www.insightcore.com

Journal of Buildings and Sustainability

2016
Vol. 1
No. 1

Sustainable Technologies for Green Buildings: An Overview

Osman Attmann[a1]

[a] *College of Architecture and Planning, University of Colorado at Denver, United States*

A B S T R A C T

Energy generation is directly related to human needs, and energy consumption can be correlated with a society's economic growth and development (Chevalier, 2007). Today, the amount of energy needed is greater than ever. Unfortunately, more than 80% of our energy generation today is through fossil-based resources, which are exhaustible and non-renewable. Buildings account for nearly half of all energy consumption and raw material use around the globe. According to the 2011 Buildings Energy Data book (USDE, 2011), commercial and residential buildings account for 39.7% of the energy consumed (residential 21.5% and commercial 18.2%). Buildings are also responsible for 76% of the electricity used (architecture2030, 2009). This is clearly an architectural problem, which requires an architectural solution. One of the tenets of this solution is to find alternative ways to generate and use energy for buildings. This paper investigates and surveys existing, emerging, and future green technologies, as they apply to residential, commercial, and institutional buildings. It provides an overview to the advanced technologies used to construct high-performance buildings.

Keywords: buildings, green technology, energy generation

1. Definitions

Technology is defined as a practical application of (technical) knowledge, which requires the use of tools and crafts to control and adapt our environment. The term originates from the Greek "techne" (craft) and "logia" (saying); however, its current use is inherently broad and elusive. It can refer to material objects (such as machines) or to broader knowledge areas (such as systems and methods). Today, most dictionaries define technology as an "applied science," assuming the two terms have a causal relationship. Although these terms often seem to overlap (especially since the Industrial Revolution), there is actually a clear distinction between them and in how they have progressed throughout history (McClellan and Dorn, 2006).

Practical knowledge is a key component within technology. Although knowledge is a prerequisite for developing technologies, it is not necessary for that knowledge to be either scientific or systematic. In fact, there is a clear distinction between the terms "knowledge," "science," and "technology." "Knowledge" is a state or fact of knowing. The American Heritage Dictionary defines the term as "familiarity, awareness, or understanding gained through experience or study." (4th Edition, 2004). As stated earlier, 'technology' is the use of that knowledge to solve practical problems. Like technology, "science" also uses knowledge but in a systematic manner. Accordingly, "science" is defined as the systematic knowledge of the physical or material world gained through observation and experimentation. In short, science is an organized knowledge, and technology is a practical application of that knowledge (Spencer, 1897; Francis, 2007).

The history of architectural technology follows more or less the same path as the overall history of technology, but with additional elements. Knowledge, technology, and science are incorporated with art and materials to define 'architectural technology.' However, as in other fields, these terms have different meanings when applied to architecture. Parallel to the original definition of 'technology,' this paper defines 'green technology' as: (a) sustainable, ecological, and performative methods and tools; (b) an efficient means to an end; and/or (c) as an ensemble

[1] Email: o.attmann@ucdenver.edu

of green buildings. But green technology also needs green architectural practices, like the creation, fabrication and the use of green concepts. This includes non-material techno-facts, such as green energy generation and energy retention methods (e.g., passive design methods). Although, they require different materials to function, architectural green technologies are not architectural green materials. For instance, the act of converting solar energy into electrical energy is a technology, not a material.

2. Energy Generation

In brief, energy generation depends on resources capable of producing energy, and related extraction methods necessary to utilize these resources. Energy generation is directly related to human needs, and energy consumption can be correlated with a society's economic growth and development (Chevalier, 2007). Today, the amount of energy needed is greater than ever. Unfortunately, more than 80% of our energy generation today is through fossil-based resources, which are exhaustible and non-renewable.

Therefore, it is daily becoming more critical to develop new energy generation resources, technologies, and methods. Interest in generating green energy, because of its sustainable and ecological nature, has increased dramatically within the last couple of years. Mandates for energy sustainability (recommended by federal and state governments) have particularly facilitated this increase. Although currently these mandates are voluntary, twenty-seven states have issued renewable portfolio standards (RPS), and a 2009 legislation introduced by Senator Tom Udall requires utility companies to produce at least 25% of their electricity from renewable resources by 2025.

The following energy resources do not depend on fossil-based resources, sustain the environment rather than deplete it, and offer great promise for architecture: (1) Bio Energy, (2) Solar Energy, (3) Geothermal Energy, (4) Wind Energy, (5) Water Energy, (6) Blue Energy, (7) Fuel Cell Energy, and (8) Hybrid Systems Energy.

3. Bio Energy

Bio-energy is energy derived from biomass, which is defined as all living plant matter and organic waste. Examples of these are: forestry residues, trees, grasses, animal and ethanol waste, sewage, garbage, wood construction residues, landfill gas, and other components of municipal solid waste (Tester, Drake et al., 2005). Bio-mass is a renewable resource, meaning it is a part of the flow of resources that occurs naturally and repeatedly within the environment.

