THESIS TITLE

STUDY OF PV SYSTEM

by

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A Thesis Submitted to the Academic Faculty in Partial Fulfilment of the Requirements for the Diploma of Electrical and Electronic Engineering

HIGHER DIPLOMA IN ELECTRICAL AND ELECTRONIC ENGINEERING

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Gazipur, Bangladesh

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STUDY OF PV SYSTEM

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Abstract

PV cells is considered as other way of generating power, it can reduce the cost of fossil fuels which become a big challenge to the world. Electricity produced using solar energy which is one of the renewable energy sources, can be an attractive from economic and environmental perspective. This study presents a techno-economic assessment by developing a bottom-up data-intensive spread-sheet-based model. The study estimates the electricity produced by a 96.8kWp stand-alone solar photovoltaic in the south hall residential at Islamic university of technology (IUT) campus.

The unit cost of electricity by solar radiation was found to be $0.456/kWh with a net present cost of $267729.42.for the components, batteries were found to be the most expensive of the PV system.

Chapter 1

Introduction

Growing concerns of the use of the world's natural resources and our future energy supply, has increased the need and development of solar power. There by developing Photovoltaic, a solar energy technology that uses the semi-conductors to directly convert solar radiation into electricity. Photovoltaic (PV) systems use wafers, which are typically made of crystalline silicon when exposed to sunlight will produce a small direct current. When these PV cells or solar cells are combined in a large arrangement also known as modules they will produce large amounts of electrical power with no moving parts, noise or emissions. This is dependent on the size and arrangement of the PV system and PV module array combined with electrical components to covert solar energy into electricity usable by loads in your home or building.

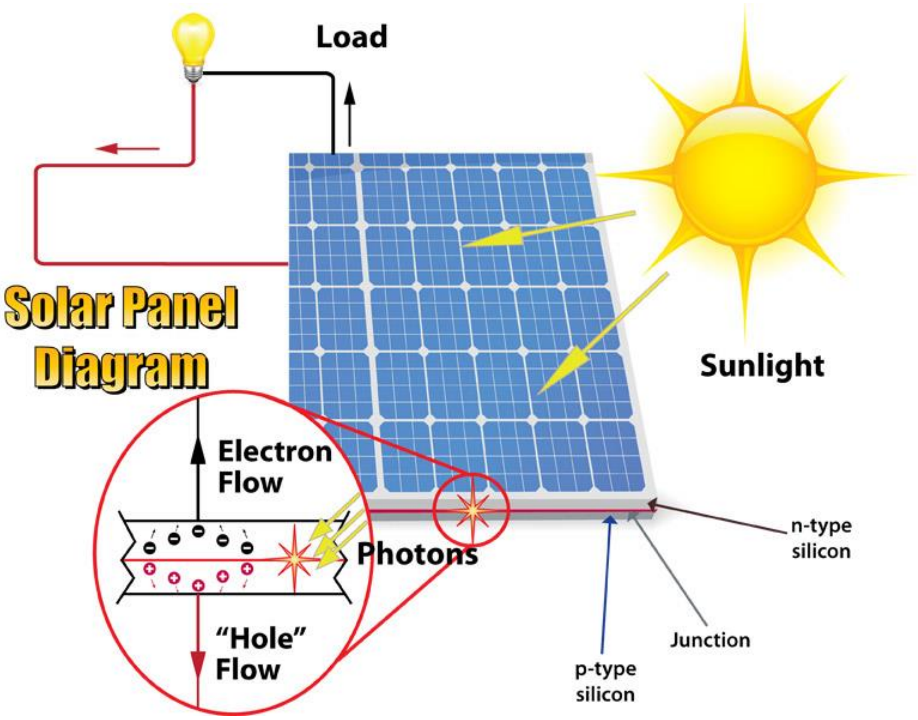


FIGURE: 1.1: Solar Panel Diagram

Most electricity is distributed through an electrical utility which, is the company that produces and/or distributes electricity to consumers in a region or state. The electricity is distributed along the grid which, is the utility's network of conductors, substations, and equipment that distributes electricity from its central hub to the consumer. The grid can span hundreds of miles from the power plants to thousands of homes and businesses. By having a PV system, you don't have to rely on the utility if there is a system distribution break down along the grid. Outages though rare, do still occur under certain circumstances such as overloaded systems or severe weather events. But, having a PV system allows you to create your own power to supply your entire house and lifestyle without being tied to the issues that can occur with utility grids. You only require the utility to activate the system and use the grid until your system is actively producing energy output your household/ business requires. Throughout the year your energy consumption changes and what energy you don’t use from the PV system will be banked along the utility grid. This can then be used during night hours or during times of the year when the sun isn’t as intense or if shading occurs due to weather.

1.1 History of Photovoltaic

French physicist Edmond Becquerel first described the photovoltaic effect in 1839, but it remained a curiosity of science for the next half century.

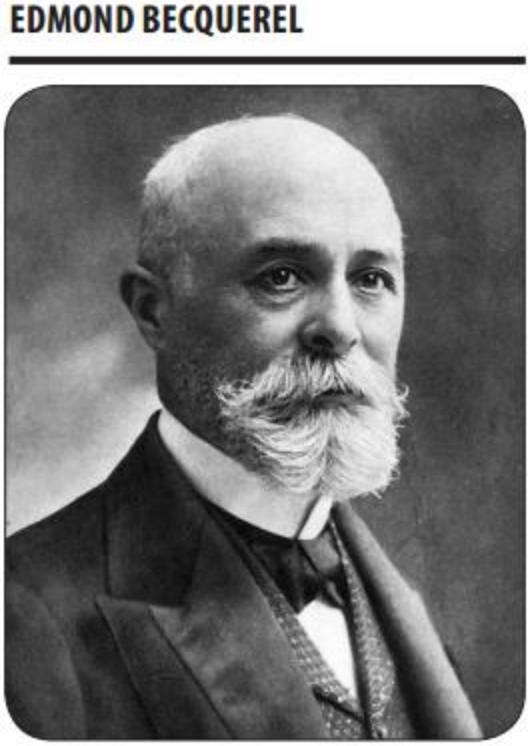


FIGURE: 1.2 physicist Edmond Becquerel.

At the age of 19, Becquerel found that certain materials would produce small amounts of electric current when exposed to light.

In the 1870s, William Adams and Richard Day showed that light could produce an electric current in selenium. Charles Frits then invented the first PV cell using selenium and gold leaf in 1883, which converted light to electricity at about one percent efficiency. The conversion efficiency of a PV cell is the proportion of radiant energy the cell converts into electrical energy, relative to the amount of radiant energy that is available and striking the PV cell. This is very important when discussing PV devices, because improving this efficiency is vital to making PV energy competitive with more traditional sources of energy, such as fossil fuels. During the second half of the 20th century, PV science was refined and the process more fully developed. Major steps toward commercializing photovoltaic were taken in the 1940s and 1950s, when the Czochralski process was developed for producing highly pure crystalline silicon. In 1954, scientists at Bell Laboratories depended on the Czochralski process to develop the first crystalline silicon photovoltaic cell, which had a version efficiency of four percent. As a result of technological advances, the cost of PV cells has decreased significantly over the past 25-30 years, as the efficiency has increased. Today's commercially available PV devices convert 13 to 30 percent of the radiant energy that strikes them into electricity. In the laboratory, combining exotic materials with specialized cell designs has produced PV cells with conversion efficiencies as high as 46 percent. The current expense of these technologies typically

Restricts their use to aerospace and industrial applications, where the unit cost of a solar array that powers, for example, a satellite is a minor concern In the 1980s, photovoltaic became a popular power source for consumer electronic devices, including calculators, watches, radios, lanterns and other small battery-charging applications. Following the energy crises of the 1970s, significant efforts also began to develop PV power systems for residential and commercial uses, both for stand-alone, remote power as well as for utility-connected applications. During the same

Period, international applications for PV systems to power rural health clinics, refrigeration, water pumping, telecommunications, and off-grid households increased dramatically, and remain a major portion of the present world market for PV products. Today, the industry’s production of PV modules is growing at approximately 25 percent annually, and major programs in the U.S., Japan and Europe are rapidly accelerating the implementation of PV systems on buildings and interconnection to utility networks.

1.2 Current PV Technology

Photovoltaic (PV) or solar cells as they are often called, are semiconductor devices that convert sunlight into direct current (DC) electricity. Groups of PV cells are electrically configured into modules and arrays, which can be used to charge batteries, operate motors, and to power any number of electrical loads. With the appropriate power conversion equipment, PV systems can produce alternating current (AC) compatible with any conventional appliances, and can operate in parallel with, and interconnected to, the utility grid.

Figure: 1.3 SOLAR TRAFFIC SIGNAL.
Solar cells provide power to this traffic signal. Attached to the support Pole are two boxes: one that stores batteries for Operation while it's dark, and one that houses a Control panel.

1.2.1 The solar resource

The researchers' first task was to examine their energy resource—sunlight. To no one's surprise, the assessment confirmed that solar energy is abundantly available and quite evenly distributed across the global. It varies by only about a factor of three across densely populated areas, and it isn't highly correlated with economic wealth. In contrast, fossil fuels, uranium, and suitable sites for hydropower are heavily concentrated, creating potential tensions between the haves and have-nots. "Solar is a much more democratic resource," notes Jean.

And the world is beginning to take advantage of it. More than 1% of total global electricity is now provided by solar. Within the United States, solar deployment is growing at rates significantly exceeding projections made by experts just five years ago. In 2014, solar accounted for fully a third of all new US generation capacity; and as shown in the figure below, residential, commercial, and (especially) utility-scale PV installations have all flourished in recent years.

Annual PV capacity additions in the United States by system type

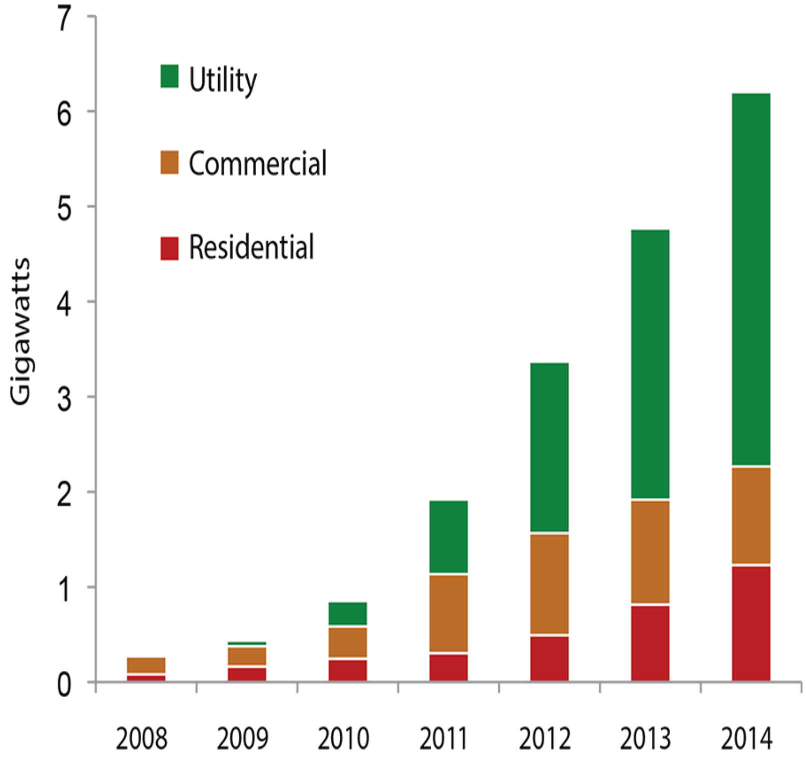


FIGURE: 1.4

The world's installed PV capacity exceeds 200 gig watts (GW), accounting for more than 1% of global electricity generation. The chart above shows annual additions to PV capacity in the United States from 2008 to 2014. Additions to utility, commercial, and residential capacity grew substantially each year, with the greatest increase occurring in the utility arena. Between 2008 and 2014, total US grid-connected PV capacity grew from about 0.8 GW to 18.3 GW. To put those numbers into context, the solar generating capacity added in 2014 is equivalent to the total capacity of several large power plants.

About 90% of current solar PV deployment is based on crystalline silicon solar cells—a technology that has been commercial for decades and is still improving.

This efficient, reliable technology could achieve the needed large-scale deployment without major technological advances, says Bulović.

But it's tough to make it cheaper. In the solar PV business, costs are divided into two categories: the cost of the solar module—the panel consisting of multiple solar cells, wiring, glass, encapsulation materials, and frame—and the "balance of system" (BOS), which includes hardware such as inverters and wiring plus installation labor, permitting, grid interconnection, inspections, financing, and the like. Since 2008, the cost of the module has dropped by 85%, but the BOS cost hasn't changed much at all. Today, the solar module is responsible for just one-fifth of the total cost of a residential installation and one-third of the cost of a utility-scale installation in the United States. The rest is the cost of the BOS.

