

SMART Competition Lesson Narratives

SMART Competition

The SMART competition is a project that has a number of phases that require background research, computer simulations, development of conceptual scenarios, and the creation of reports and presentations. While your team is working on each of these phases, logbook entries should be made to record the activity that took place, the results of any simulation or discussion, and any conclusions or suggestions for future activities that came out of the activity session.

Project Logbook:

A project logbook is a crucial part of any engineering or scientific research project. It is a detailed account of every phase of the project and is proof that certain activities occurred at specific times.

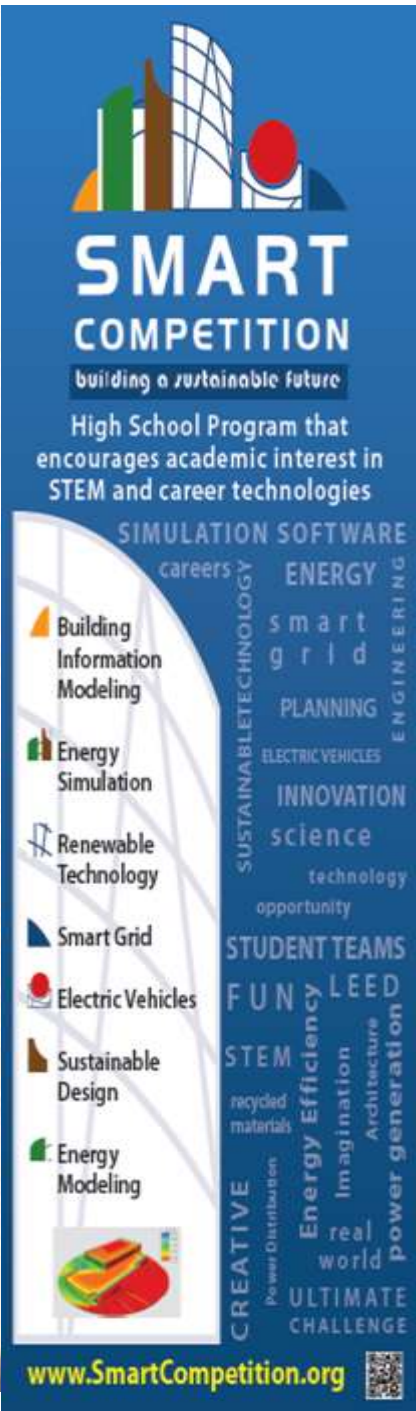
The logbook for this competition will be a Microsoft Word document. The Word template for the logbook can be accessed on the www.smartcompetition.org website.

One member of the SMART team should be designated as the “keeper of the book” and it will be his/her responsibility to ensure that logbook entries are made and the book is always saved and up-to-date. The Word document will be submitted as part of the competition electronic deliverables.

Remember, 5% of the points available in the competition are allocated to the keeping of a logbook.

Workbooks and Tutorials

This workbook contains Lesson Narratives and is a companion document to the Software Practice workbook that contains the tutorials using Bentley Systems AECO Building Designer, Energy Simulation and visualization software,



SMART Competition Lesson Narratives

Course Description

These lesson narratives are intended to provide an introduction to concepts relating to Energy and the Green Campus. They are intentionally not totally inclusive, but designed to give students a basic understanding of the topics so that they are able to perform their own research to gather more information and learn more fully how to use energy concepts in the SMART competition.

Skills Taught

- Energy Basics
- The Green Campus
- Electricity
- The Power Grid
- The SMART Grid and Campus Micro-Grid
- Energy Storage

1. Energy Basics

This lesson will provide the student with an understanding of the difference between power and energy and introduce the student to different forms of energy. The lesson also includes the concept of converting one form of energy into another and the use of fossil fuels and renewable fuels as sources of energy.

What is Energy?

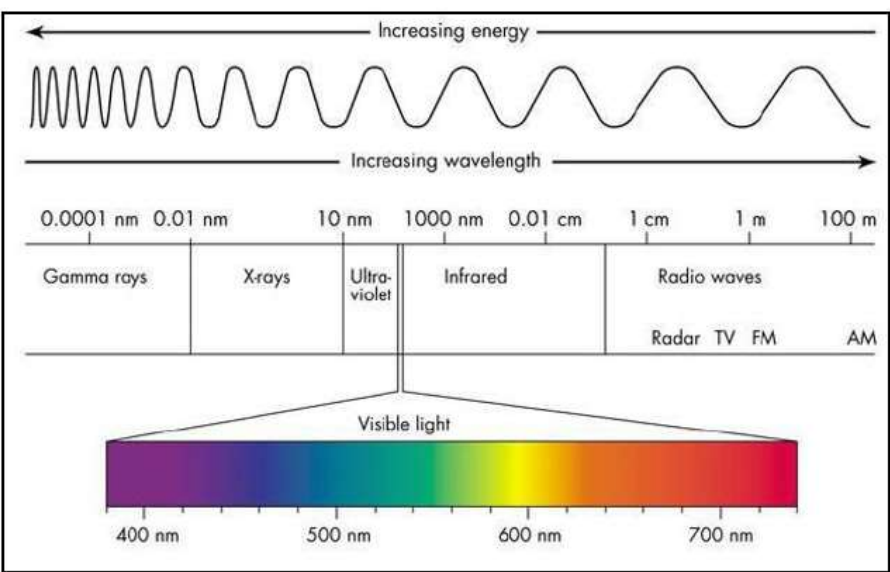
Energy is a measure of how much work an object or a system can do. For example, a gallon of gasoline contains enough chemical energy to move an average motor car about 25 miles. The energy in the liquid oxygen and liquid hydrogen in the fuel tanks of a Saturn 5 rocket can move the rocket's payload to the moon. Or, more down to earth, a wound-up clock spring contains enough potential energy to make the clock work for perhaps 48 hours before it needs rewinding.