Bio-energy needs a continuous carbon cycle between the atmosphere and the earth. In this cycle, carbon dioxide is taken from the atmosphere for plant processes such as photosynthesis and converted into biomass. From this process, additional CO2 is produced and transformed into energy (see figure). In order for this process to be effective, the continuity of the carbon cycle is essential. This explains why fossil-based energy resources are not considered biomass; their ancient biological origins have been out of the carbon cycle for too long.

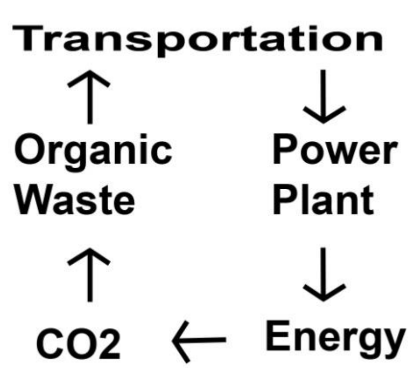

Figure 1. Bio Energy Cycle

Throughout history, biomass had been the primary fuel source for all civilizations. But as the Industrial Revolution progressed, especially in Europe, forests were severely depleted and coal was gradually introduced as a replacement fuel. In the United States, biomass was a primary source of energy up until the 19th century. However, by 1885 its use was being outpaced by coal, and by 1915, by oil and gas (Hottel & Howard, 1971; Tester, Drake, Golay, Driscoll, & Peters, 2005). Today, many developing countries still use biomass for 90% of their energy source, especially for daily activities such as heating and cooking. Although biomass is an excellent green energy source, the current method of collection, production, and processing creates harmful effects. Primitive processing techniques and inadequate devices for energy conversion waste most of the biomass and create unhealthy living environments for people (e.g., massive indoor pollution). In addition, uncontrolled overpopulation places an overwhelming demand on indigenous biomass, causing land depletion and even desertification, as seen in some parts of Africa today (Hottel & Howard, 1971).

4. Bio-Energy Types

There are primarily two types of bio-energy—traditional and advanced. Traditional bio-energy comes mostly from solid biomass sources, such as wood, charcoal, and other biomass pellets. Currently, over 80% of the energy from traditional solid biomass sources consumed as fuel for heating and cooking is generated with minimal efficiency (DOE, 2006). Advanced bio-energy requires converting biomass into a liquid and/or gas form in order to produce electricity. Advanced bio-energies, such as biogas and liquid biofuel, have increased dramatically in recent years; other forms (e.g., ethanol, biodiesel, and algae fuel) are in use but are still developing technologies.

4.1 *Solid Bio-Energy*

Solid bio-energy is derived from solid renewable resources. There are many forms of solid bio-energy material that can be directly used in gasification and combustion technologies. Agricultural and forestry biomass (and their byproducts) constitute most of the solid bio-energy raw materials. They include:

- Forestry
  - Wood pellets
  - Woodchips
  - Charcoal
  - Sawdust
- Agriculture
  - Straw
  - Husks
  - Stalks
  - Bagasse (fibers left after sugarcane or sorghum stalks are crushed in juice extraction)
- Other
  - Construction waste
  - Municipal byproducts

Figure 2. Wood pellets made from compacted sawdust have high combustion efficiency and are used as bio-fuel. (Courtesy of Scion)

4.2 *Liquid Bio-Energy*

Liquid bio-energy is derived from plants and animal fats. There are two major liquid bio-energy types—bioethanol and biodiesel. Although they only make up about 2% of the transportation fuel today, they are expected to replace existing fossil-fuels in the future.

- Bioethanol
    - Made from sugar and starches
- Biodiesel
    - Made from plant oils and animal fats

4.3 *Gas Bio-Energy*

Gas bio-energy is derived from methane and carbon dioxide, which are produced when bacteria break down biomass (e.g., animal, municipal and landfill waste, and energy crops). It can be mixed with (or used as an alternative for) natural gas. Major forms of gas bio-energy are:

- Biogas
- Biopropane
- Syngas
- Synthetic Natural Gas (SNG)

Advantages of Bio-Energy

- Directly extracted from biomass
- Renewability and domestic availability
- Evenly distributed energy source
- Biomass utilization diverts landfill accumulation
- Potential to prevent CO2 buildup in the atmosphere

Disadvantages of Bio-Energy

- Low energy density (compared to coal, liquid petroleum, or other petroleum-derived fuels)
- May contribute to environmental pollution
- Contributes to the depletion of Earth’s resources (land, water, plants, forest, food)
- High embodied energy (transportation costs do not justify the energy savings)

5. **Biomass Conversion Processes**

To generate clean bio-energy requires biomass power generation facilities with advanced technologies that can process these materials under controlled conditions. Bio-energy can be generated by thermochemical, biochemical, and combustion processes (Klass, 1998; Moo-Young, Lamptey, Glick, & Bungay, 1987; Song, Gaffney, & Fujimoto, 2002; Wereko-Brobby & Hagan, 1996).