Reducing BOS costs isn't easy with silicon. Silicon isn't very good at absorbing sunlight, so a thick, brittle layer is needed to do the job, and keeping it from cracking requires mounting it on a heavy piece of glass. A silicon PV module is therefore rigid and heavy—features that raise the BOS cost. "What we need is a cell that performs just as well but is thinner, flexible, lightweight, and easier to transport and install," says Bulović.

Research teams worldwide are now on the track of making such a PV cell. They're starting not with silicon—a structurally simple material—but rather with a variety of more complicated nanomaterials that can be specially designed to capture solar energy and convert it into electricity.

1.2.2 Comparing and contrasting the technologies

Evaluating the many PV technologies now in use and under development is difficult because they're all so different. At the most basic level, they employ different active materials to absorb light and collect electric charge. In general, they fall into three broad categories. Wafer-based cells include traditional crystalline silicon and alternatives such as gallium arsenide; commercial thin-film cells include amorphous (non-crystalline) silicon, cadmium telluride, and copper indium gallium (di) selenide (CIGS); and emerging thin-film technologies include perovskite, organic, and quantum dot (QD) solar cells.

Comparing the strengths and weaknesses of those and other options requires a way to organize them. The conventional classification system—established in 2001—groups solar technologies into three "generations" based on efficiency and cost. But that scheme "may not adequately describe the modern PV technology landscape," says Bulović, because many of the technologies—both old and new—don't fit well into their assigned categories. In addition, such a chronological scheme treats older technologies pejoratively. "Third generation" will always sound better than "first generation." But silicon—a first-generation technology—still offers many advantages and commands the vast majority of the solar cell market.

To help guide today’s thinking, the MIT team came up with a new framework. It’s based on the complexity of the light-absorbing material—a concept defined roughly as the number of atoms in the molecule or crystal unit that forms the building block for the material. The building blocks in modern PV technologies range in complexity from single silicon atoms to increasingly complicated compounds and nanomaterials —from cadmium telluride through perovskites and organics and finally to QDs (see the diagram below). In the new classification system, all of the technologies appear on a single scale; they don’t move around over time; and one location isn’t better than another. In addition, says Jean, “we find that there’s some correlation between complexity and the performance measures that we’re interested in.”

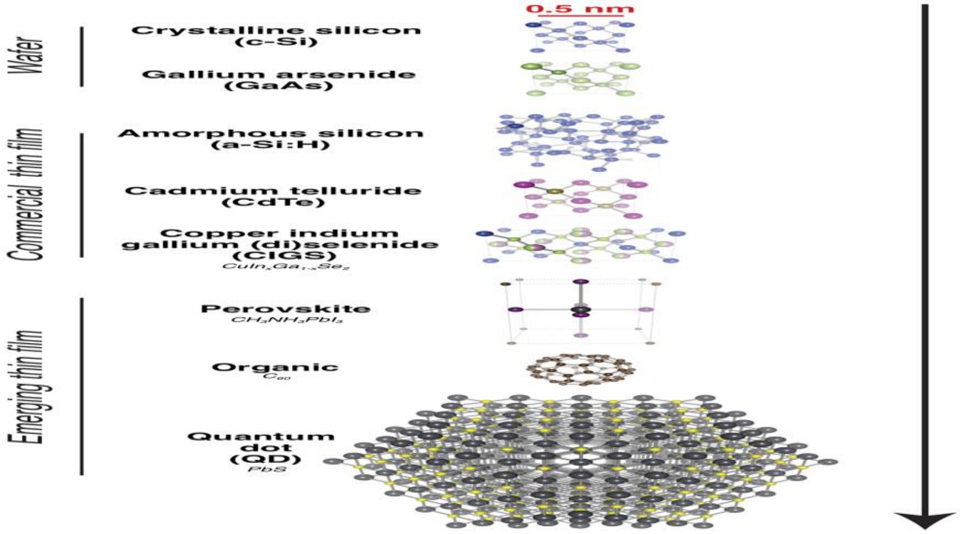


FIGURE: 1.5 Material Complexity.

PV technology classification based on material complexity

This figure shows the researchers’ proposed scheme for classifying PV technologies based on material complexity, defined roughly as the number of atoms in a molecule or repeating crystal unit. These “building blocks” are highlighted above to show their relative complexity. The wafer-based technologies near the top consist of single- or few-atom building blocks. The thin-film technologies are then arranged in order of increasing complexity, ranging from amorphous elemental materials such as amorphous silicon, through polycrystalline thin films such as cadmium telluride, to complex nanomaterials such as quantum dots, which contain thousands of lead and sulphur atoms.

One such measure is manufacturing complexity and cost. While silicon is structurally simple, turning it into wafers and solar cells is complicated and expensive, in part because of the need for stringent purity (>99.9999%) and high temperatures (>1400°C). Processing more complicated-looking nanomaterials is generally easier, cheaper, and less energy-intensive. For example, preliminary chemical reactions at moderate temperatures can be used to transform starting materials into organic molecules or QDs. Those complicated building blocks can then be deposited at low temperatures through vapor or solution processing, which could make them compatible with a variety of substrates as well as with high-speed production processes such as roll-to-roll printing.

Another critical measure of PV technology is power conversion efficiency, defined as the fraction of the incoming solar energy that comes out as electrical energy. Crystalline silicon is still the technology to beat, with record cell efficiencies of up to 26%. Emerging nanomaterial-based technologies are currently in the 10%–20% range. However, because complex nanomaterials can be engineered for maximum light absorption, they can absorb the same amount of light as silicon with orders of magnitude less material. “So while the typical silicon solar cell is more than 100 microns thick, the typical nanostructured solar cell—one that uses QDs or perovskites—can be less than 1 micron thick,” says Bulović. And that active layer can be deposited on flexible substrates such as plastic and paper with no need for mechanical support from a heavy piece of glass.

Thus far, the high efficiencies promised by such novel thin-film PV technologies have been achieved only in laboratory samples smaller than a fingernail, and long-term stability remains an issue. But with additional work, technologies based on complex materials could offer a range of valuable attributes. Such technologies could be made into lightweight, flexible, robust solar modules, which could bring down BOS costs in systems connected to the power grid. They could be used to power portable electronic devices ranging from mobile phones to small water purification systems; they could be transported and installed in remote areas; and they could be well-suited to the low-power lighting and communication requirements of the developing world. Finally, they could have unusual properties that permit novel applications. For example, some nanomaterials can be engineered to absorb ultraviolet and infrared light while letting through visible light, so they could be integrated into, say, windows, skylights, and building facades.

1.2.3 Materials availability

The prospect of scaling up today's solar generation—perhaps by a factor of 100—raises another issue: materials availability. Will the large-scale deployment of solar power be limited by the availability of critical materials needed to manufacture solar cells? How do the different technologies perform on this measure?

To find out, the researchers determined the materials requirements for each PV technology. They then calculated how much of those materials would be needed if that technology were used to satisfy 5%, 50%, or 100% of global electricity demand in 2050. (Using the International Energy Agency's estimates of demand in 2050, those fractions translate to installed PV capacities of 1,250, 12,500, and 25,000 gigawatts [GW] of power—all of which dwarf today's installed PV capacity of roughly 200 GW.) Finally, they checked current global production of each material and determined how many additional hours, days, or years of production at current levels would be needed to meet the selected deployment targets with the various technologies.

The figure below summarizes their findings. Meeting 100% of 2050 global electricity demand with crystalline silicon solar cells would require the equivalent of just six years of current silicon production. Such a scale-up of production by 2050 is certainly feasible, so materials constraints are not a major issue for silicon.

Materials requirements for PV technologies

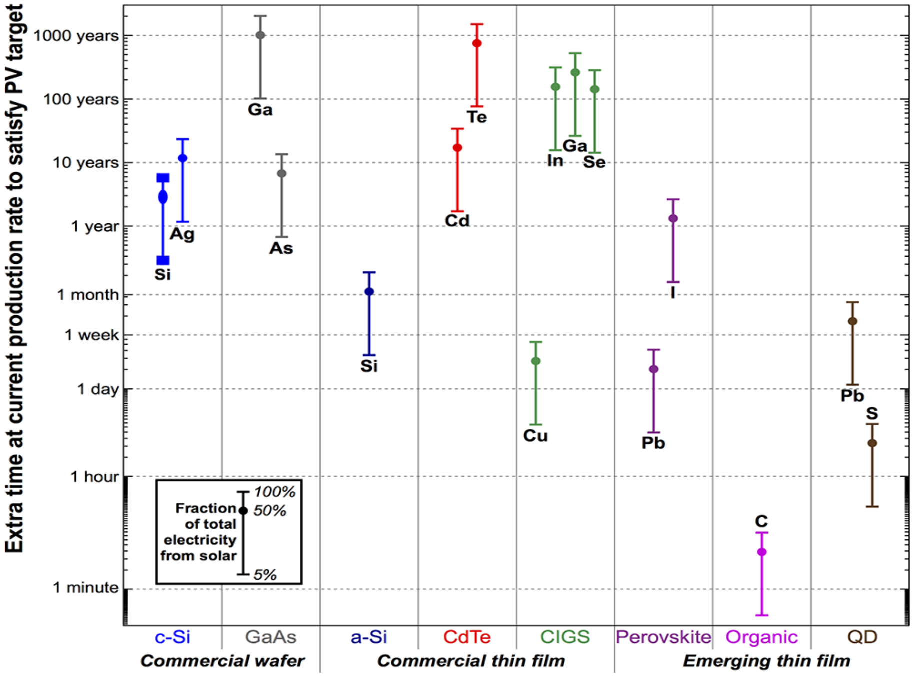


FIGURE: 1.6 Material Requirements.

The availability of critical materials could constrain a major scale-up of solar capacity using certain PV technologies. This figure shows how much additional time would be needed at current production rates to supply key materials to meet three levels of 2050 electricity demand—5%, 50%, and 100%—using selected PV technologies. Materials availability doesn't limit the expanded use of today's silicon-based cells or emerging PV technologies. In contrast, using commercial thin-film technologies such as cadmium telluride to supply the bulk of projected electricity demand would require hundreds of years of producing key materials at current rates. The needed growth in annual production of those materials between now and 2050 would be well beyond the realm of historical precedent.

The same can’t be said of today’s commercial thin-film technologies. Consider cadmium telluride. Tellurium is about a quarter as abundant as gold and is produced primarily as a byproduct of copper refining. Providing the tellurium for cadmium telluride cells to meet all of 2050 demand would require the equivalent of 1,400 years at the current rate of mining. Indium, gallium, and selenium are also produced as byproducts of major metals, and using CIGS solar cells to fulfill all electricity needs in 2050 would require well over 100 years of current production for all three. “That isn’t to say these technologies don’t have a future—they could still generate hundreds of gigawatts of power,” says Brown. “But materials constraints make it seem unlikely that they will be the dominant solar technology.” In contrast, the emerging thin-film technologies use abundant primary metals that are produced in high volume. For example, meeting 100% of demand with QD-based solar cells would require the equivalent of only 22 days of global lead production and six hours of global sulfur production. Perovskites would require at most three years of current production of their constituent elements.

1.3 Developing PV Technologies

Today there are many new PV technologies either on the market, in the pipeline, or in the research phase. These technologies will have a direct effect on how much of our energy we derive from solar power in the future. Look for technologies that will make things less expensive or serve multiple purposes as they are applied to new designs.

1.3.1 Ribbon Silicon

Thin crystalline silicon sheets are drawn out of molten silicon rather than being sawed from an ingot. This method is less expensive and less wasteful to produce silicon. However, the finished product is usually a lower quality material. In some cases, they will have cells of a higher conversion efficiency.

1.3.2 Thin-Film Technologies

This new class of materials allows the production of PV cells that are smaller and more flexible than the delicate silicon wafer technology that has dominated PV cell production in the past.

These materials are not crystalline, but amorphous, in structure. This type of PV cell can actually be applied to a variety of materials to make any number of materials that you might use for another purpose—such as glazing for a window, or shingles for a roof. Imagine windows that produce electricity! Materials used for dual purposes (building material and PV cell) are called Building Integrated photovoltaic (BIPV).

THIN-FILM TECHNOLOGY

The Schapfen Mill Tower is a flour mill in Germany. The southern facade is faced with 1,300 thin-film solar modules.

Fig: 1.7 thin-film technology

1.3.3 CdTe: Cadmium Telluride

This thin-film technology has higher solar spectrum absorption and lower costs to manufacture. It can have a conversion efficiency of up to 19%. There are concerns about the toxicity and scarcity of chemicals necessary for its production.

1.3.4 CIGS: Copper Indium Gallium Diselenide

The gallium is added to these thin-film cells to increase the energy absorption of the cells, which increases efficiency. This technology, although slightly more complicated, has a similar conversion efficiency of 20%.