Forms of Energy

There are many different forms of energy, some of which will be very familiar to you but some may be a little less familiar. Some examples of commonly encountered forms of energy are solar energy in the form of heat and light energy that we get from the sun, kinetic energy – the energy contained in an object by virtue of its motion, potential energy – the energy contained in an object by virtue of its position, and electrical energy – the energy resulting from the flow of charged particles - electrons.

Some less familiar forms of energy include chemical potential (CPE) – the energy resulting from the position or arrangement that make up a substance. For example the food we eat contains chemical potential energy. When we eat the food the atomic bonds inside the food are broken, releasing energy, then the energy is transferred into our bodies. Dynamite contains chemical energy! Once dynamite is ignited the energy is released extremely quickly, so quickly in fact that an explosion is created.

Another less familiar form of energy is electromagnetic energy – energy associated with electric and magnetic fields. It is defined as the energy in a magnetic field that is produced by the motion of charges such as an electric current. Electromagnetic energy is a fundamental form of energy; light energy is a form of electromagnetic energy.



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Figure 1. The electromagnetic spectrum

Energy can neither be created or destroyed, *however it can be converted from one form to another.*

In the examples illustrated above we can track how energy is converted from one form into another. The chemical potential energy in the gallon of gasoline is converted to kinetic energy when the car starts moving down the road. Likewise in the Saturn 5 rocket, the chemical potential energy in the fuel is converted to kinetic energy when the rocket lifts off and starts moving.

The wound up clock spring is a little more interesting. The chemical potential energy contained in the muscles of the person who initially wound up the clock is converted to potential energy in the spring. The potential energy is slowly converted to both kinetic energy and potential energy in the escapement mechanism of the clock.

Energy can be converted from one form to another in many different ways. Naturally occurring energy conversions include photosynthesis, where light energy from the sun is converted to chemical potential energy in green plants. Wind is also an example of naturally occurring energy conversion. Thermal energy from the sun heats up the ground, the air close to the ground warms and rises. As the warm air rises, cooler air moves in to take its place. The cool air molecules gain kinetic energy. It is the moving air that makes the “wind” that we feel on our faces.

It is not surprising that the examples above both start with solar (light and heat) energy. Our sun is the major source of all energy we use on earth today.

All of the machines we use today convert energy from one form into another from which we can obtain some useful work.

When energy is converted from one form to another less than 100% of the initial energy “makes it”

One of the fundamental laws of physics, the law of thermodynamics, states that the conversion of energy from one form to another is never perfect. Not all the energy will be converted from one form to another. In the examples above, in addition to the kinetic energy of the car and rocket, the chemical potential energy in the gasoline and rocket fuel is converted into both heat and sound energy. In the example of the clock spring, some of the energy in the person’s muscle is converted into heat energy, although not enough to make the person sweat! And some of the energy in the clock spring is converted into sound energy, the “tick-tock” we hear from the clock’s works.

Temperature, Thermal Energy, and Heat Transfer

On a microscopic scale, thermal energy is related to the kinetic energy of the atoms and molecules making up an object or system. The greater a material's temperature, the greater the thermal agitation and therefore the greater the kinetic energy of its constituent molecules.

Temperature is a measurement of the average kinetic energy of the molecules in an object or system and can be measured with a thermometer or a calorimeter. It is a means of determining the internal energy contained within the system.

While temperature represents the amount of thermal energy available in an object or system, heat transfer represents the movement of thermal energy from place to place. It is natural for regions containing greater molecular kinetic energy to pass this energy to regions with less kinetic energy. i.e. heat transfer is always from a hotter object to a cooler object. Heat transfers to and through some materials better than others.

There are three ways in which heat can be transferred from one object or system to another; these are conduction, convection, and radiation.

Conduction

Conduction is the transfer of heat between substances that are in direct contact with each other. The better the conductor, the more rapidly heat will transfer. If one end of a metal rod is at a higher temperature than the other end, then energy will be transferred down the rod toward the colder end by the atoms and molecules inside the rod. The higher energy particles will collide with the lower energy ones with a net transfer of energy to the lower energy ones.

Convection

Convection is the primary method by which heat moves through liquids and gases. It is the up and down movement of liquids and gases caused by heat transfer. As a liquid or a gas is heated, it warms, expands, and rises because it is less dense than the surrounding liquid and gas. When liquid or a gas cools, it becomes denser and falls. As the liquid or gas warms and rises, or cools and falls, it creates a convection current.

Radiation

Electromagnetic radiation in the infra-red frequency range is a form of thermal energy. All sources of heat, the sun, a candle flame, or a camp fire for example, all radiate infra-red electromagnetic radiation. When electromagnetic waves come in contact with an object, the waves transfer the heat to that object. This is how the "heat" from those sources can be felt by the human body.