5.1 *Thermochemical*

Although this process does not produce bio-energy, it converts biomass into a convenient form of bio-energy carrier, such as methanol, gas, or oil. This conversion is accomplished by carbonization, gasification, or pyrolysis. For more information about the thermochemical process, see “Progress in Thermochemical Biomass Conversion” (Bridgwater, 2001), “Pyrolysis and Gasification of Biomass and Waste” (Bridgwater, 2003), and “Advances in Thermochemical Biomass Conversion” (Bridgwater, 2008).

5.2 *Biochemical*

This process uses micro-organisms to produce bio-energy. The biochemical production process uses several different technologies, such as (1) anaerobic fermentations that convert plant, human, and animal waste into bio-gas and fertilizers; and (2) anaerobic digestion that uses microbial decomposition of biomass in landfills. For more information about the biochemical process, see “Biotechnology of Biomass Conversion: Fuels and Chemicals from Renewable Resources” (Wayman & Parekh, 1991), and “Biomass Conversion and Technology” (Wereko-Brobby & Hagan, 1996).

5.3 *Combustion*

This process is used for direct power generation. It is one of the most efficient conversion technologies today with 30% efficiency in electricity generation and more than 75% in cogeneration of electricity and heat. For more information about the combustion process, see “The Handbook of Biomass Combustion and Co-firing” (Loo & Koppejan, 2008), and “Biomass Combustion Systems” (Reupke, Sarwar, & Tariq, 1994).

6. Solar Energy

The second type of green energy generation is solar energy. Solar energy is gained directly from the sun, our most abundant source of energy. The sun emits radiation during the fusion process, which produces various wavelengths of electromagnetic radiation. The earth captures only a small fraction of that energy from the interstellar void (Kambezidis & Gueymard, 2004; Vita-Finzi, 2008), and about 30% of the radiation that does reach Earth is immediately reflected by various layers (i.e., atmosphere, clouds, the earth’s surface) (Houghton et al., 2001).

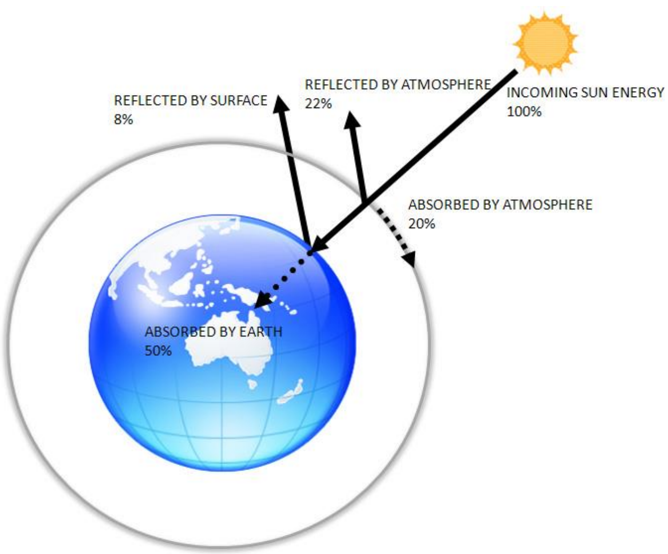

Figure 3. Solar Radiation Distribution. The earth and the atmosphere absorb approximately 70% of the solar radiation. 30% of the incoming radiation is reflected.

Consequently, the amount of solar energy the earth receives in a year is approximately 3.1 million exajoules (EJ) (Houghton et al., 2001). According to the 2008 International Energy Outlook Report, our global energy consumption is 462 EJ/year (2005) and is expected to double by the year 2030 (DOE, 2008). The vast discrepancy between these production and consumption statistics clearly show that the earth receives approximately 6,900 times more energy from the sun than we consume globally. If harvested correctly, even a small fraction of the sun’s tremendous energy output could provide more than we need.

Existing solar technologies convert solar energy into other forms of energy, namely electricity and heat. Although there are numerous ways to convert solar energy into usable energy (Sark, Patel, Faaij, & Hoogwijk, 2006), three primary conversion technologies are used: (1) Greenhouse, (2) Solar Thermal, and (3) Solar Electricity.

6.1 *Greenhouse*

The passive Greenhouse technology is the oldest and simplest way to harvest solar energy, wherein the heat of the sun penetrates a special window system and is trapped inside. This system has been primarily used to provide adequate temperature control for plants in cold weather and climates (Hanan, 1997; Marshall, 2006; McCullagh, 1978).

6.2 *Solar Thermal*

Solar Thermal technology uses the same principle as the greenhouse technique (i.e., using sunlight to create heat) but is more advanced and needs water to operate. It was originally developed to pump water in the nineteenth century. Once solar-thermal technologies receive sunlight, they concentrate the light and generate heat. The generated heat warms the water, which can either be circulated and used directly, or it can be used to drive a turbine that generates electricity (Peuser, Remmers, & Schnauss, 2002). There are three types of solar-thermal systems: parabolic troughs, parabolic dishes, and power towers.