1.3.5 Earth Abundant Materials

Manufacturing PV cells from abundant, low cost resources is a research priority. One of the promising technologies is sulfoselenide or CZTS. The drawback to CZTS is a lower efficiency than other PV cells.

Thin-film materials are much cheaper to produce and are lightweight. They are very versatile in how they can be applied to many structural materials. They can also be less efficient than current silicon crystal PV cells. However, what they lack in efficiency may be overcome by their flexibility of application and low cost.

1.3.6 Multijunction Technologies

This category actually combines multiple layers of materials that are designed to absorb different wavelengths of solar energy—improving the efficiency of the cell by combining the output of the various layers. Multijunction cells are a high-cost PV technology, but can reach efficiencies of over 43 percent. The Schapfen Mill Tower is a flour mill in Germany. The southern facade is faced with 1,300 thin-film solar modules.

Chapter 2

Statistics of Photovoltaic

It took until 2010, to install the first 40 GW of photovoltaic (PV) modules

FIGURE: 2.1

Source: BP, Statistical Review of World Energy; IRENA Renewable Capacity Statistics 2016

By the end of 2012, more than 100 GW had been installed.

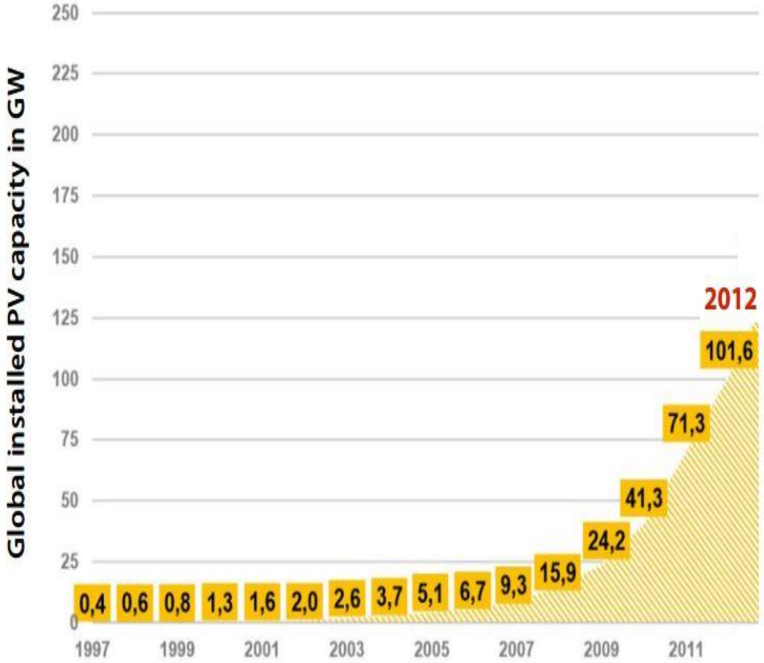


FIGURE: 2.2

Source: BP, Statistical Review of World Energy; IRENA Renewable Capacity Statistics 2016

Now, more than 40 GW are installed every year!

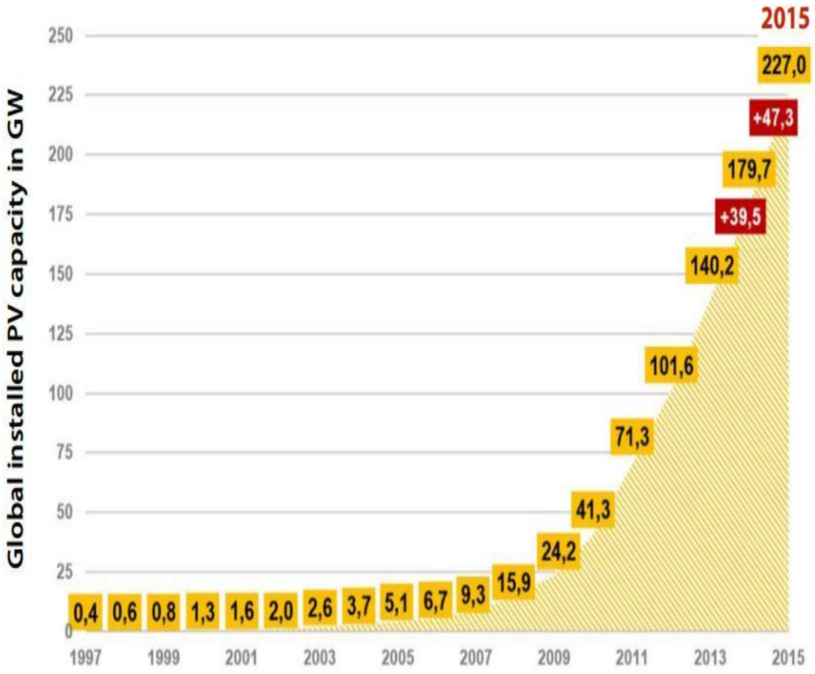


FIGURE 2.3

Source: BP, Statistical Review of World Energy; IRENA Renewable Capacity Statistics 2016

Between 1997 and 2015 the average annual growth was 43%!

Photovoltaic has the largest growth rate of no fossil electricity generation technologies!

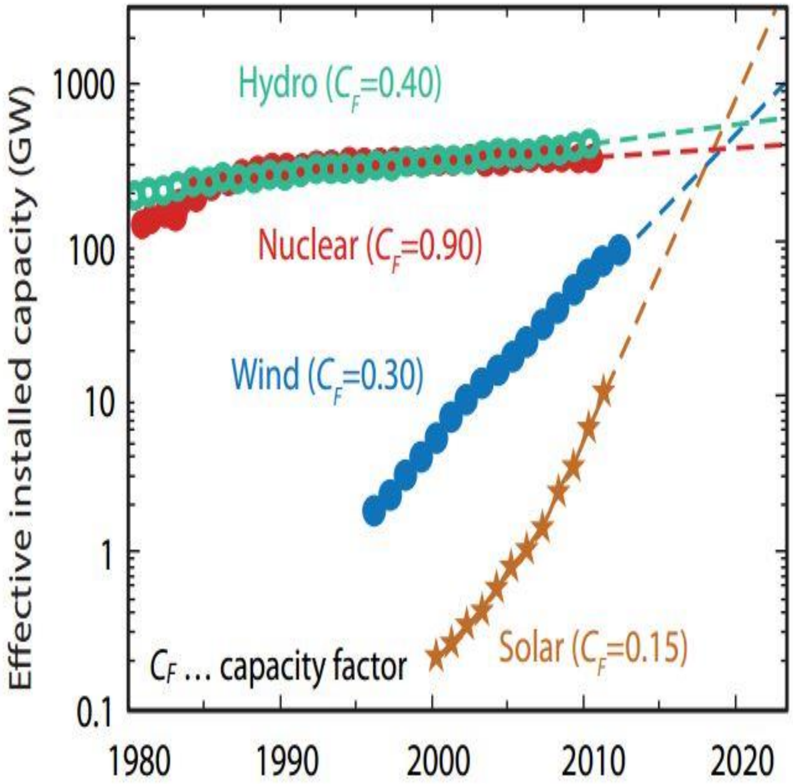


FIGURE: 2.4 Effective Installed Capacity (GW) A. Smets, K. Jäger, et al., “Solar Energy” (UIT Cambridge, 2016)

In 2015, more than 7%of electricity was generated by PV in Germany, Greece, and Italy.

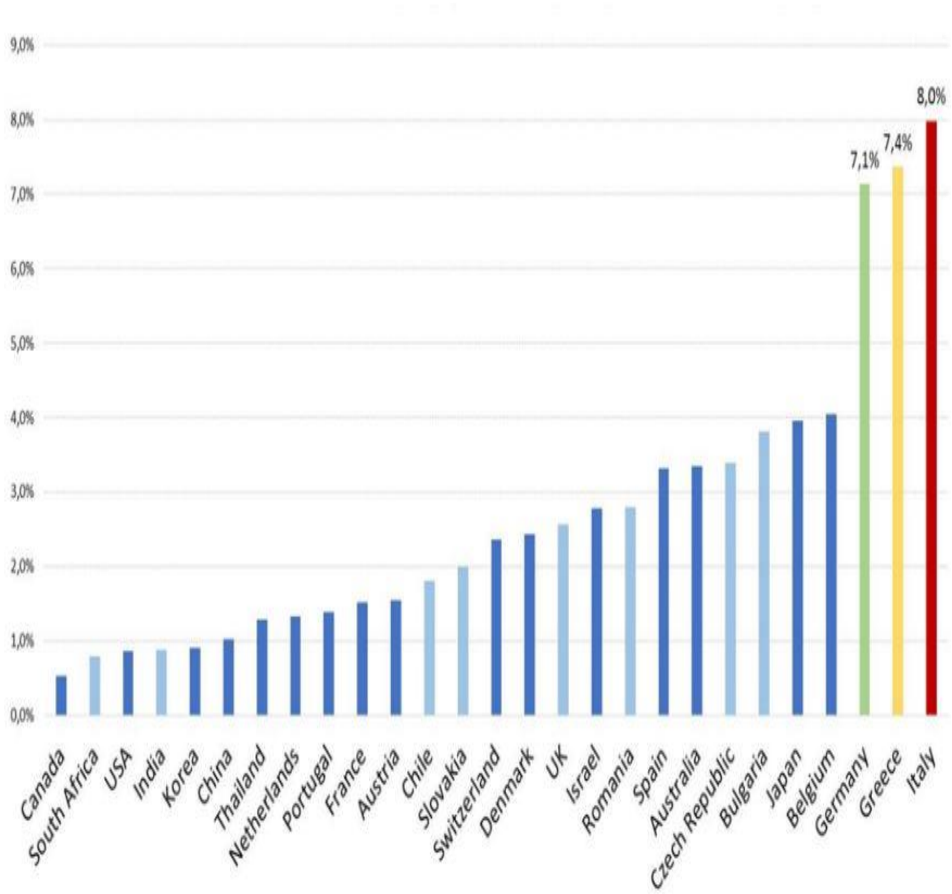


FIGURE: 2.5

Figure: 2015 Snapshot of Global Photovoltaic Markets - IEA PVPS

Chapter 3

PV Systems

3.1 PV System Components

Although a PV module produces power when exposed to sunlight, a number of other components are required to properly conduct, control, convert, distribute, and store the energy produced by the array. Depending on the type of system, these components may Include:-

1. **Power Inverter**

PV modules, because of their electrical properties, produce direct current rather than alternating Current. Direct current (DC) is electric current that flows in a single direction. Many simple devices, such as those that run on batteries, use direct current. Alternating current (AC), in contrast, is electric current that reverses its direction of flow at regular intervals (120 times per second).

This is the type of electricity provided by utilities, and the type required to run most Modern appliances and electronic devices. In the simplest systems, DC current produced by PV modules is used directly. In applications where AC current is necessary, an inverter can be added to the system to convert DC to AC current.

2. **Battery System**

PV systems cannot store electricity, so batteries are often added. A PV system with a battery is configured by connecting the PV array to an inverter. The inverter is connected to a battery bank and to any load. During daylight hours, the PV array charges the battery bank. The battery bank supplies power to the load whenever it is needed. A device called a charge controller keeps the battery properly charged and prolongs its life by protecting it from being overcharged or completely discharged. PV systems with batteries can be designed to power DC or AC equipment. Systems operating only DC equipment do not need an inverter, only a charge controller. It is useful to remember that any time conversions are made in a system, there are associated losses.

For example, when an inverter is used there is a small loss of power that can be described by the Inverter's conversion efficiency. Likewise, when batteries are used to store power, not only is there Additional expense to purchase the batteries and associated equipment, but due to the internal Resistance of the batteries there is a small loss of power as the charge is drawn out of the batteries

3.2 How a PV System Works

Photovoltaic (or PV) systems convert light directly into electricity. The term photo comes from the Greek phos, which means "light." The term volt is a measure of electricity named for Alessandro Volta (1745-1827), a pioneer in the development of electricity. Photovoltaic literally means light–electricity. Commonly known as solar cells, PV cells are already an important part of our lives. The simplest PV systems power many of the small calculators, wrist watches, and outdoor lights we see every day. Larger PV systems generate electricity for factories and warehouses, provide electricity for pumping water, powering communications equipment, and lighting homes and running appliances. In certain applications and remote settings, such as motorist aid call boxes on highways and pumping water for livestock, PV power is the cheapest form of electricity. Electric utility companies are building and including PV systems into their power supply networks. Simply put, PV systems are like any other electrical power generating systems, just the equipment used is different than that used for conventional electromechanical generating systems. However, the principles of operation and interfacing with other electrical systems remain the same, and are guided by a well-established body of electrical codes and standards. Although a PV array produces power when exposed to sunlight, a number of other components are required to properly conduct, control, convert, distribute, and store the energy produced by the array.