Sources of Energy

Although energy can take many forms such as heat and light energy and potential energy etc., there are only nine (9) “primary” sources of energy from which all other forms of energy are derived. The primary energy sources are: the sun (solar), the earth’s heat (geothermal), the wind, water (rivers, lakes, tides, and oceans – “hydro-kinetic”), fossil fuels (coal, oil, and natural gas), biomass, and radioactive minerals. These can be further categorized into three families, mineral fuels, fossil fuels, and renewable fuels.

Mineral Fuels

Uranium

Fossil Fuels

Coal

Oil

Natural Gas

Renewable Fuels

Solar

Wind

Geothermal

Bio Fuel

Hydro-kinetic

All other forms of energy are “secondary” and are produced by conversion from one or more of the primary sources.

Mineral Fuels originated billions of years ago during colossal supernova explosions of stars.

Uranium

Uranium was formed long before the earth existed. Atoms of uranium and other elements were ejected into space when stars were destroyed by supernova explosions. These elements eventually came together during the formation of our solar system and the formation of earth about 6 billion years ago. Today, Uranium is mined where there are concentrations in the earth’s crust.

Uranium can be processed into fuel rods that are used in a nuclear reactor. The radioactive decay of the uranium atoms can be controlled and the heat generated during the nuclear interactions is used to boil water and make steam to spin electric turbine generators.

Fossil Fuels originated millions of years ago on earth.

Coal

About 300 million years ago, enormous ferns and other prehistoric plants and animals were common on the swamp-like earth. When those plants and animals died and fell to the ground, they were covered with water and they slowly decomposed. As decomposition took place in the absence of oxygen, much of the hydrogen content of the matter was eroded away, leaving a material rich in carbon. The material was compressed over the years by sand and dirt, leaving the form of carbon known as coal.

Coal can be burned to provide a source of heat that can be used for heating homes or for industrial processes including generating electricity.

Coal can also be gasified by heating it in an oxygen free atmosphere. The “coal-gas” produced in this way can also be burned to provide a source of heat.

Oil

Petroleum oil was formed in a similar way to coal except in the case of oil the original organic materials were marine organisms. When animals that lived in the sea millions of years ago died underwater, their remains were gradually covered by layers of very fine dirt known as "silt" on the ocean floor. Then, as the years passed, pressure from the layers built up and compressed the organic material, forming the oil.

Petroleum oil is processed in an oil refinery where different "grades" of oil are produced. These include gasoline, diesel fuel and aviation fuel. Also, different chemicals can be extracted from the petroleum oil to make plastics and other synthetic materials.

Natural Gas

Natural gas is almost always found with deposits of petroleum oil. When the oil is pumped from oil wells, the natural gas is also recovered. Wells with only natural gas also exist.

Natural gas can be burned to provide a source of heat; it can also be used as a fuel for internal combustion engines and combustion turbines. Compressed Natural Gas (CNG) vehicles are becoming more popular and most of the new electricity generation power plants use natural gas as their main fuel.

Renewable fuels are fuels that are essentially inexhaustible or replenished in a timely manner rather than over millions of years.

Solar Energy

Solar energy is the energy we get from the sun. There are two forms of solar energy, light and heat, and there are two families of technologies we can turn to in order to use these forms of solar energy.

The first family takes advantage of the light we get from the sun and is the technology of photovoltaics (PV). PV technology involves the direct conversion of sunlight to electricity. Specially fabricated PV panels are able to produce electricity when they are exposed to sunlight.

The second family of technologies takes advantage of the heat energy we receive from the sun and uses the heat to make steam and power a conventional turbine/generator or uses the heat to directly power a heat-engine/electric generator. Solar thermal technologies can also be used to simply produce hot water or steam for domestic and industrial applications.

Wind Energy

When thermal energy from the sun heats up the ground the air close to the ground warms and rises. As the warm air rises, cooler air moves in to take its place. Wind energy is the kinetic energy in the moving air molecules and has been used for hundreds of years for sail boats, windmills, and more recently to power large wind turbines to produce electricity.

A wind turbine is made up of turbine blades which are connected to a shaft that turns when the wind makes the blades move. The shaft is connected to a gearbox with an electric generator that produces electricity.

Hydro-kinetic Energy

The energy contained in moving water can be converted to mechanical energy for industrial use or to produce electricity. Historically, water wheels were used as a means of converting the kinetic energy in moving water into mechanical energy to grind corn or to pump water. Today, hydro-kinetic technologies can be used to convert the energy in flowing rivers and flow-streams from dams into electricity. The vertical movement of waves can be used to make electricity and the temperature differences between the surface and sub-surface waters of lakes and oceans can also be used to make electricity.

Bio Fuel

The source of Bio-Fuel is generally referred to as Biomass which is defined as any material that can be obtained from a growing, living or recently dead biological organism. This can include wood from trees, husks from corn, grass, and waste from humans and animals.

Different technologies can be used to extract the energy from biomass material or to convert biomass material into a different form which can be used more conveniently as an energy source or other product. This process can be as simple as burning the biomass to produce heat and then using the heat in some other process such as generating electricity; or as complex as extracting the oils contained in the biomass and using those oils as a basis for manufacturing other fuels such as “bio”-diesel or “bio”-jet fuel. Other technologies can be used to convert the chemical contents of biomass material into other material forms such as plastics, fertilizers or food flavorings.