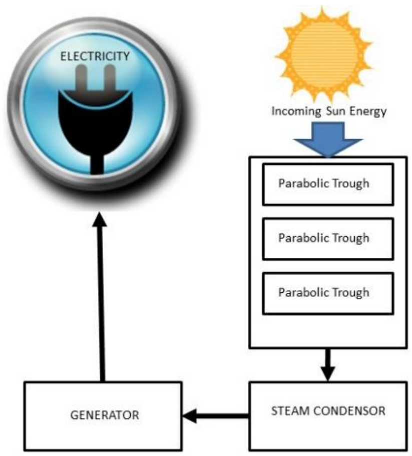

Figure 4. Parabolic trough collectors

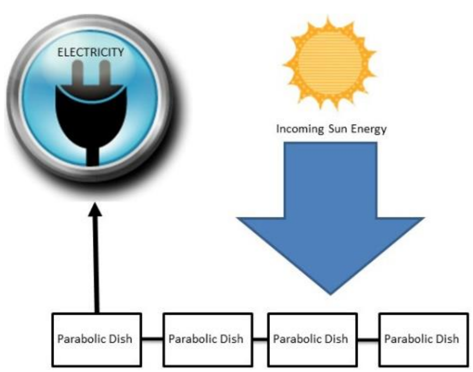

Figure 5. Dish power plant

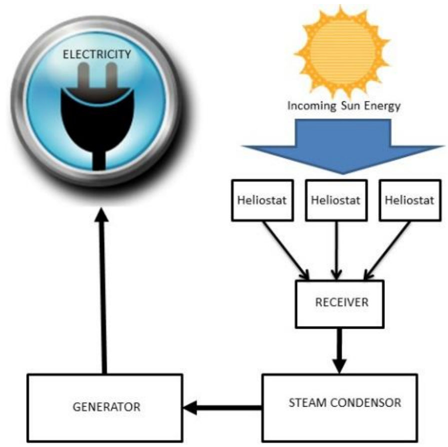

Figure 6. Power tower plant

The parabolic trough is the most established low-cost solar-thermal technology available today. Though parabolic dish systems have great potential for performance and cost efficiency, they are currently more expensive than the trough systems and are still under development. One of the main advantages of parabolic dish systems, however, is their flexibility. Since these systems are modular, they can be used independently as a single dish or grouped together to create solar-thermal dish farms. Power towers are mostly used for large grid systems in the 50-200 MW size, and require a large area to operate (Duffie & Beckman, 2006; Peuser et al., 2002). They work with an extensive number of light-tracking mirrors (heliostats) that reflect light to the tower receiver.

7. Solar Electric (Photovoltaic)

Of the solar electric systems currently available, photovoltaic (PV) technology is the most advanced and mature. The material used in this technology will be covered in the next chapter, but briefly, PV technologies are non-mechanical devices that convert sunlight into electricity. First discovered by French physicist Edmond Becquerel in 1890, and later developed by Bell Laboratories researchers in 1954, PV technologies are widely used in our everyday lives. Their applications range from pocket solar calculators to large systems that power our buildings.

A photovoltaic system consists of: PV cells, mounting hardware, electrical connections, power conditioning equipment, and an energy storage device. Individual PV cells, which can be as small as a dime, can generate between 0.5 to 1.2 volts of electricity. Individual cells can be grouped into modules to form larger collectors, which can in turn be further grouped into PV arrays, necessary for industrial-level electricity production. The number and size of the modules can vary depending on: the availability and intensity of the sunlight, the geographical location of the modules, and the user's needs.

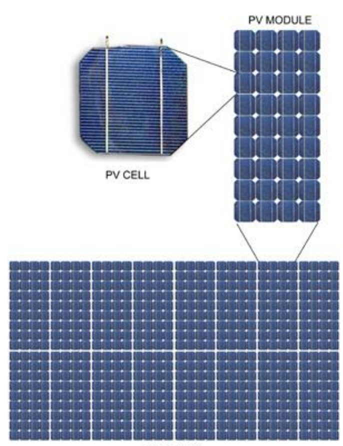

Figure 7. Photovoltaic systems

A majority of PV cells are made of silicon, and there are three main PV technologies used commercially in the market today: (1) Single Crystalline, (2) Polycrystalline, and (3) Thin Film.

7.1 *Single Crystalline PV-cells (SCPV)*

Single Crystalline is a first-generation PV cell, and while it is currently the most efficient technology, it also has high production costs. SCPVs are made of large cylindrical, single-crystal silicon, which is produced in an oven and sliced into wafers. This is a very clean and efficient process with very low degradation (between 0.25% and 0.50% per year). SCPV's electricity conversion efficiency rate averages between 12-15%, and it has an exceptional 24% efficiency in laboratory conditions.