Depending on the functional and operational requirements of the system, the specific components required may include major components such as a DC-AC power inverter, battery bank, system and battery controller, auxiliary energy sources and sometimes the specified electrical load (appliances). In addition, an assortment of balance of system (BOS) hardware, including wiring, overcurrent, surge protection and disconnect devices, and other power processing equipment. Figure 3 show a basic diagram of a photovoltaic system and the relationship of individual components.

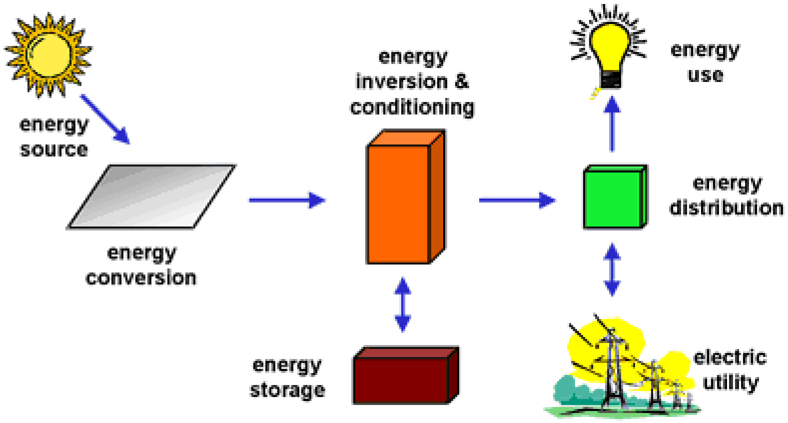


Figure: 3.1 Major photovoltaic system components.

Why Batteries Are Used in Some PV Systems?

Batteries are often used in PV systems for the purpose of storing energy produced by the PV array during the day, and to supply it to electrical loads as needed (during the night and periods of cloudy weather). Other reasons batteries are used in PV systems are to operate the PV array near its maximum power point, to power electrical loads at stable voltages, and to supply surge currents to electrical loads and inverters. In most cases, a battery charge controller is used in these systems to protect the battery from overcharge and over discharge.

3.3 Types of PV Systems

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. The two principal classifications are grid-connected or utility-interactive systems and stand-alone systems. Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems.

1. **Grid-connected or utility-interactive PV systems**

Grid-connected or utility-interactive PV systems are designed to operate in parallel with and interconnected with the electric utility grid. The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized. A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at an on-site distribution panel or service entrance. This allows the AC power produced by the PV system to either supply on-site electrical loads, or to back-feed the grid when the PV system output is greater than the on-site load demand. At night and during other periods when the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the electric utility This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back into the utility grid when the grid is down for service or repair.

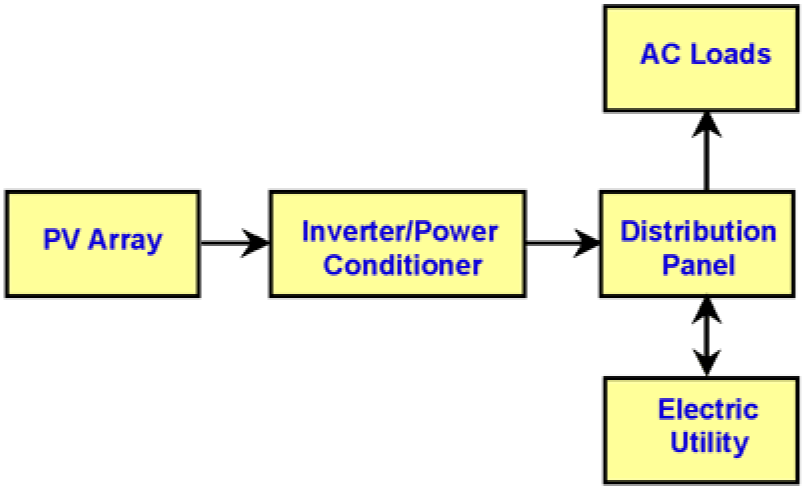


Figure: 3.2 Diagram of grid-connected photovoltaic system.

2. Stand-Alone Photovoltaic Systems

Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads. These types of systems may be powered by a PV array only, or may use wind, an engine-generator or utility power as an auxiliary power source in what is called a PV-hybrid system. The simplest type of stand-alone PV system is a direct-coupled system, where the DC output of a PV module or array is directly connected to a DC load (Figure 3). Since there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates during sunlight hours, making these designs suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems. Matching the impedance of the electrical load to the maximum power output of the PV array is a critical part of designing well-performing direct-coupled system. For certain loads such as positive- displacement water pumps, a type of electronic DC-DC converter, called a maximum power point tracker (MPPT), is used between the array and load to help better utilize the available array maximum power output.

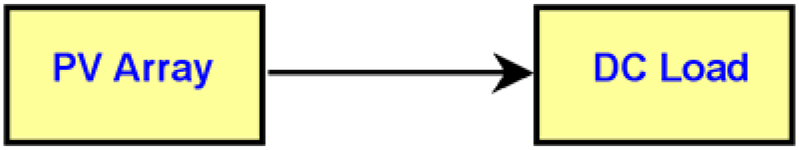


Figure: 3.3, Direct-coupled PV system.

In many stand-alone PV systems, batteries are used for energy storage. Figure 3.4 shows a diagram of a typical stand-alone PV system powering DC and AC loads. Figure 3.5 shows how a typical PV hybrid system might be configured.

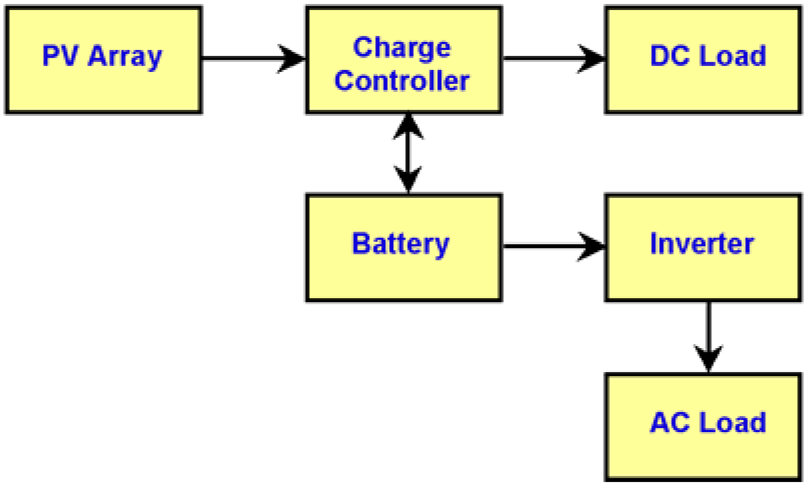


Figure: 3.4 Diagram of stand-alone PV system with battery storage powering DC and AC loads.

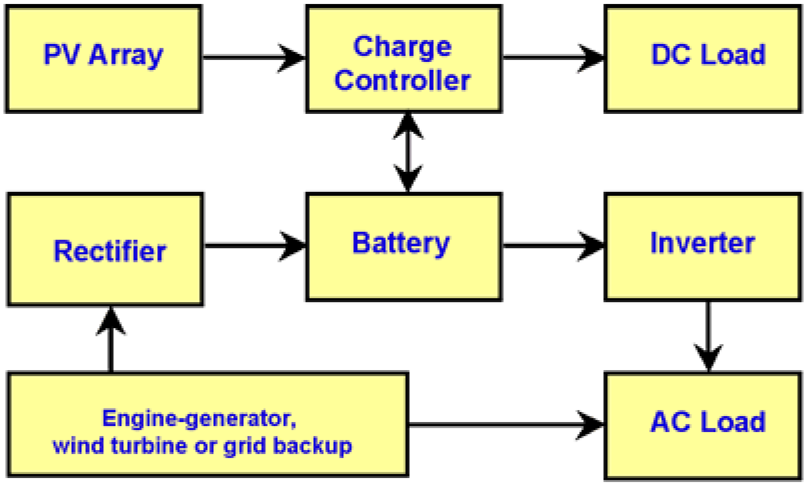


Figure: 3.5 Diagram of photovoltaic hybrid system.

3.4 Scale of PV Systems

There are three general scales at which photovoltaic systems are generally installed. They are:

1. **Residential**

A residential system is designed to offset power usage at an individual residence. While usually unable to provide all power used by the homeowners, the system could help to offset the home’s electricity usage. This type of system might produce enough electricity to power part, or all, of one home’s electricity needs.

2. Commercial

A commercial system is designed to offset power usage at a business or industrial site. These systems are much larger than residential systems that can produce more power due to the often expansive roof-top space available for their installation. An example would be a grocery store that contracts with a company to place a solar array on their flat roof while simultaneously contracting to buy power from the installer at a fixed rate for many years. This type of system might produce enough electricity to operate all or part of the business or industrial site.

3. Utility

Utility systems are employed by energy companies to produce base load or peak load power for sale to consumers. Large areas of land are typically required for their installation. An example would be a large PV array that is employed to produce power at peak usage times in the summer months when air conditioning accounts for a large part of the electrical usage. The array produces the most power when the sun is at its peak and causing consumers to turn down their thermostats—requiring the extra electricity produced by the array

4. Other Solar Technologies

Like solar cells, solar thermal systems use solar energy to make electricity. Concentrated solar power (CSP) technologies focus heat in one area to produce the high temperatures required to make electricity. Since the solar radiation that reaches the Earth is so spread out and diluted, it must be concentrated to produce the high temperatures required to generate electricity. There are several

Types of technologies that use mirrors or other reflecting surfaces to concentrate the sun’s energy up to 2,000 times its normal intensity. Parabolic troughs use long reflecting troughs that focus the sunlight onto a pipe located at the focal line. A fluid circulating inside the pipe collects the energy and transfers it to a heat exchanger, which produces steam to drive a turbine. The world’s largest parabolic Trough power plant is located in the Mojave Desert in California. The SEGS facility consists of several small facilities with a total generating capacity of 354 megawatts. Solar power towers use a large field of rotating mirrors to track the sun and focus the sunlight onto a thermal receiver on top of a tall tower. The fluid in the receiver collects the heat and either uses it to generate electricity or stores it for later use. The Ivanpah Solar Electric Generating System, located in California, uses three power towers and 170,000 heliostats to generate electricity for over140,000 homes. It is the largest CSP facility of any kind in the entire world and can generate 392 megawatts. Dish/engine systems are like satellite dishes that concentrate sunlight rather than signals, with a heat engine located at the focal point to generate electricity. These generators are small mobile units that can be operated individually or in clusters, in urban and remote locations. Concentrated solar power technologies require a continuous supply of strong sunlight, like that found in hot, dry regions such as deserts. Developing countries with increasing electricity demand will probably be the first to use CSP technologies on a large scale.

Chapter 4

Cells, Modules, & Arrays

Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels. Photovoltaic modules consist of PV cell circuits sealed in an environmentally protective laminate, and are the fundamental building blocks of PV systems. Photovoltaic panels include one or more PV modules assembled as a pre-wired, field-installable unit. A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels.

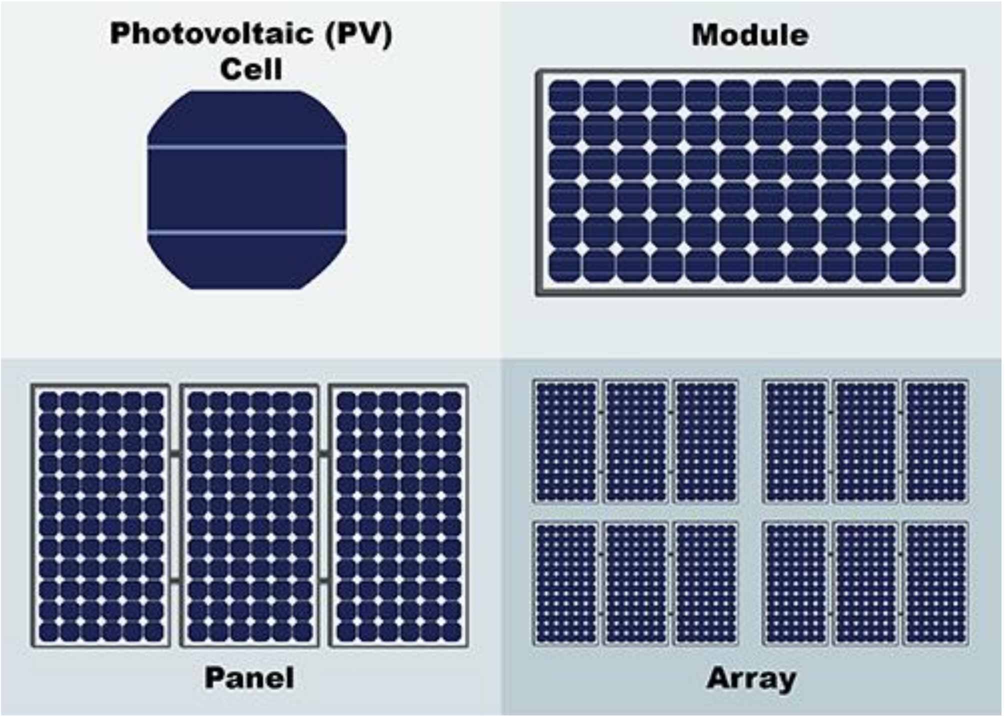


FIGURE: 4.1 Photovoltaic Cells, Modules, Panels and Arrays.