Geothermal Energy

Geothermal Energy is the energy contained in the heat inside the earth. The source of the heat is the radioactive decay of elements deep inside the earth.

Where the earth’s tectonic plates meet and slide under/over each other there are opportunities for the heat contained at the center of the earth to rise and approach the earth’s surface.

Such situations can manifest themselves in the form of:

Spectacular and devastating volcanoes

Spectacular but relatively harmless geysers (for example Old Faithful)

or Hardly noticeable warm or hot springs

The presence of any of the above is a good indication of the proximity of a geothermal energy source. Drilling a hole into the earth in these locations – a geothermal production well – can very often allow us to tap into the geothermal reservoir and use the heat to produce electricity or for some other process.

The technologies used to produce electricity are different depending on the temperature of the geothermal resource.

Renewable Energy Sources

There is a growing understanding and concern that sources of fossil and mineral fuels are being depleted, that is, whenever we extract them from the ground and use them, they are not being replenished, and, eventually we will literally run out of them. Renewable fuels on the other hand are either inexhaustible – like solar energy – or are replenished naturally – like bio fuels – and, if their use is managed appropriately, will never run out. Consequently, there is a substantial effort in progress to make more use of the renewable energy sources.



Logbook: Make a logbook entry - What did you learn from this narrative?

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2. The Green Campus

This lesson focuses on energy conservation and professional building design codes, standards, design criteria and evaluation. It also provides an introduction to building materials and systems designed to minimize energy use. Heating and cooling systems and intelligent buildings are also described along with an introduction to the concept of the micro-grid.

Design Considerations

Concerns over rising electrical generation costs, eventual depletion of fossil fuels, and future environmental issues have changed the approach to building design and construction.

Designers and developers are realizing the value of using up-to-date materials that prevent heat and cooling losses, utilizing renewable energy to develop electricity for buildings, landscaping that can use “gray water”, incorporating low-flush or waterless urinals to save water resources, and many other “sustainable” building methods. While the design and construction of buildings has used environmentally friendly practices in the past, today, there is a greater focus and awareness of health and climate issues.

Several formal institutions have been formed to monitor and certify building design and construction. Among them is the U.S. Green Building Council (USGBC). The USGBC and its community are changing the way buildings and communities are designed, built and operated through its LEED® (Leadership in Energy and Environmental Design) Green Building Rating System™.

A further concept in the design and operation of environmentally friendly buildings is the net-zero building – also known as the zero-energy building (ZEB). ZEBs are buildings that consume an average of zero energy over the course of a year. ZEB is a program being championed by the US Department of Energy (DOE). The DOE has established an aggressive goal to create the technology and knowledge base for cost-effective zero-energy commercial buildings by 2025.

LEED

Leadership in Energy and Environmental Design is a green building rating system developed by the U.S. Green Building Council (USGBC) to provide a streamlined set of standards for environmentally sustainable construction. LEED certified buildings promote sustainable design and are primarily designed by a LEED AP (Accredited Professional) who has been certified through the USGBC. As an internationally recognized mark of excellence, LEED provides building owners and operators with a framework for identifying and implementing practical and measurable green building design, construction, operations and maintenance solutions.

The government has worked to model sustainable green building by achieving certification on many of its state buildings. In order to increase the number of new and redeveloped buildings eligible for LEED certification, the government also offers many incentives within the building industry, including grant funding and tax breaks based on the level of LEED certification attained.

There are four different levels on which LEED certification can be attained: LEED Certified, LEED Silver, LEED Gold, and LEED Platinum; which are determined by a credit or point system. A building or project can attain LEED certification by submitting an application that documents compliance with the requirements set forth in the rating system. The Green Building Council issues LEED certification upon satisfactory application, review and compliance verification.

The table below shows the potential points that can be submitted for LEED certification of a building.

Sustainable Sites	26 Possible Points
Water Efficiency	10 Possible Points
Energy and Atmosphere	35 Possible Points
Materials and Resources	14 Possible Points
Indoor Environmental Quality	15 Possible Points
Innovation in Design	6 Possible Points
Regional Priority	4 Possible Points
Demand Response Participation	1 Possible Point
Platinum 80 points and above	Gold 60–79 points
Silver 50–59 points	Certified 40–49 points

The LEED for Schools Rating System recognizes the nature of design and construction of K-12 schools. Based on the LEED for New Construction rating system, it addresses issues such as classroom acoustics, master planning, mold prevention and environmental site assessment. By addressing school spaces and children's health issues, LEED for Schools provides a unique, comprehensive tool for schools that wish to build green, with measurable results.

The USGBC has a website specifically for students, called the Center for Green Schools, which addresses the needs of K-12 schools as well as higher education.

ASHRAE

Another set of building codes and standards come from ASHRAE, the American Society of Heating, Refrigeration and Air Conditioning Engineers. This is a group of professional engineers and society members who focus on energy efficiency, indoor air quality, refrigeration and air conditioning, and sustainability, and develop standards and guidelines relating to HVAC systems, building envelope insulation, and other issues affecting the indoor environment. The standards developed by ASHRAE are often referenced in building codes.

The standards are not legally enforceable, except when referenced as mandatory provisions in building codes, but are commonly accepted as standards for architects and engineers when designing buildings and their HVAC systems.