7.2 *Polycrystalline PV-cells (PCPV)*

Polycrystalline cells are made of silicon that is cast into cylinders, and then sliced into wafers. Since this process is less precise than SCPV fabrication, it has lower manufacturing costs. PCPV's conversion efficiency is slightly lower (10-11% on average) than SCPV, but overall it is quite comparable. Degradation, assembly, and doping processes are the same as for SCPV.

7.3 *Thin Film*

Thin film is a low-cost, low-efficiency PV technology with an average electricity conversion rate of 5-7%. Its manufacturing process is different from that of crystalline systems, as it involves vaporizing and depositing silicon onto glass, stainless steel, or plastic. It is also less expensive to manufacture because of its large module production, use of fewer semiconductor materials, and lack of individual wiring and framing costs. Because of its low efficiency,however, thin film technology is primarily used in small consumer products. Recently, more advanced, efficient (13.5% conversion rate) thin film materials have been created by stacking multiple layers of PV materials within a module.

Table 1. Efficiency rate of PV technologies

	Single Crystalline	**Polycrystalline**	**Thin Film**
Typical Efficiency	12%-15%	11%-14%	5%-7%
Maximum Efficiency	24.7%	19.8%	13.5%

Advantages of Solar-Energy

- Free energy with unlimited supplies
- Environmentally safe (produces no pollution)

Disadvantages of Solar-Energy

- High initial cost
- Inconsistent delivery of energy (the amount of sunlight is not constant, depending on location, time, and weather conditions)
- Large surface area installation is required to produce sufficient energy
- Indirect high embodied energy (production of solar energy technologies)

8. Geothermal Energy

A third method of 'green' generation of energy is geothermal. Geothermal energy is produced by using the heat below the earth's surface. This heat originates from the earth's core 4,000 miles below the surface, where temperatures can reach up to 9,000° F. Although most geothermal basins are deeply rooted underground and are, therefore, unseen, they occasionally burst forth in the form of hot springs, geysers, volcanoes, and fumaroles. In addition to the earth's core, geothermal energy may emerge from other sources, such as from continental plate frictions and the decay of naturally-occurring radioactive substances within the crust. Geothermal resources have the potential to provide a tremendous amount of energy, up to 50,000 times more energy than all the earth's oil and gas resources combined (Berinstein, 2001).

There are various ways to extract geothermal energy. The simplest is to drill into geothermal reservoirs in order to bring the heat source (steam or hot water) to the surface. Geothermal heat pumps are necessary for residential use, and, for commercial use, power plants are built on the surface to convert geothermal energy into electricity. There are three main types of power plants: (1) Dry Steam, (2) Flash Steam, and (3) Binary Power.

8.1 Dry Steam Plants (DSP)

DSPs are the most widely used geothermal energy power plant today. They must be located near accessible steam reservoirs, where the steam is tapped and piped directly to the plant in order to power the generator's turbines.

8.2 Flash Steam Plants (FSP)

FSPs convert high pressure hot water into steam, which powers the generator's turbines. Their efficiency is 50% lower than for DSPs because of energy losses during the water to steam conversion (Berinstein, 2001). However, the condensed water can be recycled and reused.

8.3 Binary Power Plants (BPP)

BPPs are complex versions of flash steam plants and are especially useful in that they allow cooler geothermal reservoirs to be tapped. The cooler reservoir water is pumped into a heat exchanger and then back down into the reservoir. Then another liquid with a lower boiling point is rapidly pumped in. The heat is sufficient to vaporize the second liquid, and the steam that is produced powers the turbines. As in FSPs, the second liquid is condensed and reused.

8.4 Geothermal Heat Pumps (GHP)

Geothermal heat pumps are used to heat or cool residences, rather than relying on fossil fuels. They run on the same principle as commercial power plants, utilizing the constant heat source of the earth's interior. The Environmental Protection Agency (EPA) states that a geothermal system can save between 30-70% on home heating and 20-50% on home cooling over conventional systems (EPA, 2008). However, installing these systems is still quite expensive.

A geothermal heat exchanger system consists of indoor pump equipment, a ground loop, and a flow center to connect the indoor and outdoor equipment. The ground loop uses the temperature of the earth or water, several feet underground, to heat or cool the dwelling. A pump circulates a temperature-sensitive fluid through this ground loop, and since the loop is buried below the freezing line, the temperature stays constant all the time (approximately 60° F). GHPs transfer stable temperatures into houses but in reverse order according to the season. As such, in the winter warm fluid carries heat into the house, and in the summer cool fluid draws heat out of the house.

Advantages of Geothermal Energy

- Clean, No polluting emissions
- Reliable
- Flexible
- Regional (contributes to local economy)
- Resource availability

Disadvantages of Geothermal Energy

- Not a renewable resource like sunlight and wind
- Location-specific
- Problems with accessibility
- Potential Environmental Damage (e.g., erosion, sedimentation, toxic antifreeze solutions in heat pump systems)
- Residential heat pump systems are expensive

9. Wind Energy

Wind energy is yet a fourth form of green energy, related to solar energy, as wind is generated by solar patterns and their influence on the earth's topography. The planet's rotation, climate, and topography contribute to the speed and direction of the wind that will be harnessed. However, wind energy provides a significantly smaller amount of energy than solar energy. The global theoretical wind energy potential is only 2% of the amount of solar energy that reaches our atmosphere (Hubert, 1971; Sark et al., 2006).

