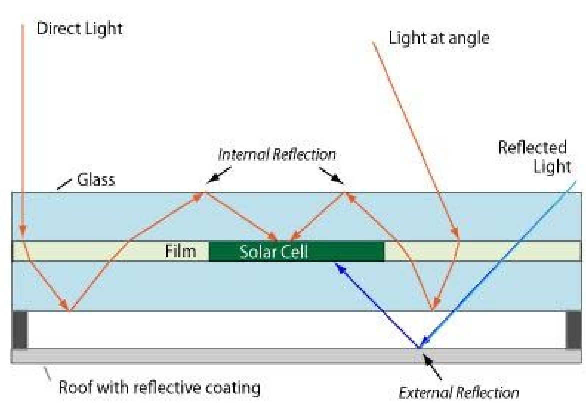
electricity, as seen in the image[3]. (Kostuk, Rosenberg and Zecchino, 41). Such a system, is called a Holographic Planar Concentrator (HPC). It is made of a glass layer lying



above, or around the solar cell, in which lies a layer of holographic planar concentrator. HPC is "built up from several layers of a film composed of gelatin on polyethylene terephthalate" which are imprinted inside the glass. (Kostuk, Rosenberg and Zecchino, 42). It diffracts the light's wavelengths that are usable by the solar cells, and allows the unusable wavelengths to pass through without being absorbed. Using HPC Increases efficiency on different rates, depending on the Sun Irradiance,which is the amount of power [produced per meter squared of solar cells (Power per unit area, or Watt per meter squared). A similar mechanism would be the Luminescent Concentrators (as shown in the figure[4]) in which "light is refracted in a luminescent film [similar to HPC film] and then being channeled towards the photovoltaic material" ("Concentrating Photovoltaic " *Green Rhino Energy).*



[3] An HPC Mechanism - Taken from the Laser Focus World Magazine, by Kostuk, Rosenberg and Zecchino, page 42.
[4] A Luminescent Concentrators Mechanism - Taken from the website *Green Rhino Energy*, "Concentrating Photovoltaics".

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Theoretical ideas to further increase the efficiency, was the use organic materials for the film, which will require no cooling as the film could be constructed such that wavelengths that cannot be converted by the solar cell would just pass through, in other words: unwanted wavelengths would be removed ("Concentrating Photovoltaic " *Green Rhino Energy).*

Another approach that has been tried to increase the efficiency of solar cells in converting light to electricity, is trapping reflected light by invisibility cloaking devices of the photovoltaic cell. "Invisibility cloaks are made of materials that bend the path of light around them and so hide things under them from view" (Hall). After covering six percent (6%) of the surface area of the solar cell with fingers and adding the invisibility cloak, efficiency rose by nine percent (9%), which is due to light being trapped within the cloak and then absorbed by the solar cell rather than reflected (Hall). However, although this is a very positive and exciting result, there are many other issues with this system. The metallic contact fingers that were put on a small section of the panel and extract the generated current, prevent and block sunlight of being absorbed by this small section of the panel, which decreases the efficiency by the same percentage (6% in this case). Besides, another problem that may occur when attempting to increase efficiency using cloaking devices, is degrading of the metal fingers by Ultraviolet Light. Ultraviolet light (UV), which lies within the electromagnetic wave spectrum, near the range of visible light, can degrade the polymer of which the metal fingers are made, decreasing its effectiveness, and is known for its ability to induce degradation., and discolouration of solar cells ("How Efficient are Solar Panels?" *Green Match*). Furthermore, dust could potentially gather in the grooves in the cloaking

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material, and clock even more sunlight. Martin Schumann, a researcher at Karlsruhe Institute of Technology in Germany, suggests a solution to the many problems that may arise with installing cloaking devices to increase efficiency of solar cells. Schumann suggests to “enclose the whole solar module in a glass case” (Hall), which may solve problems like reflection light from the metal fingers, gathering of dust between grooves, and entrance of Ultraviolet light to the system (which could harm the metal fingers), and more, but Schumann also says he does not know how it would impact the efficiency of the solar cell, as an attempt to build such a system is yet to be made (as of July 2017).