ASHRAE and LEED consolidation

In August, 2014 ASHRAE, ICC (*International Code Council*), AIA (*American Institute of Architects*), Illuminating Engineering Society of North America, and the U.S. Green Building Council signed a memorandum to partner on the development of Standard 189.1, the standard for the Design of High Performance, Green Buildings.

This move will combine all codes into one regulatory tool and aligns the LEED program with the new code to ensure a streamlined, effective set of regulatory and code options for jurisdictions across the U.S.

Zero Energy Buildings (ZEB)

Net-zero homes and other buildings may be the next wave of architecture, as they are virtually free of heating bills, electric expenses, air conditioning costs and other energy uses.

At the heart of the ZEB concept is the idea that buildings can meet all their energy requirements from low-cost, locally available, nonpolluting, renewable sources. At the strictest level, a ZEB generates enough renewable energy on site to equal or exceed its annual energy use.

Because design goals are important to achieving high-performance buildings, the way a ZEB goal is defined is crucial to understanding the combination of applicable efficiency measures and renewable energy supply options.

A zero energy building can be defined in several ways, depending on the project goals and the values of the design team and building owner. For example, building owners typically care about energy costs. Organizations such as DOE are concerned with national energy numbers, and are typically interested in primary or source energy usage. A building designer may be interested in site energy use for energy code requirements. Finally, those who are concerned about pollution from power plants and the burning of fossil fuels may be interested in reducing emissions. Four commonly used definitions are: net zero site energy, net zero source energy, net zero energy costs, and net zero energy emissions.

Net Zero Site Energy: A “site ZEB” produces at least as much energy as it uses in a year, when accounted for at the site.

Net Zero Source Energy: A “source ZEB” produces at least as much energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site.

Net Zero Energy Costs: In a “cost ZEB”, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year.

Net Zero Energy Emissions: A “net-zero emissions ZEB” produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources.

Each definition uses the grid for net use accounting and has different applicable renewable energy sources. Off-site ZEBs can be achieved by purchasing renewable energy from off-site sources, or in the case of an off-site zero emissions building, purchasing emissions credits.

A ZEB typically uses traditional energy sources such as the electric and natural gas utilities when on-site electrical generation is not sufficient to meet the energy loads. When the on-site electrical generation is greater than the building’s loads, excess electricity is exported to the utility grid. By using the grid to account for the energy balance, excess production can offset later energy use.

Achieving a ZEB without the grid would be very difficult, as the current level of development of energy storage technologies is limited. Despite the electric energy independence of off-grid buildings, they usually rely on outside energy sources such as propane (and other fuels) for cooking, space heating, water heating, and backup generators. Off-grid buildings cannot feed their excess energy production back onto the grid to offset other energy uses. As a result, the energy production from renewable resources must be oversized. In many cases (especially during the summer), excess generated energy cannot be used and is wasted.

Structural Considerations

Both LEED and ZEB building designers rely on building techniques and practices that have evolved through common sense and best practice reviews. The tools that are available to the designer include the choice of building materials, insulating technologies for thermal management and the interface between the building and its surroundings in terms of landscaping and building orientation. Some aspects of these “tools” are described below.

Sustainable Materials

Sustainable Materials are materials that are manufactured or obtained from resources that are managed in a way that they are, for all practical purposes, sustainable over an extended period of time (i.e., the resource is not depleted).

Examples of sustainable building materials tend to be bio-based and include forest stewardship certified wood products, and soy based spray foam insulation and roofing sealants.

There are many other “eco-friendly” materials that can be used, which, while not being truly sustainable, have a minimal negative effect or even have a positive effect on the environment. Naturally pigmented paint, recycled construction materials, and porous concrete paths are examples of eco-friendly materials.

Insulation

Maintaining a comfortable temperature inside a building is important for health and productivity and usually requires the addition of heat in the winter and the removal of heat, i.e. the addition of cooling, in the summer. This requires the use of fuel, so preventing heat energy escaping from the building or entering the building is an important issue to manage.

Heat energy is transferred by conduction through the walls, floor, roof and windows of a building. It is also transferred by convection. For example, cold air can enter the building through gaps in doors and windows, and convection currents can transfer heat energy in the attic to the roof tiles. Heat energy also leaves the structure by radiation through the walls, roof and windows. Properly insulating a building will decrease this heat flow by providing an effective resistance to the flow of heat.

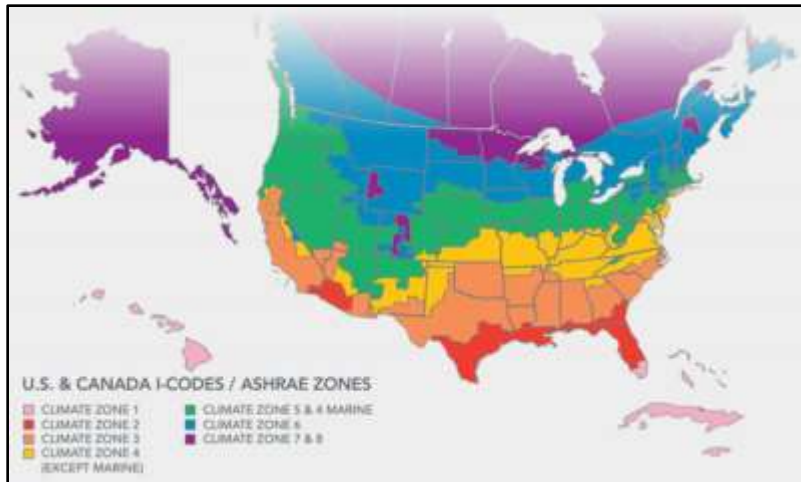
Insulation’s resistance to heat flow is measured or rated in terms of its thermal resistance or R-value. An *R-value* indicates an insulation’s resistance to heat flow. The higher the R-value, the greater the insulating effectiveness.