Wind energy turns a windmill's blades on a rotor that is connected to a main shaft. The main shaft spins a generator, producing energy. The amount of energy generated depends on various factors, such as the speed and the direction of the wind. Even though strong winds can produce more energy, it is difficult to design and maintain windmills that can withstand such force. Another problem is proximity of the wind generation facilities to the distribution centers and/or to the homes. The farther the distance, the more distribution lines that need to be extended. This affects the quality and cost of the energy transmission.

There are three types of wind machines used today: (1) Horizontal-axis, (2) Vertical-axis, and (3) Wind Amplified Rotor Platform.

The Horizontal-axis is the most widely-used wind machine today. This type has three long blades similar to an airplane's propeller, installed at the top of a tower whose height is comparable to that of a 15 to 20-story building. The taller and wider the wind machine's blades are, the more wind that can be captured.

Vertical-axis machines have vertical blades attached from top to bottom. These machines are thought to be more efficient than horizontal-axis types, generating more wind energy with less wind. However, they account for a very small percentage of the windmill power generation today.

Wind Amplified Rotor Platform (WARP): WARP is a completely different wind machine design, as it does not have blades. Instead, independent modules are stacked on top of each other with small high-capacity turbines mounted on each module. Their concave surfaces significantly amplify the wind's speed. WARP systems are considered to be very efficient, using less wind and land area, yet generating more power. These systems are currently under development and are expected to be used in offshore oil platforms and remote telecommunication towers.

Advantages of Wind Energy

- Clean, No emissions
- Reliable
- Renewable
- Regional (contributes to local economy)
- Resource availability

Disadvantages of Wind Energy

- Location-specific
- Problems with accessibility
- Requires land allocation and wind farming
- Noisy
- Potentially dangerous for birds

10. Hydro Energy

Hydro (water) energy, generated from the force of moving water, is a fifth ecologically-sensitive type of generating power. It is a clean, renewable energy resource but usually requires large installations, such as dammed water, to drive a water turbine and generator. The amount of generated energy is controlled by pumping water to different reservoir levels. This pumped storage technique is used in large-scale grid power stations, and today they provide 20% of the world's energy and 52% of the total electrical energy generated from renewable sources (REN21, 2009).

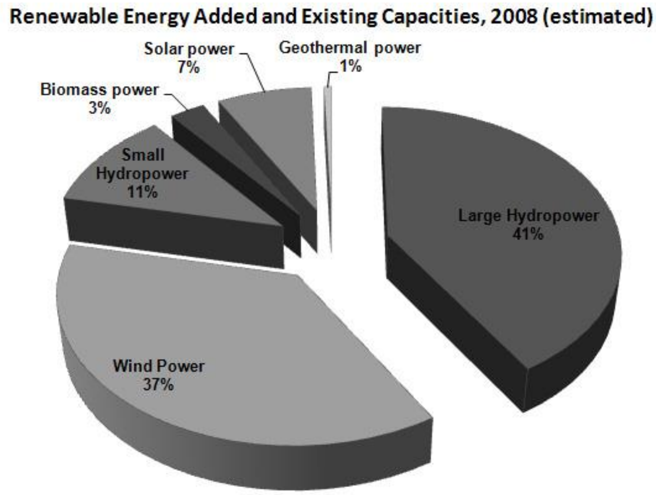

Figure 8. Renewable Energy Added and Existing Capacities, 2008 (estimated). Sources: Renewables: Global Status Report, 2009 Update (REN21, 2009).

Although hydro energy is primarily generated by large installations, there are smaller, mobile hydro-generators available for individual home use. These devices, which have a generating capacity between 50 kW and 1000 kW, produce enough electricity to power homes built near water or for home-boats. The advantages of the mobile hydropower generators are that they operate on any available stream without requiring additional water storage, reservoir, and/or dams. The amount of energy generated depends on the amount of available water, the power of the stream, and the size of the residence. The problems with small hydro-generators are their complexity and site specificity. In addition, while these devices are inexpensive to operate, they are costly to buy, install, and maintain.

11. Blue Energy

Yet another source of clean energy is Blue Energy, also called osmotic energy. It is generated from a chemical reaction between fresh water and sea water. Energy is retrieved from a dilution process, designed to balance the salt concentration differences between the two solutions, in a process called ‘pressure osmosis’ or ‘reverse electro dialysis.’