The performance of PV modules and arrays are generally rated according to their maximum DC power output (watts) under Standard Test Conditions (STC). Standard

Test Conditions are defined by a module (cell) operating temperature of 25o C (77o F), and incident solar irradiance level of 1000 W/m2 and under Air Mass 1.5 spectral distribution. Since these conditions are not always typical of how PV modules and arrays operate in the field, actual performance is usually 85 to 90 percent of the STC rating.

Today's photovoltaic modules are extremely safe and reliable products, with minimal failure rates and projected service lifetimes of 20 to 30 years. Most major manufacturers offer warranties of 20 or more years for maintaining a high percentage of initial rated power output. When selecting PV modules, look for the product listing (UL), qualification testing and warranty information in the module manufacturer's specifications.

4.1 How PV Cells Are Made

4.1.1 How a Traditional PV Cell is made

Let's look more closely at how a PV cell is made and how it produces electricity.

Step 1

A slab (or wafer) of pure silicon is used to make a PV cell. The top of the slab is very thinly diffused with an "n" dopant, such as phosphorous. On the base of the slab, a small amount of a "p" dopant, typically boron, is diffused. The boron side of the slab is 1,000 times thicker than the phosphorous side. Dopants are similar in atomic structure to the primary material. The phosphorous has one more electron in its outer shell than silicon, and the boron has one less. These dopants help create the electric field that motivates the energetic electrons out of the cell created when light strikes the PV cell. The phosphorous gives the wafer of silicon an excess of free electrons; it has a negative character. This is called the n-type silicon (n =negative).

The n-type silicon is not charged—it has an equal number of protons and electrons—but some of the electrons are not held tightly to the atoms. They are free to move to different locations within the layer. This silicon has a negative character, but not a negative charge. The boron gives the base of the silicon wafer a positive character, which will cause electrons to flow toward it. The base of the silicon is called p-type silicon (p = positive). The p-type silicon has an equal number of protons and electrons; it has a positive character, but not a positive charge.

Step 2

Where the n-type silicon and p-type silicon meet, free electrons from the n-layer flow into the p-layer for a split second, then form a barrier to prevent more electrons from moving between the two sides. This point of contact and barrier is called the p-n junction. When both sides of the silicon slab are doped, there is now a negative charge in the p-type section of the junction and a positive charge in the n-type section of the junction due to movement of the electrons and "holes" at the junction of the two types of materials. This imbalance in electrical charge at the p-n junction produces an electric field between the p-type and n-type.

Step 3

If the PV cell is placed in the sun, photons of light strike the electrons in the p-n junction and energize them, knocking them free of their atoms. These electrons are attracted to the positive charge in the n-type silicon and repelled by the negative charge in the p-type silicon. Most photon-electron collisions actually occur in the silicon base.

Step 4

A conducting wire connects the p-type silicon to an external load such as a light or battery, and then back to the n-type silicon, forming a complete circuit. As the free electrons are pushed into the n-type silicon, they repel each other because they are of like charge. The wire provides a path for the electrons to move away from each other. This flow of electrons is an electric current that can power a load, such as a calculator or other device, as it travels through the circuit from the n-type to the p-type.

In addition to the semi-conducting materials, solar cells consist of a top metallic grid or other electrical contact to collect electrons from the semiconductor and transfer them to the external load, and a back contact layer to complete the electrical circuit.

4.2 Functioning of the photovoltaic cells

The word „photovoltaic" consists of two words: photo, a Greek word for light, and voltaic, which defines the measurement value by which the activity of the electric field is expressed, i.e. The difference of potentials. Photovoltaic systems use cells to convert sunlight into Electricity. Converting solar energy into electricity in a photovoltaic installation is the most Known way of using solar energy.

The light has a dual character according to quantum physics. Light is a particle and it is a Wave. The particles of light are called photons. Photons are massless particles, moving at Light speed. The energy of the photon depends on its wavelength and the frequency, and we can calculate it by the Einstein's law, which is:

$$E = hv$$

Where:

E - photon energy

H - Planck's constant = 6.626×10 e− 34Js

V- photon frequency

4.3 PV Modules and Arrays

For more power, PV cells are connected together to form larger units Called modules. Photovoltaic cells are connected in series and/or parallel circuits to produce higher voltages, currents, and power Levels. A PV module is the smallest V component sold commercially, and can range in power output from about 10 watts to 300 watts. Fig: Photovoltaic Arrays Are Made of Individual Cells

A typical PV module consists of PV cells sandwiched between a clear Front sheet, usually glass, and a backing sheet, usually glass or a type of tough plastic. This protects them from breakage and from the Weather. An aluminum frame can be fitted around the PV module to enable easy affixing to a support structure. Photovoltaic arrays include two or more PV modules assembled as a pre-wired, field installable unit. A PV array is the complete power-generating unit, consisting of any number of modules and panels. System might be configured to operate normally in grid-connected mode and also power critical loads from a battery bank when the grid is de-energized.

4.3.1 Flowchart for PV Array Mode

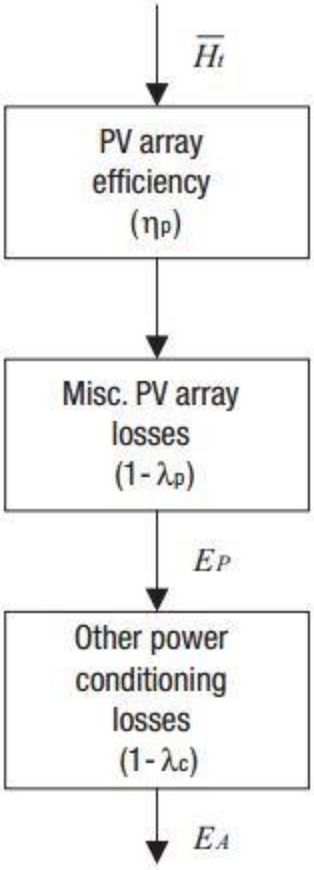


FIGURE: 4.2 flowchart for PV array mode

4.4 Types of loads

RET Screen carefully considers the correlation between load and solar resource. In some cases, part of the energy demand can be met directly by the photovoltaic system without any energy flowing through the battery (this has some important consequences in terms of energy delivered by the system, because inefficiencies in the battery storage can then be ignored). How much of the energy demand can be met directly depends on the solar-load correlation specified by the user:-

i) **Positive**. This is, for example, the case of a fan connected directly to a PV module; the fan works only when there is solar energy to power it (water pumping also falls into that category, although a separate model is used.

ii) **Zero**. This is treated in RET Screen as the case of a constant load, i.e. a load that has the same value throughout the day. This of course requires the use of a battery. Examples are cathodic protection or monitoring systems.

iii) **Negative**. In this case all the energy flows through the battery first before being delivered to the load. This corresponds to all cases not falling into the Positive and Zero categories. Note that daytime intermittent loads (e.g. refrigerator) also fall into this category. The final result of this calculation is a division of the DC equivalent electrical demand in three parts:

$$D_{DC,equ} = D_{matched} + D_{continuous} + D_{battery}$$

Where:-

$D_{matched}$: is the part of the demand that is met directly by the PV modules Whenever there is enough energy produced;

$D_{continuous}$: is the part of the demand that is constant throughout the day; and

$D_{battery}$: is the part of the demand that will be met primarily by the battery.

Note $D_{continuous}$ that will be met either directly by the PV modules (during the day

When there is enough sunshine) or through the battery (at night, or when there is Not enough sunshine). The method used to calculate this is described in the next Section. It makes use of the critical PV P_{crit} absorption level, defined as the load corresponding to the constant energy demand:

$$P_{crit} = \frac{D_{continuous}}{24}$$

Where $D_{continuous}$ is P_{crit} expressed in WH and is expressed in W

4.5 Benefits and Limitations

4.5.1 Benefits

Photovoltaic systems offer many advantages:

1. they are safe, clean, and quiet to operate;
2. they are highly reliable;
3. they require virtually no maintenance;
4. they are cost-effective in remote areas and for some residential and Commercial applications;
5. they are flexible and can be expanded to meet increasing electrical Needs for homes and businesses;

6. they can provide independence from the grid or back-up during Outages;
7. the fuel is renewable, domestically available, and free

4.5.2 Limitations

There are also some practical limitations to PV systems:

- PV systems cannot operate all the time;
- PV systems are not well suited for energy-intensive uses such as Heating;
- grid-connected systems are becoming more economical, but can Be expensive to buy and install;
- large amounts of land or space are required for utility or large scale Generation;
- The process to make PV technologies can have harmful effects on The environment.

Chapter 5

Increasing Efficiency of Photovoltaics

5.1 Making Solar Panels More Efficiency

Researchers are working on a new way to capture solar energy that makes it easier to store and be used on demand at a later time.

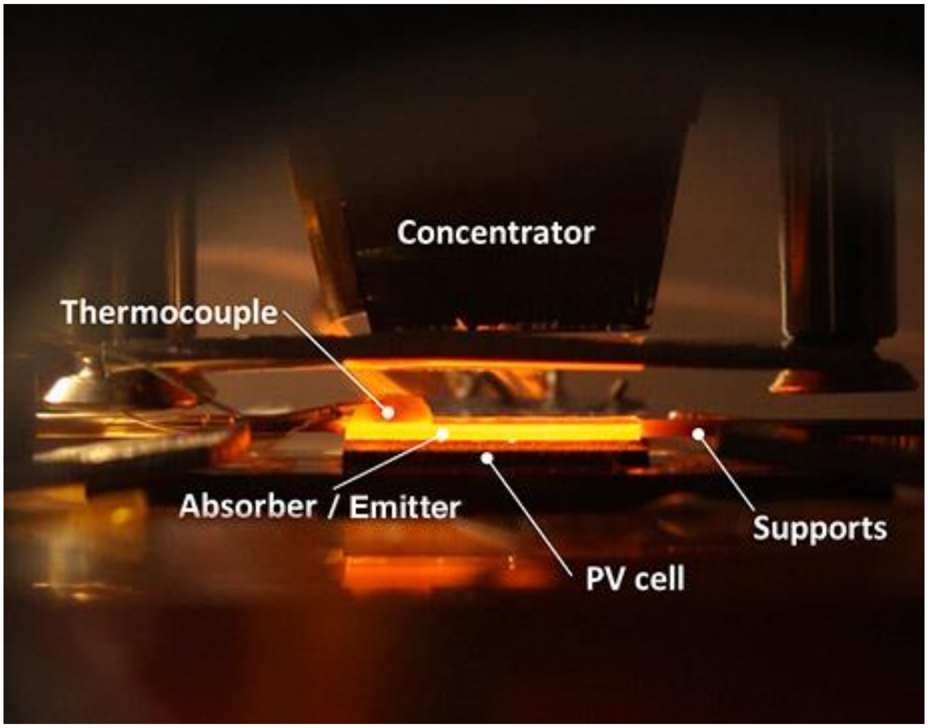


FIGURE: 5.1 Cross-sectional View of an Operating Solar Thermo Photovoltaic

Image: MIT.edu

A team of researchers at Massachusetts Institute of Technology has come up with a new way to capture solar energy that makes it easier to store and be used on demand at a later time.

The team created a device that improves the efficiency of solar panels by using wavelengths of light that normally are wasted because they cannot be captured by conventional photovoltaic cells. In this new system, the sun heats a high-temperature material, a two-layer absorber-emitter device placed over the PV cells. The outer sunlight-facing layer, the absorber, includes an array of multi-walled carbon nanotubes that efficiently absorbs the light’s energy and turns it into heat. A bonded layer of silicon/silicon dioxide photonic crystals, the emitter, is engineered to convert the heat back into light that can then be captured by the PV cells. This allows much more of the energy in the sunlight to be turned into electricity.

This new system combines the advantages of solar photovoltaic systems, which turn sunlight directly into electricity, and solar thermal systems, beneficial for delayed use because heat is more easily stored than electricity. The basic concept has been explored for several years, according to the team.

Earlier Studies

A lot of work has been done on the theoretical design of surfaces for solar thermo photovoltaic systems (STPVs) and fabrication of single components for potential integration in these systems, says team member Andrej Lenert, an MIT graduate student who expects to be awarded his PhD in mechanical engineering this spring.