The R-value depends on the type of insulation and includes its material, thickness, and density. When calculating the R-value of a multilayered installation, the R-values of the individual layers are added together. Installing more insulation increases the R-value and the resistance to heat flow.

Climate Zones

Building codes require structures to meet certain *R*-values to achieve a specific level of efficiency. The local climate plays a big role in determining what the minimum *R*-value has to be for a specific region. ASHRAE has developed a series of eight climate zones for the USA that warrant a slightly different level of *R*-value to achieve the desired effect.

(Picture courtesy ASHRAE)



The ASHRAE climate zones are described in the following table.

Zone Number	Zone Name
Zone 1A and 1B	Very Hot – Humid (1A) Dry (1B)
2A and 2B	Hot - Humid (2A) Dry (2B)
3A and 3B	Warm – Humid (3A) Dry (3B)
3C	Warm –Marine (3C)
4A and 4B	Mixed – Humid (4A) Dry (4B)
4C	Mixed – Marine (4C)
5A, 5B and 5C	Cool – Humid (5A), Dry (5B) Marine (5C)
6A and 6B	Cold – Humid (6A) Dry (6B)
7	Very Cold
8	Subarctic

The ASHRAE climate zones have been adopted by others both nationally and internationally in formulating guidelines and standards for building envelope design around the world.

Insulated Wall Materials

Many architects have started using structural insulated panels (SIPs) or modular, stacked insulating concrete forms (ICFs) to ensure air-tight insulation inside net-zero buildings. Though initially more expensive than typical wood construction, these newer insulating technologies are vastly superior and result in lower long-term costs.

Insulated Windows

Windows that are just one pane of glass have very little insulation value, and don't do much to keep buildings cool in summer or warm in winter. Years ago, it was discovered that two panes of glass with air or argon gas sandwiched between the glass gives a window much better insulation. While most new buildings have double-pane windows, net-zero buildings have better insulation with triple-pane windows, though they are more expensive and much heavier than double-pane windows.

Roof insulation

Specifying an insulation system that facilitates proper roof performance is fundamental, but is only one of the factors when it comes to roof insulation. Roof insulation selection must also consider the thermal needs of the building, satisfy applicable energy codes, and result in a roof assembly that is approved by the property insurance carrier.

There are basically four types of roof insulation used in building construction, batts and rolls, loose-fill, rigid foam and foam-in-place. In commercial roofing, typically the rigid board foam and sprayed in place systems are prevalent.

Batts and rolls are available in widths suited to standard spacing of wall studs, and attic or floor joists. Batts with a special flame-resistant facing are available in various widths for basement walls where the insulation will be left exposed. A facing also helps facilitate fastening during installation.

Loose-fill insulation comes in loose fibers or pellets and is usually blown into a space such as an attic.

Rigid foam comes in boards of varying thicknesses and is more expensive than fiber, but has a higher R-value.

Foam-in-place is a complete polyurethane foam roofing system that is sprayed onto the roof surface where it rapidly hardens.

The shape of the roof can also determine the type of insulation that should be used; for example, rigid insulation is a critical component to consider when selecting a low-slope roofing system for a building. The insulation layers become an integral part of the roof assembly and must function in concert with the roof membrane and the structural deck. Wise choices result in successful roof systems that perform over the long term. Poor choices can negatively impact roof performance, possibly within a short time after the roof's installation.

ASHRAE R-values - examples

A substantial list of ASHRAE R-values can be found in their 1997 Handbook of Fundamentals. An abbreviated list is provided below.

(R-values are additive. For instance, if a material with an R-value of 12 is used with another material with an R-value of 3, then their combined R-value is 15.)

The R-values of some common materials:

MATERIAL	THICKNESS	R-VALUE
Air Films		
Exterior		0.17
Interior Wall		0.68
Interior Ceiling		0.61
Air Space		
Minimum 1/2" up to 4"		1.00
Building Board		
Gypsum Wall Board	1/2"	0.45
Gypsum Wall Board	5/8"	0.5625
Plywood	1/2"	0.62
Plywood	1"	1.25
Fiber board sheathing	1/2"	1.32
Medium Density Particle Board	1/2"	0.53
Insulating Materials		
R-11 Mineral Fiber with 2x4 metal studs @ 16" OC		5.50
R-11 Mineral Fiber with 2x4 wood studs @ 16" OC		12.44
R-11 Mineral Fiber with 2x4 metal studs @ 24" OC		6.60
R-19 Mineral Fiber with 2x6 metal studs @ 16" OC		7.10
R-19 Mineral Fiber with 2x6 metal studs @ 24" OC		8.55
R-19 Mineral Fiber with 2x6 wood studs @ 24" OC		19.11
Expanded Polystyrene (Extruded)	1"	5.00
Polyurethane Foam (Foamed on site)	1"	6.25
Polyisocyanurate (Foil Faced)	1"	7.20