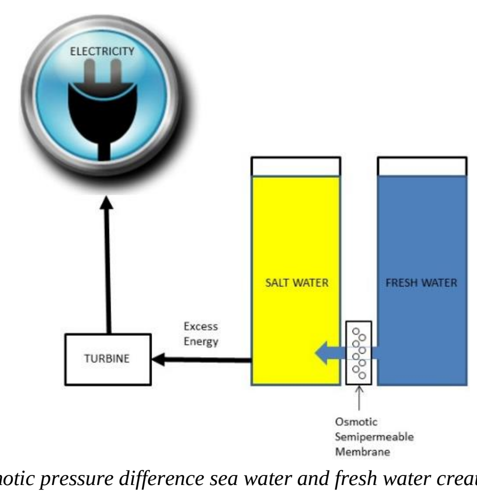

Figure 9. Osmotic pressure difference sea water and fresh water creates Blue Energy

This is a new, promising, renewable clean energy source with no harmful environmental effects. It can either be installed near a salt water resource (i.e., at the mouth of a river) or operated independently using stored water. Although the technology has been developed, there are no commercial applications available today. This is primarily because its complexity requires operational expertise to run, and the costs associated with its installment and use, are high.

12. Fuel Cell Energy

Fuel cell energy is a sixth promising method of generating energy. A fuel cell is a kind of battery that produces electricity from the reaction between an externally supplied fuel and an oxidant, in the presence of an electrolyte. There are different fuel cell combinations, depending on the type of fuel and/or oxidant. For example, a hydrogen fuel cell uses hydrogen as the fuel and oxygen as its oxidant. Other fuels may include (but are not limited to) methane, ethanol, bio-fuels, or chlorine. Although they resemble batteries, these devices are different in that they generate but do not store energy. Traditional batteries store energy chemically in a defined and enclosed system, whereas fuel cells consume renewable reactants. Thus, these cells cannot store energy, but they can provide non-stop, continuous operation as long as the required energy flow is maintained.

Fuel cells are manufactured in different sizes and capacities, and can be used for products ranging from small consumer electronics to energy generators for large buildings. For home use, fuel cells are currently being developed by various manufacturers, such as General Electric Fuel Cell Home Power Plant (HomoGen, 7000), Tokyo Gas with Ballard Power Systems and Matsushita Electric (1 kilowatt combined heat and power fuel cell generator), and Astris Energy of Canada with Alternate Energy Corp (4-kilowatt residential fuel cell).

Fuel cells provide clean, renewable energy and do not need distribution lines. Small-size home fuel cell units generate about 10 kW and produce heat as a by-product. This heat can then be used as a thermal co-generation system for applications such as domestic hot water and space heating. Fuel cells can be used in conjunction with power grid systems, or be used independently as an off-the-grid system in remote areas. The main problems associated with using this energy for home use are its complexity, fuel regulations and liability issues, and high cost.

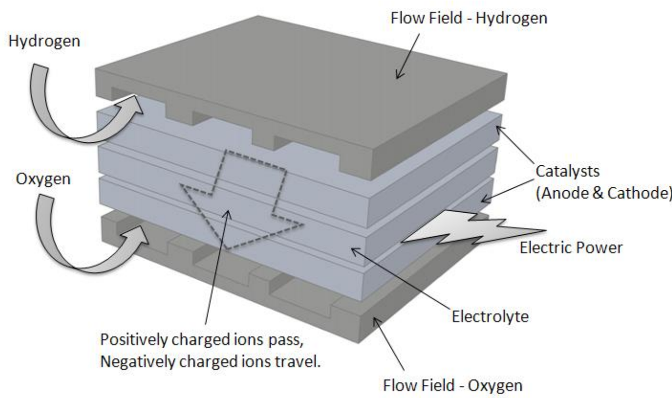

Figure 10. Fuel cells provide clean, renewable energy without distribution lines

13. Hydro Systems

The eighth and last source of energy generation with no damaging environmental impact is the hybrid system. This is a method that uses two or more distinct power sources to run a device. Examples could include: an on-board rechargeable energy storage system (RESS) with a fueled power source (internal combustion engine or fuel cell); air and internal combustion engines; and PV modules and wind turbines with electric power.

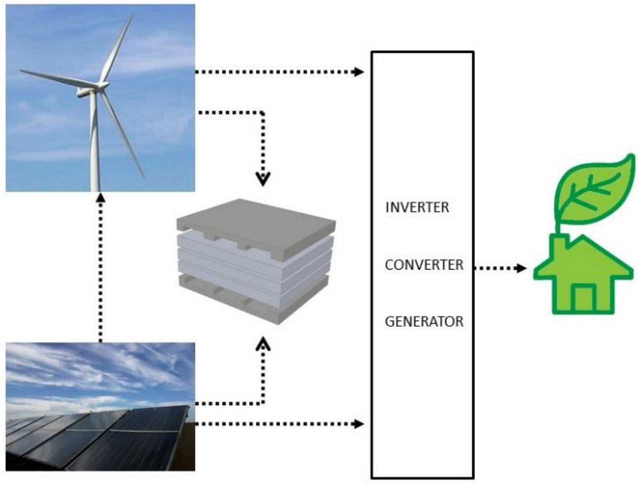

Figure 11. Hybrid power systems

REFERENCES

Architecture2030. (2009). "The 2030 Challenge." from http://www.architecture2030.org.