A standard method to increase the efficiency of solar cells, is to increase the concentration of incoming light. It is observed that the “efficiency of the solar cell increases slightly in concentrated light” (Penn State University Department of Energy and Mineral Engineering). Mathematically it has been derived as well: as the current generated in the solar cell is a function of the number of photons hitting the photovoltaic surface (light shining on the solar cell) is given by the formula:

$I_L = q N A$ (Penn State University Department of Energy and Mineral Engineering) it can be derived that the current generated in a photovoltaic cell is directly proportional to the number of photons hitting a specific cross sectional area A. To increase this concentration, engineers have designed different optical devices to increase the concentration of incoming light. These optical devices are not only much cheaper than new photovoltaic cells (“Concentrating

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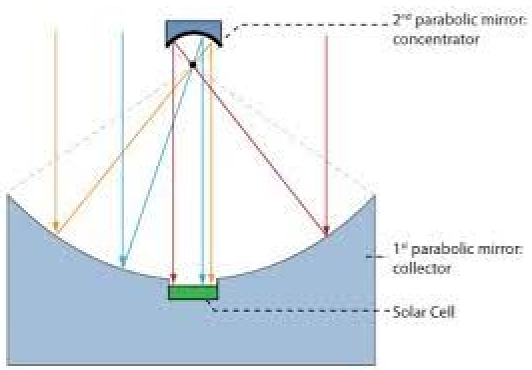
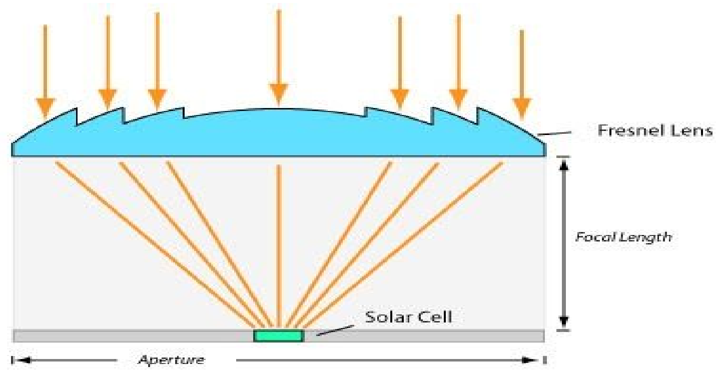
Photovoltaics", *Green Rhino Energy*), but also show positive results; they operate on concepts of optics, and the bending of light waves using lenses and mirrors.





In both figures[5], examples of methods to concentrate light are presented. In the first figure (to the left), for example, is presented a device which uses a set of parabolic mirrors to concentrate light into the solar power. In other words, it collects light from a greater range of distance, and concentrates it such that it will be collectively redirected towards the photovoltaic cell. Similarly, in the second example (the figure to the right), is presented a Fresnel Lens with a greater surface area than the area of the solar cell, through which passes light. The light is concentrated towards the small area of the solar cell, which increases the number of photons hitting the cell per unit area. Considering the fact that the maximum voltage that can be produced in a solar cell (minimal resistance) varies logarithmically with light intensity ("Efficiency of Solar Cells - Measurements"), and the fact that intensity of light is defined as the number of photons hitting the solar cell per unit area, increasing the intensity and concentration of the light, would

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[5] Reflection and Refraction mechanisms and optic devices used to increase light concentration; Taken from the website *Green Rhino Energy*, "Concentrating Photovoltaics (CPV)".

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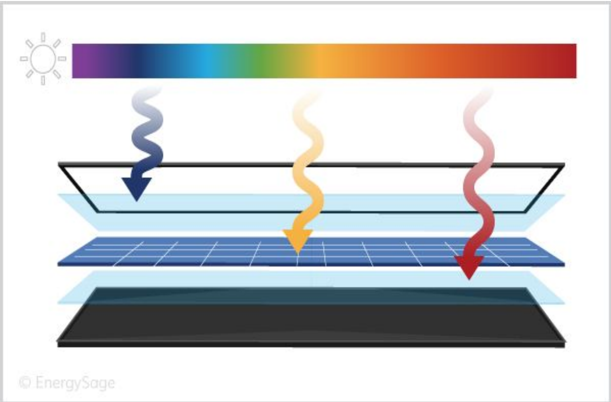
therefore amplify the current generated (“Concentrating Photovoltaic ” *Green Rhino Energy*) and magnify the voltage difference in the system. Additionally, an HPC mechanism, would be considered a device to increase light concentration as well since it traps and concentrates all reflected waves towards the solar cell’s surface.

Another method that should be taken into consideration, is building a multi - junction solar cell. As of today, it is considered to be the most efficient mechanisms of a photovoltaic cell. A record of over forty percent (40%) efficiency was measured and independently confirmed, for a metamorphic three junction cell under a standard spectrum (Fetzer, Law, Kinsey, Yoon, Edmondson, Karam, Sherif and King). In the website *EnergySage*, multijunction photovoltaic cells are defined as “tandem solar cell[s] with more than one PN junction”. In other words, there are several layers of different semiconductors, each which produces electric currents in response to different wavelengths.