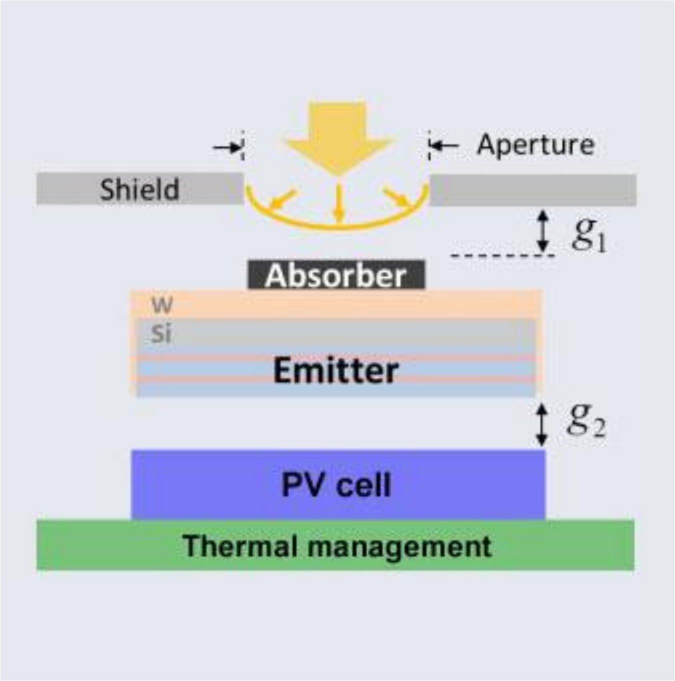


FIGURE: 5.2

Schematic of the planar STPV layout. Incoming solar radiation is converted to heat at the absorber; heat is selectively radiated by the emitter, and converted to electrical power at the PV cell. Image: MIT.edu

Lenert has been involved with STPV efforts at MIT ever since the university opened the Solid-State Solar Thermal Energy Conversion (S3TEC) Center in 2010, but his interest goes back even further to a radiation class. “I was drawn to this work initially because of the elegance of the concept and later because of the multi-disciplinary nature of its practical implementation,” he says. “My interest in renewable power generation stems as far back as my interest in pursuing an engineering degree.” He expects to continue research in this area after graduation. While the earlier studies have suggested efficiencies as high as 40%, experiments remained below 1%, Lenert says. “The large discrepancy is in part due to the challenging experimental nature of spectral engineering at high temperatures. It is also in part due to fact that the overall system efficiency is highly dependent on the performance of each one of the energy conversion steps and components, just like in a conventional solar cell, except with the added spectral conversion steps in the hot absorber-emitter."

He says the team came up with the idea for the absorber-emitter after developing a framework to identify which parts of the spectrum are most critical to the success of an STPV system. "We then tuned the spectral properties of the absorber-emitter using carbon nanotubes and silicon/silicon dioxide photonic crystals to target these properties and achieve the improved performance," he says.

Key to the breakthrough was an understanding of the interplay between the use of structure at small scales to tune spectral properties and macro scale device design. Lenert's team has produced an initial test device with a measured efficiency of 3.2%, and they say with further work they expect to be able to reach 20% efficiency, enough for a commercially viable product.

Further Optimization In their experiments using simulated sunlight, the researchers found peak efficiency came when the intensity was equivalent to a focusing system that concentrates sunlight by a factor of 750. This level of concentration is already much lower than in previous attempts at STPV systems, which concentrated sunlight by a factor of several thousand. But the MIT researchers say that after further optimization, it should be possible to get the same kind of enhancement at even lower sunlight concentrations, making the systems easier to operate.

Lenert says this is because the research center is currently working on getting even better control of the thermally-driven spectral conversion process using wavelength and angular selective surfaces. "This selectivity will lower the required level of solar concentration in two ways: Control over re-emission losses from the absorber and a more efficient TPV process that will contribute to lowering the input solar power needed to reach the same operating temperature.”

If the team achieves its goal of generating power from sunlight both efficiently and on demand from an STPV system, it could have a major impact on the way society uses solar power or at least provide another renewable option for applications when solar thermal plants or photovoltaics cannot meet the requirements, Lenert says.

5.2 Ways to Improve Solar Cell Efficiency

Why is solar cell efficiency so important? The energy that is radiated by the sun onto the surface of the Earth exceeds the global consumption of energy in a year. Solar cells helps in the conversion of the light that is available into electrical energy. This is done without the aid of any moving parts or chemical reaction. It is important that this energy is harnessed in an efficient and cost-effective manner. Thus, maximizing solar cell efficiency becomes necessary. Here are a few ways you can improve the efficiency of your solar cell to obtain the maximum output.

- **Make an Informed Decision**

The most important thing you can do is to make an informed decision while purchasing a solar panel. By doing this, you can find out which system offers the best value for your money as well as ensure that you get the best output from your solar system. Check out newer models of solar cells that give you improved levels of energy conversion. These models incorporate at least two layers of materials that are not similar with dissimilar sensitivities of wavelength.

- **Use a Solar Concentrator**

Solar light can be concentrated with the help of a solar concentrator. The purpose of these concentrators is to concentrate the light falling on a large area to smaller areas. Large mirrors or other devices are used in the facilitation of the task. Thus, the overall efficiency of solar cells, which are generally very expensive, can be increased. You not only get more energy but also save money.

Correctly Install Your Photovoltaic Panels Photovoltaic panels should be installed correctly. The orientation as well as the angle it tilts at should be right. This would ensure that the panels receive optimal sunlight all through the day, as well as all through the year. The orientation of your solar panels should be more toward the true south if you live in the northern hemisphere. Similarly, they should be facing the north if you are in the southern hemisphere. The panels should be tilted in such a way that they receive sunshine directly without any obstruction from 9 am to 3 pm.

- **Avoid Shaded Areas**

Ensure that your solar cell is not shaded as this would have an adverse effect on the power output. This is especially true when you connect your solar cells in a series. If a photovoltaic cell is shaded, it causes the energy that is generated by its neighbors to be drained. This is because it acts as a resistor and helps in determining the total current.

- **Keep Your Solar Panels Clean**

If dust accumulates on the glass surface of your solar panel, it reduces the panel’s efficiency. As a result, the sunlight that would normally reach the photovoltaic cells gets dissipated. It is therefore important that you ensure that no dust and dirt collects on surface of your cell.

- **Prevent an Increase in Temperature**

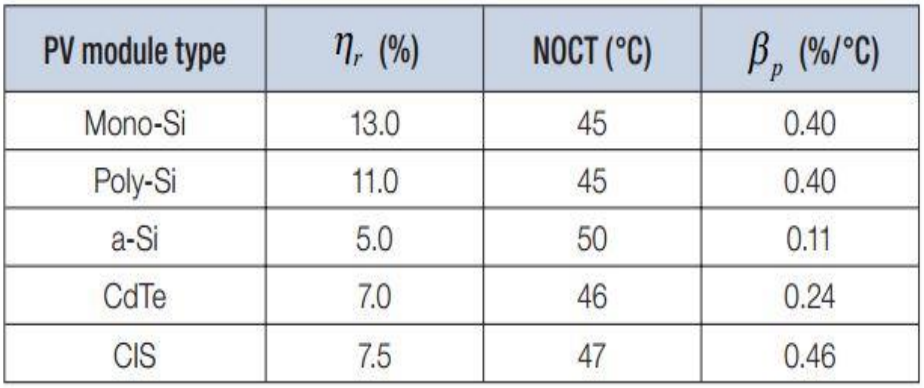
The efficiency of your photovoltaic panel is affected by temperature levels. Efficiency drops as the temperature gets higher. Care should be taken that there is a sufficient gap between the solar panels and the roof, as this would allow easy movement of air and prevent the heat from affecting your photovoltaic panels.

5.3 Calculation of average efficiency

The array is characterised by its average efficiency, ηp, which is a function of average module temperature Tc where ηr is the PV module efficiency at reference temperature Tr (= 25°C), and βp is the temperature coefficient for module efficiency. Tc is related to the mean monthly ambient temperature Ta through Evans' formula (Evans, 1981):

$$T_C - T_a = (219 + 832k_t)\,\frac{NOCT - 20}{800}$$

Where NOCT is the Nominal Operating Cell Temperature and Kt the monthly clearness index. Hr, NOCT and βp depend on the type of PV module considered. They can be entered by the user or, for "standard" technologies, are assumed to take the values given in Table below



PV module type	η_r (%)	NOCT (°C)	β_p (%/°C)
Mono-Si	13.0	45	0.40
Poly-Si	11.0	45	0.40
a-Si	5.0	50	0.11
CdTe	7.0	46	0.24
CIS	7.5	47	0.46

Table: PV Module Characteristics for Standard Technologies

The equation above is valid when the array's tilt is optimal (i.e. equal to the latitude minus the declination). If the angle differs from the optimum the right side of equation (17) has to be multiplied by a correction factor Cf defined by:

$$C_f = 1 - 1.17 \times 10^{-4} (s_M - s)^2$$

where Sm is the optimum tilt angle and sis the actual tilt angle, both expressed in degrees (in the case of tracking surfaces, RET Screen uses the tilt angle at noon although Evans does not provide any indication about what the correction should be in such configurations).

5.3.1 On-Grid Model

The on-grid model is the simplest system model (see Figure below). In particular no load is specified and no array size is suggested. Instead, the latter is suggested by the user. The suggested inverter is simply equal to the nominal array power.

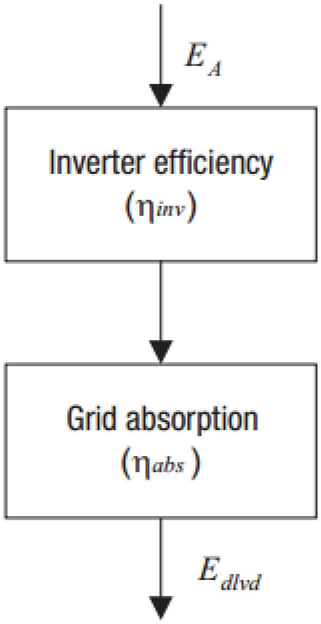


FIGURE: 5.3 On-Grid Model

The energy available to the grid is what is produced by the array, reduced by inverter losses:

$$E_{grid} = E_A \ \eta_{inv}$$

Where η_{inv} is the inverter efficiency. Depending on the grid configuration not all this energy May be absorbed by the grid.

The energy actually delivered is:

$$E_{dlvd} = E_{grid}\ \eta_{abs}$$

Where η_{abs} is the PV energy absorption rate.

5.3.2 Off-Grid Model

5.3.2.1 Overview

The off-grid model represents stand-alone systems with a battery backup, with or without an additional genset. The conceptual framework of the model is shown in Figure 12. Energy from the PV array is either used directly by the load, or goes through the battery before being delivered to the load. The remainder of the load is provided by the genset if there is one, that is, stand-alone and hybrid systems differ only by the presence of a genset that supplies the part of the load not met directly or indirectly by photovoltaics.