Berinstein, P. (2001). *Alternative Energy* (1st Edition ed.). Westport, CT Oryx Press.

Bridgwater, A. (Ed.). (2001). *Progress in Thermochemical Biomass Conversion* (1st Edition ed.). Oxford ; Malden, MA: Wiley-Blackwell.

Bridgwater, A. (Ed.). (2003). *Pyrolysis and Gasification of Biomass and Waste*. Newbury Perks, UK: CPL Press.

Bridgwater, A. (Ed.). (2008). *Advances in Thermochemical Biomass Conversion* (1st Edition ed.). New York City, NY: Springer.

Chevalier, J.-M. (2007). Energy Economics and Energy Econometrics. In J. H. Keppler, R. Bourbonnais & J. H. Keppler (Eds.), *The Econometrics of Energy Systems* (1st Edition ed., pp. Introduction, xiii-xxv). New York, NY: Palgrave Macmillan.

DOE. (2006). Biomass Energy Databook: U.S. Department of Energy and Energy Information Administration (EIA).

DOE. (2008). International Energy Outlook - 2008: U.S. Department of Energy and Energy Information Administration (EIA).

Duffie, J. A., & Beckman, W. A. (2006). *Solar Engineering of Thermal Processes* (1st Edition ed.). New York, NY: Wiley.

EPA. (2008). Heating and Cooling Efficiency of Geothermal Heat Pumps. In U. S. D. o. Energy (Ed.), *Energy Efficiency and Renewable Energy*: Environmental Protection Agency (EPA).

Hanan, J. J. (1997). *Greenhouses: Advanced Technology for Protected Horticulture* (1st Edition ed.). Boca Raton, FL: CRC Press.

Hottel, H. C., & Howard, J. B. (1971). *New Energy Technology - Some Facts and Assessments* (1st Edition ed.). Cambridge, MA: MIT Press.

Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., Linden, P. J. v. d., & Xiaosu, D. (Eds.). (2001). *Climate Change 2001: The Scientific Basis* (1st Edition ed.). New York, NY: Cambridge University Press.

Hubert, M. K. (1971). The Energy Resources of the Earth. *Scientific American*(225), 60-84.

Kambezidis, H., & Gueymard, C. (2004). *Solar Radiation and Daylight Models* (2nd Edition ed.). Oxford ; Burlington, MA Elsevier Butterworth-Heinemann.

Klass, D. L. (1998). *Biomass for Renewable Energy, Fuels, and Chemicals* (1st Edition ed.). San Diego, CA: Academic Press.

Loo, S. v., & Koppejan, J. (Eds.). (2008). *The Handbook of Biomass Combustion and Co-firing* (1st Edition ed.). London, UK: Earthscan Publications Ltd. .

Marshall, R. (2006). *How to Build Your Own Greenhouse* (1st Edition ed.). North Adams, MA: Storey Publishing.

McCullagh, J. C. (1978). *The Solar Greenhouse Book* Emmaus, PA: Rodale Press.

Moo-Young, M., Lamptey, J., Glick, B., & Bungay, H. (1987). *Biomass Conversion Technology: Principles and Practice* (1st Edition ed.). New York, NY: Pergamon Press.

Peuser, F. A., Remmers, K.-H., & Schnauss, M. (2002). *Solar Thermal Systems: Successful Planning and Construction* (1st Edition ed.). London, UK: Earthscan Publications Ltd.

REN21. (2009). Renewables: Global Status Report, 2009 Update (pp. http://www.ren21.net/pdf/RE_GSR_2009_Update.pdf): Renewable Energy Policy Network.

Reupke, P., Sarwar, G., & Tariq, A. S. (1994). *Biomass Combustion Systems: A Guide for Monitoring & Efficient Operation* (1st Edition ed.). New York, NY: Hyperion Books

Sark, W. v., Patel, M., Faaij, A., & Hoogwijk, M. (2006). The Potential of Renewables as a Feedstock for Chemistry and Energy. In J. Dewulf & H. V. Langenhove (Eds.), *Renewables-Based Technology*. New York, NY: Wiley.

Song, C., Gaffney, A. M., & Fujimoto, K. (Eds.). (2002). *CO2 Conversion and Utilization* Oxford, UK; Washington, DC.: American Chemical Society Publication.

Tester, J. W., Drake, E. M., Golay, M., Driscoll, M., & Peters, W. (2005). *Sustainable Energy* (1st Edition ed.). Cambridge, MA: MIT Press.

Vita-Finzi, C. (2008). *The Sun: A User's Manual*. New York, NY: Springer.

Wayman, M., & Parekh, S. (1991). *Biotechnology of Biomass Conversion: Fuels and Chemicals from Renewable Resources* (1st Edition ed.). Hoboken, NJ: Wiley.

Wereko-Brobby, C. Y., & Hagan, E. B. (1996). *Biomass Conversion and Technology* (1st Edition ed.). Hoboken, NJ: Wiley.