As shown in the figure[6], multi - junction photovoltaic cells have different absorption layers; each layer produces electricity from the different electromagnetic wavelength. Theoretically, this means multi - junction cells are capable of producing more electricity from

[6] Multi - junction solar cell have different layers that take in different wavelengths of light; Taken from the EnergySage Website “Multi - junction Solar Cells: What You Need to Know”.

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sunlight that hits the board, rather than a single - junction photovoltaic cell. As the theoretical ideal efficiency of a single - junction solar cell stands at approximately thirty three point five percent (33.5%), the theoretical efficiency of a three layer multi - junction solar cell is near forty five percent (45%), according to the National Department of Energy (EnergySage). As there are not any commercially available multi - junction solar cells yet, the prices of multi - junction photovoltaic cells is expected to be much higher, than that of a single - junction solar cell, which is highly available today to the public, and of which expenses and prices are dropping. Engineers recently have developed a metamorphic multi - junction solar cell as well. In such photovoltaic cells (metamorphic), the semiconductors are different and no longer are made of silicon only, rather from gallium indium phosphide (GaInP), indium gallium arsenide (InGaAs) and germanium (Ge). These semiconductors respond the best to different ranges of wavelengths of incoming sunlight ("Multi-junction Solar Cells: What You Need To Know", *EnergySage*), and therefore are more frequently used nowadays, as engineers attempt to create even more efficient solar cells. As concluded, multi - junction solar cells are theoretically highly efficient, and once will become commercially available to the public, at reasonable prices, will change the green energy industry significantly.

Equally important, "side effects" of some of the mentioned methods to increase efficiency must be taken into consideration as well. Factors that can be increased or decreased as a result of the applications of different methods to increased the efficiency of photovoltaic cells, can impact the performance of the system. Temperature, humidity and solar radiation, are just

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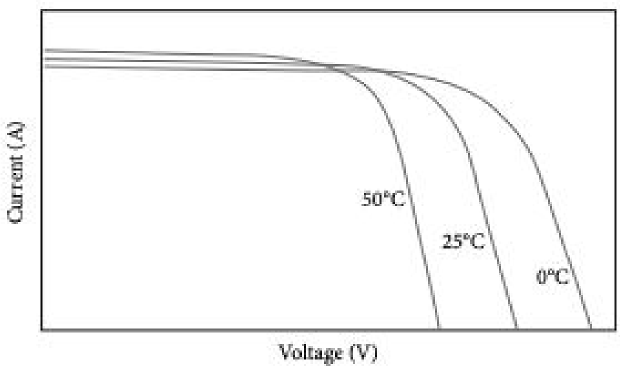
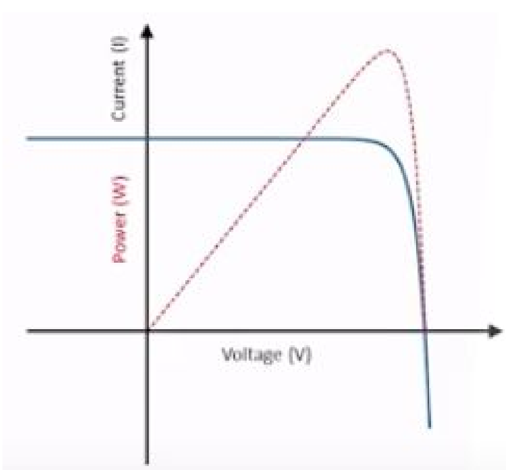
some of the factors that must be taken into account. In applying a glass container around a solar cell to trap the reflected light rays and photos, or in applying a cloaking device around a PV cell, heat can increase quickly in the system as energy from the photons carried by the sunlight is repeatedly transferred to the surface rather than passing through it, causing to an increase in the system's temperature. The temperature has a significant impact on photovoltaic (PV) cells: for each 1° C increase in temperature in the system, the power obtained by the solar cells is reduced by 0.5% (Bugutekin, Gursoy, Icel and Mamis, 2). The graph[7] (Voltage vs. Current) presents the impacts temperature has on a PV cell. The curve shows the power produced as temperature changes, where power is given by the product of voltage (as seen from the image)[8] and current in the system: $P = V I$ (Harpell). If the system overheats, the circuits in the system can be shorted, and the photovoltaic cells may malfunction, as well as efficiency can decrease. Furthermore, the temperature can cause significant damage to solar cells,