Masonry and Concrete		
Common Brick	4"	0.80
Face Brick	4"	0.44
Concrete Masonry Unit (CMU)	4"	0.80
Concrete Masonry Unit (CMU)	8"	1.11
Concrete Masonry Unit (CMU)	12"	1.28
Concrete 60 pounds per cubic foot	1"	0.52
Concrete 70 pounds per cubic foot	1"	0.42
Concrete 80 pounds per cubic foot	1"	0.33
Concrete 90 pounds per cubic foot	1"	0.26
Concrete 100 pounds per cubic foot	1"	0.21
Concrete 120 pounds per cubic foot	1"	0.13
Concrete 150 pounds per cubic foot	1"	0.07
Granite	1"	0.05
Sandstone / Limestone	1"	0.08
Siding		
Aluminum / Vinyl (not insulated)		0.61
Aluminum / Vinyl (1/2" insulation)		1.80
Flooring		
Hardwood	3/4"	0.68
Tile		0.05
Carpet with fiber pad		2.08
Carpet with rubber pad		1.23
Roofing		
Asphalt Shingles		0.44
Wood Shingles		0.97
Glazing		
Single Pane	1/4"	0.91
Double Pane with 1/4" air space		1.69
Double Pane with 1/2" air space		2.04
Double Pane with 3/4" air space		2.38
Triple Pane with 1/4" air spaces		2.56
Triple Pane with 1/2" air spaces		3.23
Doors		
Wood, solid core	1 3/4"	2.17
Insulated metal door	2"	15.00

(Information courtesy Archtoolbox)

(The R-values above for specific assemblies like doors and glazing are generalizations because they can vary significantly based on special materials that the manufacturer uses. For instance, using argon gas in a double pane insulating glass unit will dramatically improve the R-value.)

Heat Recovery Systems

The choice of building materials can actually affect the health of the building's occupants. "Sick Building Syndrome" describes a range of health problems that can occur through exposure to pollutants inside a home, office or other building that come from dozens of sources including the very fabric of the building itself.

Carbon monoxide, for example, is usually the result of heat combustion produced by furnaces, space heaters, cigarettes or auto exhaust that enters a building.

Volatile organic compounds (VOCs) can come from paints, copier toners, carpet adhesives, disinfectants and ordinary household items like shower curtains and scented air fresheners. Because they're "volatile," these compounds vaporize and emit gases, even long after they've dried. Paint, for example, emits only half of its VOCs in the first year.

Radon is a naturally occurring gas that seeps up from the ground and is odorless, colorless and unhealthy.

Heat recovery systems in net-zero buildings, also called heat recovery ventilation systems, move fresh outdoor air into a building while also allowing improved climate control and reduced heating and cooling costs through the use of a heat exchanger that stabilizes the temperature of both incoming fresh air and circulating indoor air.

Landscaping

Landscaping with native wildflowers and grasses improves the environment and brings a taste of wilderness to urban, suburban, and corporate settings by attracting a variety of birds, butterflies and other animals. Once established native plants do not need fertilizers, herbicides, and pesticides or watering because they have adapted to the local conditions. Additionally, potable water consumption for irrigation can be minimized using:

- Drought tolerant plants
- Drip irrigation, moisture-sensing irrigation technologies
- Recycled rainwater system
- Municipally-provided non-potable water source use

Another landscaping method is referred to as "Xeriscaping", which is a landscape design that also minimizes water usage. Xeriscaping is a growing trend in preserving the environment, and as a means to lower water consumption. The advantages to Xeriscaping are:

- More water available for the community and the environment
- Appropriate planting design, soil grading and mulching takes full advantage of rainfall retention
- Less time and work for maintenance
- When there are water restrictions, plants will survive

Planting shade trees in sunny areas will result in a reduction in energy usage by shading the windows and walls of the building; each tree will also directly absorb about 25 pounds of CO₂ from the air annually.

The proximity of trees to buildings should take into account growth rate, life span, and ultimate canopy shape. Planting decisions and decisions about which trees to leave in place requires a careful balance between the desirable qualities of shade with the loss of future solar access. Evergreen trees may provide shade and block cold winter winds, but on the south side deciduous trees are preferred because they lose their leaves and admit more sun in the winter. When existing tree plantings are too dense, selective thinning may improve air movement, enhance ground-level vistas, and allow remaining trees better growth potential.

Orientation

Building orientation is the practice of facing a building so as to maximize certain aspects of its surroundings, such as street appeal, to capture a scenic view, for drainage considerations, etc. With rising energy costs, it is becoming increasingly important for builders to orient buildings to capitalize on the Sun's free energy.

Where buildings are situated on a site and how they are oriented provide significant opportunities to reduce overall environmental impacts—including both direct site impacts and indirect impacts relating to energy consumption by the building(s). A well-planned and optimally oriented building relates well to its site and the climate. This maximizes opportunities for (1) passive solar heating when heating is needed, (2) solar heat gain avoidance during cooling times, (3) natural ventilation as needed, and (4) high-quality daylighting throughout the year.