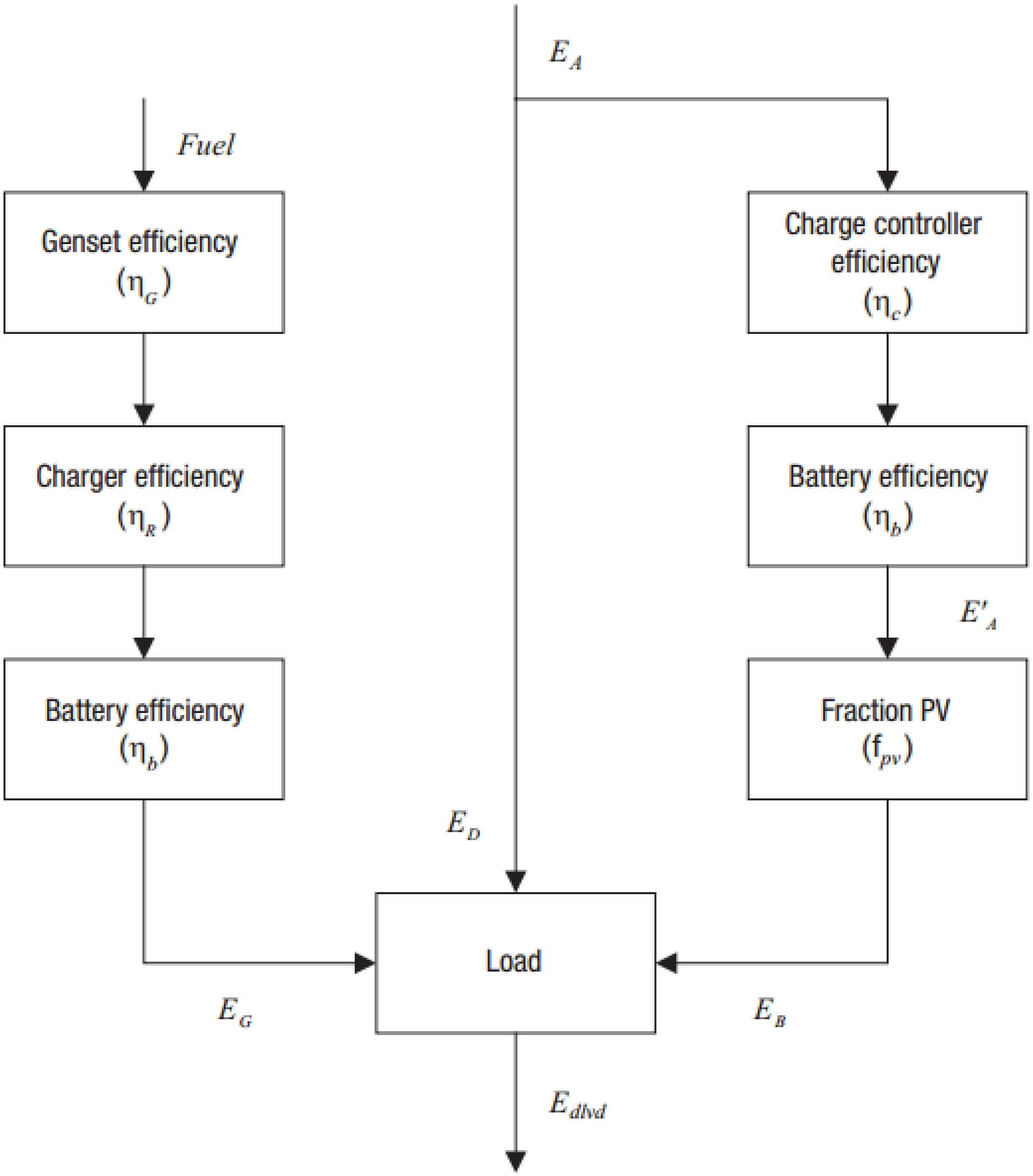


FIGURE: 5.4 On-Grid Model's Flow Chart

5.3.2.2 Load calculation

<u>Equivalent DC demand:</u>

The user specifies the total DC D_{DC} demand, and the total D_{AC} AC demand, (both are expressed in kWh/d). AC energy demand is converted to a DC equivalent by dividing it by the inverter efficiency. Hence the total equivalent DC equivalent $\acute{D}_{DC,equ}$ is:

$$D_{DC,equ} = D_{DC} + \frac{D_{AC}}{\eta_{inv}}$$

η_{inv} Where is the efficiency of the inverter.

Chapter 6

Conclusion

6.1 Fossil Fuels vs. Solar Energy

6.1.1 Energy Density

Energy density is a measure of how much energy you can extract from a particular source on each square meter. It's not a perfect comparison, because energy sources are so different from each other that the calculations aren't directly comparable, but however you measure it, fossil fuels are far higher in energy density than solar power. That's one reason why you don't see solar panels powering too many cars: gasoline provides much more energy than could be supplied from solar panels on a car.

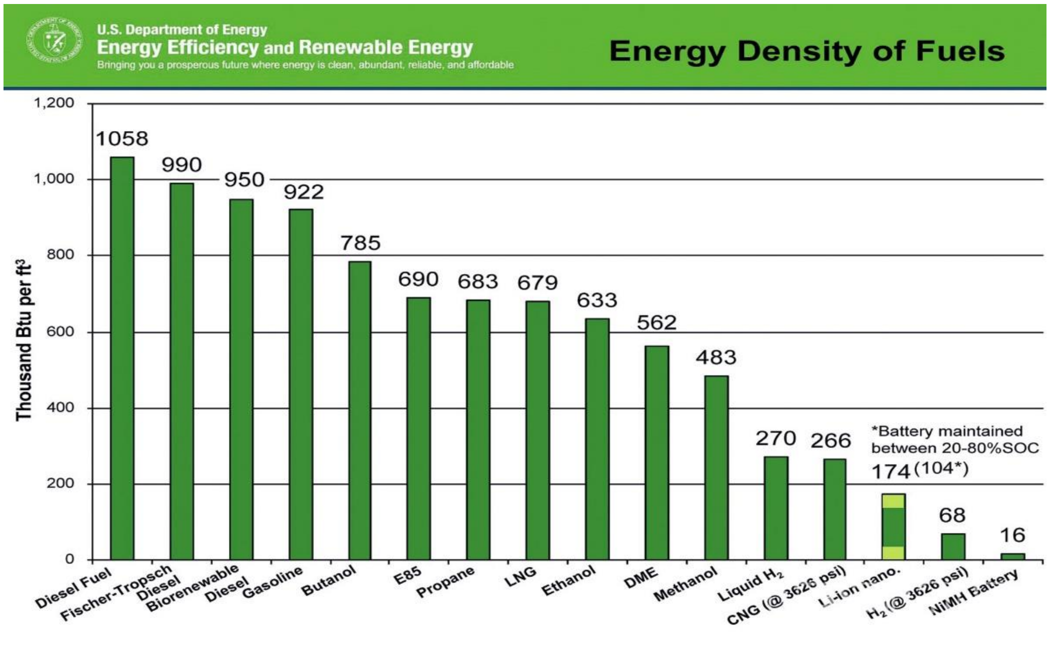
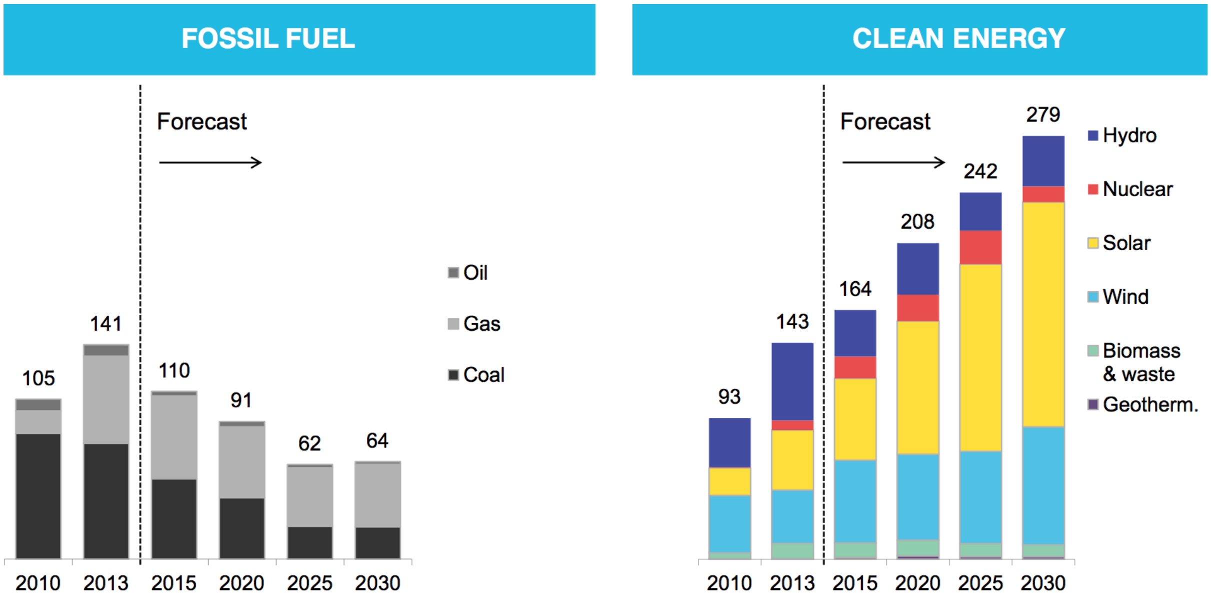


Figure: 6.1 Energy density of fuel

6.1.2 Availability

Coal, natural gas and petroleum are all examples of fossil fuels whose energy density is much greater than that of solar energy. Unfortunately, all three forms of fossil fuels must be mined or extracted from under the ground -- an expensive, and sometimes dangerous, task. But once the fossil fuel is extracted and delivered, it can be used anytime. For example, you can drive your car at 2 a.m. or 2 p.m., or bake a cake at noon or midnight. Solar energy is only available when the sun is shining. Short winter days, cloudy weather and the simple rising and setting of the sun all limit the availability of solar power. To make solar power available at other times you need to have some way of storing the energy -- which are currently available, but at a significant price.



(a)

(b)

Figure: 6.2: (a) Fossil Fuels Availability. **(b) Availability Of Clear Energy.**

6.1.2.1 Long-Term Availability

Fossil fuels are a limited resource. The gallon of gasoline you burned to get to grandma's took millions of years to make, but you used it in just a few minutes. So when you burn a gallon of gas, there's one less gallon to go around. Solar energy is -- at least for the next 4 or 5 billion years -- a renewable resource. If you collect 1,200 watt-hours on Tuesday, you will not reduce the amount of solar energy you can collect on Wednesday. No matter what you believe about how much coal, natural gas and petroleum remains buried in the Earth, those fossil fuels will run out far earlier than the life of the sun.

6.1.3 Emissions

Some energy is expended in the manufacture of solar energy systems, some toxic compounds are used in their fabrication and large solar farms can disrupt the habitat of their locales, but the net environmental impact of solar energy generation is extremely small. Fossil fuels can damage the environment during their collection and transport, but even more importantly, fossil fuel combustion produces environmental toxins. On top of that, they also produce huge volumes of carbon dioxide, which is a gas that influences the global climate.

6.1.4 Cost

Because solar power is generated in a completely different way from fossil fuel-based power, it's a little complicated to compare the price. Fossil-fuel plants are not as expensive per megawatt as solar power systems, but you'll need to pay for the fuel as long as you use the plant. Solar power costs more up front, but the fuel is free, and the maintenance costs are much lower than for fossil fuel plants. Putting the factors together, the basic costs of solar power generation are about two to three times the cost of fossil fuel plants. When you add in distribution costs and specific local variables, there are some places where solar energy is already as cheap as fossil-fuel energy -- and solar costs are likely to fall more than fossil-fuel costs.

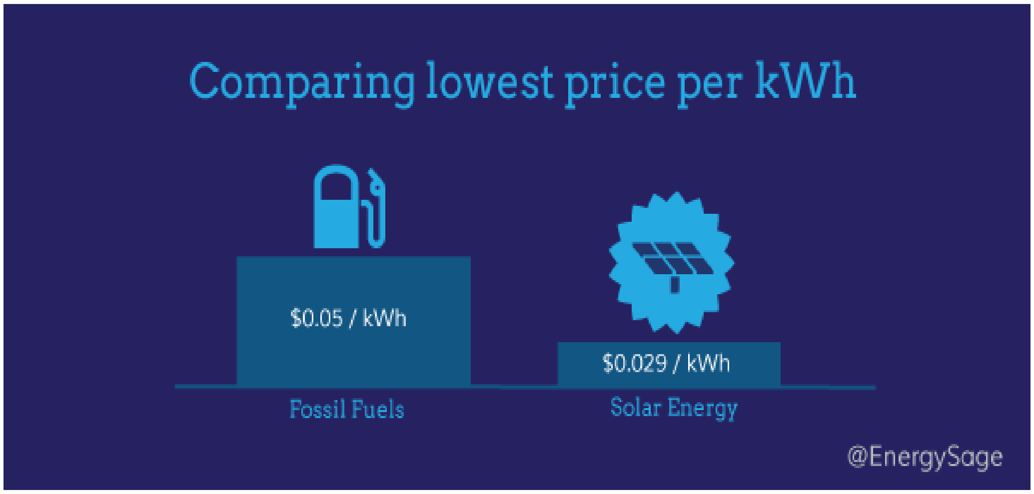


Figure: 6.3 comparison of cost pricing

6.2 Wind energy vs. solar energy

In the United States, wind power is significantly more popular than solar. Out of all the renewable energy produced in the U.S. in 2015, 19% came from wind, while just 6% came from solar power. Utilities and large scale operations prefer heavily utilize wind energy while homeowners prefer solar energy.

The primary benefit of wind over solar power for your home is that wind turbines aren’t dependent on sunlight. This means that they have the ability to generate power 24 hours a day, whereas solar panels only generate power during sunlight hours. Wind come with a significant caveat, however: in order to be effective, wind turbines need to be situated high above any obstacles that would block the wind.

A typical wind turbine for residential use is about 80 feet tall, and it needs to be in the path of some serious wind to produce power efficiently. Most installers recommend sites with average wind speeds of at least 12 miles per hour. If you live in a rural, windy area with lots of open space and few obstructions blocking the wind’s path, then installing wind turbines at your property can be a great option for renewable energy production. If you’re looking for a supplementary power source, rather than a primary one, you can also find smaller wind turbines at a relatively low cost that will provide an extra ‘boost’ of electricity.

In contrast, solar panels can be installed on almost any roof, as well as on the ground, and still produce enough power to meet the majority of your electricity needs. In the Energy Sage Solar Marketplace, the average solar shopper met 84 percent of their annual electricity needs with solar in 2015.

Wind turbines also have moving parts, which can result in more wear-and-tear and higher maintenance requirements. Unless you choose ground-mounted solar panels with a tracking system (a technology generally reserved for utility solar installations), your solar PV system will be stationary and require limited maintenance.