[7] A Voltage - Current graph, representing power from a solar cell in different temperatures. Taken from the International Journal of Photoenergy by Bugutekin, Gursoy, Iced and Mamis.
[8] An IV Curve whose product shows the power dissipated - Taken from the YouTube Video "Efficiency of Solar Cells - Measurements"

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as the voltage in such a system is highly sensitive to high temperatures ("Efficiency of Solar Cells - Measurements"). To keep the system fresh and prevent overheating of the system, fans and other devices can be installed as solar cells function better when in a cold environment (Glenn, "Solar Panel Efficiency: Key Things for Home Solar"), however, this will take more energy to activate, which reduces the total energy and electricity produced by the cells for human use. As sunlight intensity varies based on many factors (location, altitude, time of the year, and more), there is not much to do when it comes to improving our systems to perform the best under any circumstances. The current generated in the solar cell is directly proportional to sunlight intensity and radiation, although the potential difference (voltage) in the system remains the same, significant changes in sunlight radiation causes major significant on the current produced. Considering these facts, the location of solar panels on the face of the Earth is essenatial, as some areas receive more radiation and higher light intensity than others. For example, Turkey, located in the mid - northern hemisphere receives considerably more intense light than in northern Sweden, or South Africa, located towards the poles of the planet (Bugutekin, Gursoy, Icel and Mamis, 4). Solar efficiency could be magnified and amplified if located in similar locations, where light intensity is higher. Humidity, as well, should be taken into consideration. Humidity can impact the amount of light absorbed by a solar cell: "when the water in the air is condensed in the form of rain and snow, the atmosphere is more transparent and the radiation is blocked at the minimum level" (Bugutekin, Gursoy, Icel and Mamis 2). In other words, the lower the humidity (the less condensed water in the air), the clearer are the atmosphere and the air. As the

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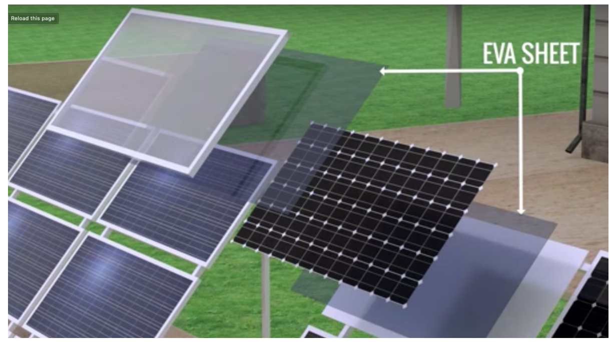
air is clearer, sunlight is less blocked, and the light absorbed to the solar panels is more intense, and less radiation is blocked. This results in more electricity produced in the same amount of time, for the same amount of light screened to Earth. On our planet, in less humid



areas, PV cells could potentially be more efficient and perform better. To resolve issues of this king (humidity, high temperatures, dust and more), the layer of solar cells inside the solar panel is protected by EVA sheets (as seen in the picture[9]), from dust, humidity, snow, hail and rain, and other harmful conditions. (“How do Solar Cells Work?”, Learn Engineering).

In the last two decades, green energy has become much more available to the public, and has been breaking records of contributions to our modern society (“How do Solar Cells Work?”, Learn Engineering). “The most efficient solar cell yet, only converts forty six percent (46%), of the available sunlight, to electricity” (Komp), however, this solar cell is yet to be available to the public nor to be commercialized. According to the website EnergySage, the top five best solar panels manufacturer in the year of 2019, include SunPower, with a twenty two point two percent (22.2%) efficiency, LG with twenty one point one percent (21.1%) and Panasonic with twenty point three percent (20.3%) (“What are the most Efficient Solar Panels on the Market? Solar

[9] Solar cell structure and EVA placement in a solar cell; Taken from the YouTube video “How do Solar Cells Work?” by Learn Engineering.

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Panel Efficiency Explained", EnergySage). Along with the fact that most solar panels are single - junction cells with an efficiency of between fifteen to twenty percent (15 - 20%), it is conclusive the currently commercialized solar cells offered to the public, are not as efficient as society thinks. On the contrary, engineers have designed theoretical mechanisms and devices that could increase efficiency to near fifty percent (50%) (Fetzer, Law, Kinsey, Yoon, Edmondson, Karam, Sherif and King). Such a mechanism would include many of the methods to increase efficiency discussed in this paper: multi junction photovoltaic cells around which are built lenses, glass boxes, or invisibility cloaking devices that would increase the intensity and concentration of light bundles per unit area (photons hitting the solar cell), and more factors and theoretical ideas, that could potentially create the ideal solar cell.