All things considered, solar isn’t as popular as wind on the utility scale, but is generally a more practical renewable option for residential energy production. An experiment by Inland Power & Light, a utility in the Pacific Northwest, underscores the comparative benefits of residential solar. After fielding many inquiries about the benefits of solar vs. wind energy for homes, the utility actually installed both technologies at their corporate headquarters in Spokane, Washington to provide a definitive answer to their customers. Their result: Over the course of 14 months, the solar panels produced about five times as much electricity as the wind turbine.

For most suburban and rural settings and applications; solar power is usually the best choice for the following reasons.

A solar power system:

- Has no moving parts
- Has better reliability and a 25 year warranty
- Requires less monitoring
- Does not require expensive maintenance
- Provides more predictable energy output based on BOM and NASA data.
- Better value for money in sites with average wind speeds less than 5 meters per second
- Is less conspicuous than a wind turbine
- Is totally silent in operation
- Allows for quicker installation with less cable required
- Is less susceptible to lightning damage
- Is less susceptible to high wind damage.
- Requires less space in most cases as the panels can be installed on a roof

6.2.1 Comparing Costs

With all of the factors to consider, all of the advantages and disadvantages to solar, wind and other alternative energy resources to take into account, there's one fundamental question everyone has about renewable energy systems: "What's it going to cost?"

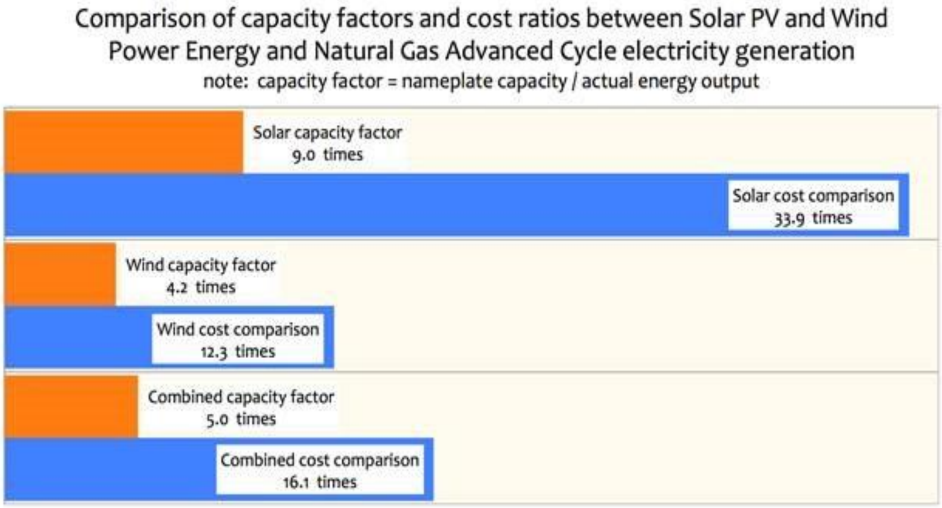


Figure: 6.4 cost comparison of Solar vs. Wind

- ## Solar

The total cost of a residential solar energy system varies substantially depending on several factors, including size of household, location, panel and accessory manufacturers, etc. Nevertheless, you should expect some steep upfront costs for the purchase and installation of any home solar system. However, those steep upfront costs are substantially mitigated by a federal government tax credit, through which the homeowner can claim a 30 percent credit for qualifying expenditures on his or her purchase of a home solar system. State and/or local incentives may also be available

- **Wind**

Like solar, residential wind energy systems come with steep upfront costs. Economies of scale play a big role in the cost of wind turbines. Residential or small farm-scale turbine systems, for example, come with lower costs overall, but a higher cost per kilowatt of energy production capacity. According to U.S Department of Energy's 2014 Distributed Wind Market Report, the average cost for turbines 2.5 to 10 kW in size (a 10 kW turbine, for example, is a reasonably sized unit for powering a large home) was $7,200 per kW, with small wind turbine installed costs trending downward.

Figure: 6.5 wind energy

6.3 HYDRO POWER VS. SOLAR POWER

Figure: 6.6 Hydro vs. Solar

Hydro and solar power technologies are two time-tested forms of renewable energy. While both of these technologies offer significant benefits to the environment compared to the burning of fossil fuels, such as coal or gas, each also comes with its own distinct set of advantages and potential drawbacks that affect energy policy and power production in the United States.

6.3.1 COST CONSIDERATIONS

In terms of production costs, hydropower holds a strong advantage over solar power. The U.S. Department of Energy calls hydropower the most common and least expensive form of renewable energy in the United States. Hydroelectricity represents 6 percent of all U.S. energy production, and accounts for 70 percent of all renewable energy generated in the United States. Solar installations tend to cost much more. For example, 1 megawatt-hour of electricity costs $90.3 in 2011 dollars to generate using hydropower, or $144.30 to generate using solar collectors, according to the U.S. Energy Information Administration.

6.3.2 ENVIRONMENTAL IMPACT

Solar power production poses few risks to the environment, according to the National Atlas of the United States. Much of the environmental cost of solar energy use comes from the manufacture, production and transportation of the collector panels themselves. Hydroelectric power generation, on the other hand, often comes with significant impact to the environment. Damming rivers impacts local habitats and ecosystems and may lead to flooding, changes in flow patterns and problems with fish migration.

6.3.3 SUPPLY STABILITY

Hydropower represents a more stable and reliable means of generating electricity than solar power. Solar power generation works best when the sun is at its peak, which generally happens during the middle of the day. After the sun sets, solar power systems have no more energy to draw from. Storms and clouds can also impact solar power production. The U.S. Department of the Interior calls hydropower more responsive than other systems for meeting peak energy demands. Hydro plants have the ability to switch systems on and off with ease to respond to changes in demand, which can help to eliminate blackouts and brownouts.

6.3.4 AVAILABILITY AND ACCESS

Solar energy can be used almost anywhere to power a home, generate electricity or run small appliances like roadside signs or even calculators. The U.S. Department of Energy's Solar Energy Potential Map shows that every location in the continental United States offers enough sunlight to generate at least 250 watts of electricity per square foot of collector space per day, with many locations capable of generating much more than that. Hydropower production, on the other hand, is limited to locations with access to a sufficient supply of running water to power turbines and other generating equipment. Many areas in the United States are considered exclusion areas, where federal or other statutes prohibit the use of hydropower production.

6.4 Solar energy vs. nuclear energy

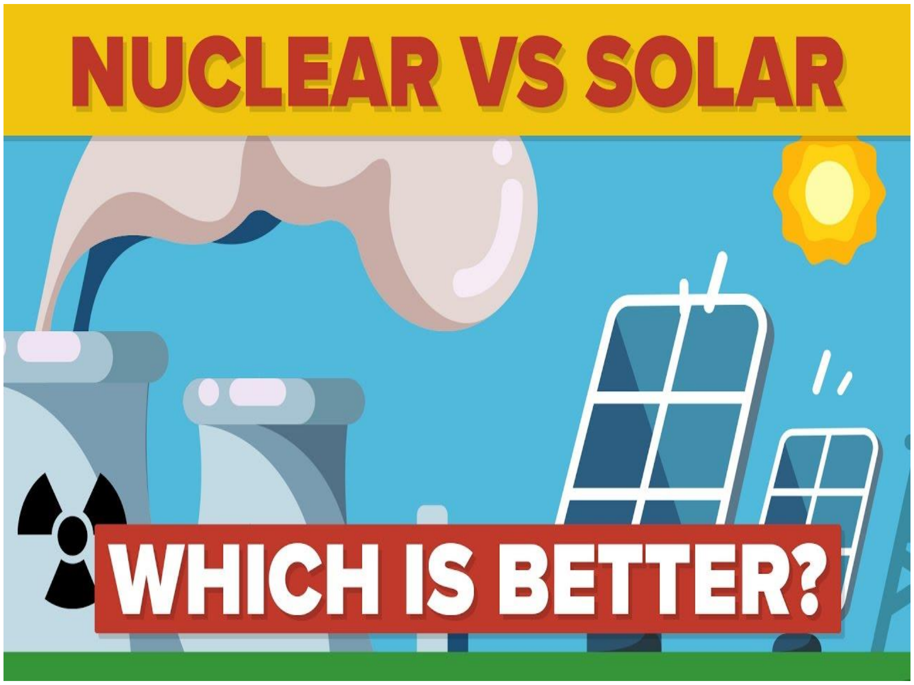


Figure: 6.7 Solar vs. Nuclear

To produce electricity, both solar and nuclear power use the energy produced by mass-to-energy conversion, Energy = Mass x (Speed of Light, squared). This is where the commonality ends.

Solar power uses radiation that results from the heat produced by nuclear *fusion*, with the reactor (the sun) located a distance away (93 million miles) that is sufficient to keep us relatively safe. But to avoid radiation damage to your health, don't forget to use your secondary radiation shield (i.e., sunscreen). Also, we need to avoid doing things that damage our primary radiation shield (the ozone layer in the upper atmosphere).

Nuclear power uses the heat produced by nuclear *fission*, with the reactor located here on planet earth, behind lead, steel, and concrete shielding. The fission process results in radioactive materials that must be taken out of the reactor and stored elsewhere (behind other lead, steel, and concrete shielding). All of the facilities and processes involved are subject to the effects of age, human error, and natural catastrophe. In the event of radiation leakage through the shielding, the only practical thing you can do to protect your health is to get far away from the source (if you can’t get far away, then swallowing iodine tablets might be advisable). And then trust the same experts that design, construct, operate, and maintain such facilities to deal with the problem. Overall their track record is not bad, but also not perfect (they are, after all, mere mortals)

6.5 Geothermal and Solar

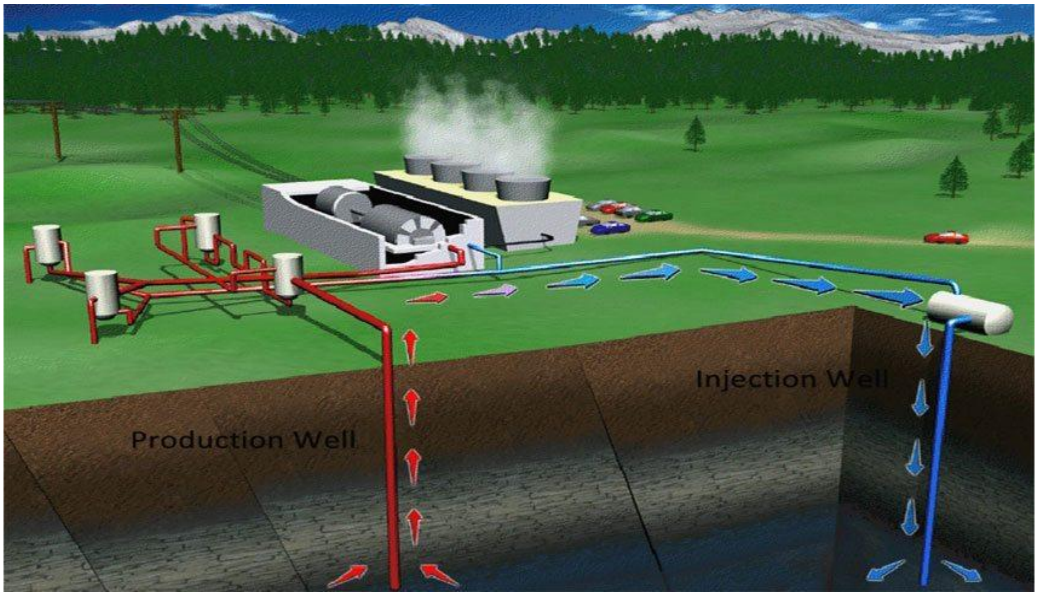


Figure: 6.8 Solar vs. Geothermal

No matter where you are on the planet, if you dig just six feet underground, you'll find the soil there maintains a steady temperature of around 50°F–no matter what the weather's like up top. You may have experienced this phenomenon before in cave systems, which generally maintain a consistent temperature year-round.

Dandelion's geothermal system pumps water into a closed loop into your house, and down 300 to 500 feet underground. In the winter, the solution enters your house at 50°F, where electricity is used to heat from 50°F up to your desired temperature. In the summer, this process gets reversed. The heat pump uses a little electricity to pump hot air into the cooler ground.

Every geothermal heat pump system uses a small amount of electricity, roughly equivalent to the amount of electricity you'd use if you bought a second, energy-efficient refrigerator. Geothermal heat pumps use about 75 percent less electricity than a traditional electric HVAC system, and are both cheaper and more eco-friendly than using heating oil or propane.

Here's where solar comes in, since solar = electricity. With solar electricity + geothermal, you can eliminate your home's entire carbon footprint. Homeowners who install a residential solar system generate most (if not all) of their home's electricity needs from the sun, allowing them to not only keep the lights on, but also power their geothermal heat pump. If you own your solar and geothermal systems outright, you'll have abundant electricity, heating and cooling covered for free.

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