The physical efficiency of a single photovoltaic solar cell, is only one solution to the problem. In order to amplify the energy produced from our most reliable source - light - other factors can be taken into account as well. As our modern society progresses technologically, solar panels are more convenient and easy to utilize: on roofs, roads, and even cars. Solar cells are more comfortable and natural to utilize, and therefore will increase in numbers. More area could be covered, at a more affordable price, which will lead to the result of more electricity being produced by more panels. As we progress, the solar technology is positively changing, and become cheaper, more affordable to the public, and more commercialized ("How Efficient are Solar Panels?" *Green Match*). According to the article "How Much do Solar Panels Cost in the U.S. in 2019" from the website EnergySage, the average national solar panel cost in 2019 is

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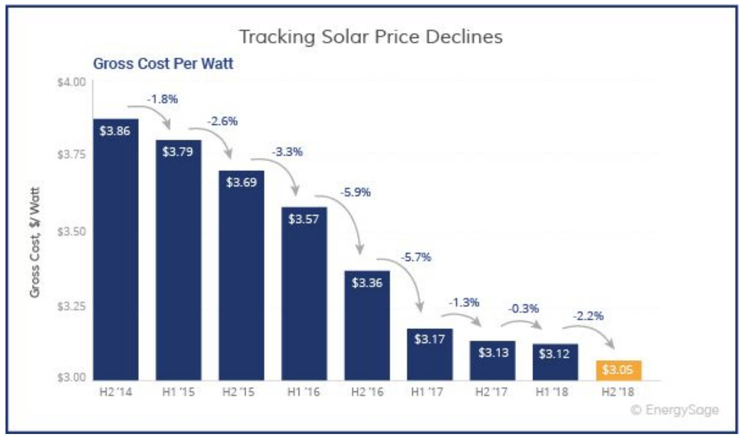
three point zero five dollars per watt ($3.05 / W), [...] where the average solar panel system would cost thirteen thousand dollars ($13,000). It observed[10] that solar prices have exponentially declined over recent years, and will continue to decay ("How Much do Solar Panels Cost in the U.S. in 2019?"). These changes will lead to an increase in purchases of solar cells and panels, creating a higher demand and supply of solar panels and an increase in the number of used solar cells; as there are more used photovoltaic cells, more electricity is produced, and a higher percentage of the light coming to the Earth, is used to produce electricity.



In conclusion, our modern society has created great inventions, based on great ideas, of converting the energy of photons carried by light, the most abundant source of energy available to humans, into electricity and power that can be used for various human needs. It can be done using solar panels (photovoltaic cells), which are typically made of the second most abundant material on our planet - sand, which along with carbon and hydrogen, at a high temperature, is converted to silicon, used in thin films in photovoltaic cells to convert light to electricity by freeing electrons and create a movement of them by having a potential difference between the

10 Examine the decaying prices of solar cell technology in the market in the last decade.Taken from the article "How Much Do Solar Panels Cost in the U.S. in 2019?" from the website *EnergySage*

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layers of silicon ("How do Solar Cells Work?", Learn Engineering). However, due to factors such as expenses, availability of resources and even political decision, it is physically impossible to create a perfect solar cell that will entirely convert light to electricity, but it is possible to increase this efficiency rate to more than the current records (22% for the most efficient photovoltaic panel that is available to the public). To make solar cells perform the best they could, and produce the most electricity to us, our modern society had invented many creative ways to increase efficiency and performance of photovoltaic cells: use monocrystalline materials rather than polycrystalline, build containers and expand the systems, so no sunlight is lost or reflected away. Install optical devices such as lenses and mirror to increase light intensity and concentration before hitting the solar cell, as well as installing these cells at convenient locations: low temperature, high light intensity and lower humidity. Methods like painting PV cells in darker colors, so more light is absorbed, organizing the cells in more efficient shapes (hexagons and octagons) such that as much light as possible is absorbed and installing cloaking devices, have been attempted as well to increase solar efficiency. As the highest efficiency record of a solar cell stands currently at forty six percent (46%), for a multi - junction solar cell, our society faces many battles to make it more accessible and available to the public; that includes prices, politics, area and more. It is certain, without a doubt, that solar power, although the many methods already applied, can be improved, efficiency can always be increased. Nowadays, solar cells efficiency is on a positive rate of change, increasing as our society progresses technologically. However, like every aspect of life, there is always room for improvement.

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