Rectangular buildings should be oriented with the long axis running east-west. In this configuration, east and west walls receive less direct sun in summer, so unwanted heat gain is reduced. This same configuration works well for buildings in cold climates where passive solar heat gain on the south side during the winter is desired. A long, narrow building plan also facilitates daylighting and natural ventilation.

Some additional information about placement of windows is offered by the scientists at the Lawrence Berkley National Laboratory:

The north side is where multiple panes and airtight windows are most crucial in winter. The north side gets little direct sunshine, and the north wind is often the coldest

Windows on the east and west receive light and heat, but they are hard to shade from the summer sun. East windows are advantageous as they let in the morning sunshine, however, west windows should be avoided as they tend to overload the building with heat on summer afternoons.

In the Northern Hemisphere, the winter sun rises in the southeast and passes low through the southern sky to set in the southwest. Thus the best place for windows is the south side of the house, so the winter sun can reach deep into the living space, warming the house when you need heat most. South windows are easy to shade from the summer sun. In the summer, the sun rises in the northeast, passes almost overhead at midday, and sets in the northwest.

Orienting not only the building's profile but the building's floor plans can also be effective. Frequently used rooms should be located on the southern side of the building; and areas that are less frequently used should be situated at the northern part of the building to act as buffers against harsh winter climates.

Energy Efficiency and Energy Conservation

Energy efficiency is "using less energy to provide the same service". Energy Conservation is the reduction in the use of energy through the elimination of waste. Energy efficiency is not the same as energy conservation. For example: Replacing an incandescent lamp with a compact fluorescent lamp (which uses much less energy to produce the same amount of light) is energy efficiency. Turning off a light is energy conservation.

Energy Efficiency

Until recent years, energy efficiency has been a relatively low priority to building owners and investors. However, with the dramatic increase and awareness of energy use concerns, and the advances in cost-effective technologies, energy efficiency is fast becoming part of real estate management, facilities management and operations strategy.

Lighting

Compact Fluorescent Bulbs (CFL) or Light Emitting Diodes (LED) use less energy than incandescent light bulbs. CFLs use only 1/4 the energy of an ordinary incandescent bulb and last 8-12 times longer than incandescent light bulbs. In the search for energy-efficient lighting, LEDs have proven to be the most efficient bulbs available. Energy Star-rated LEDs use at least 75 percent less energy than traditional incandescent bulbs and last 25 times longer, according to the U.S. Department of Energy. LEDs even outdo CFL bulbs in efficiency, primarily because they have twice the lifespan of CFLs. LEDs are more efficient than both incandescent and CFLs because they emit light in a targeted direction instead of all directions and don't require or emit great amounts of heat.

Ground Source and Water Source Heat Pumps

Traditional air-source heat pumps use the outside air as a source of heat during the heating cycle and a sink for heat during the cooling cycle. The outside air, however, suffers some extreme temperature fluctuations, tending to be very cold in the winter when heat needs to be extracted from it, and very hot in the summer when it is needed as a heat sink. The efficiency of the air-source heat pump therefore goes down during these extreme outside air temperature occurrences.

Ground-source heat pump:

The geothermal heat pump or ground source heat pump takes advantage of the relatively constant year round temperature of the earth and uses the earth as a source and sink of heat. By burying pipes carrying either water, or the heat pump refrigerant, in horizontal trenches or vertically drilled holes, heat can be absorbed from the earth or rejected to the earth at a fairly constant efficiency all year round. A variant of the ground-source heat pump using the constant temperature of the earth is to use a lake or a pond of water as the constant temperature source/sink and place the pipe loops at the bottom of the body of water

Water-Source Heat Pumps:

Yet another variant is the water-source heat pump which uses a closed loop of water as the “constant” temperature source/sink.

In buildings with multiple rooms it is possible for cooling and heating to be required simultaneously in different areas or “zones” of the building at any time of the year.

Water-source heat pumps offer a solution to this need for flexibility by using water rather than air as the heat source and heat sink. If the water can be maintained at a temperature between 60° and 90°, it can be used as a source of heat when heating is required and a sink for heat when cooling is required.

Closed loop water-source heat pumps utilize a system in which there is a heat pump in each zone of a building. The heat extractors of all these units are connected together by a closed loop of circulating water which is maintained within the above temperature range. To keep the temperature within this range, the system must have two additional components – a supplemental heater and a heat rejector or evaporative cooler. The supplemental heater is used to maintain a minimum water loop temperature of 60° during the winter and an evaporative cooler is used to limit the maximum water loop temperature to 90° in the summer.

Solar thermal heating and cooling

Solar thermal technologies can be used to cut energy bills by providing hot water for use in domestic applications such as showers and laundry. They can also be used to supplement conventional space heating and space cooling systems making them more efficient in their job of providing a comfortable indoor temperature.

Figures 2 and 3 show conceptually how solar thermal technologies can be used for these applications. Both applications use either flat plate or parabolic trough solar collectors to

heat water. In the case of solar water heating the hot water is stored in a tank until it is required for use. Conventional forms of water heating can also be used to provide hot water for the tank. The solar heated water in the heating and cooling system is also stored in a tank and then circulated through the building's heating system along with water that has been

heated conventionally to warm the building, or, for cooling, the hot water is used to operate an absorption chiller which produces cold water. The cold water is circulated through the building's cooling loop along with water that was cooled with a conventional chiller.

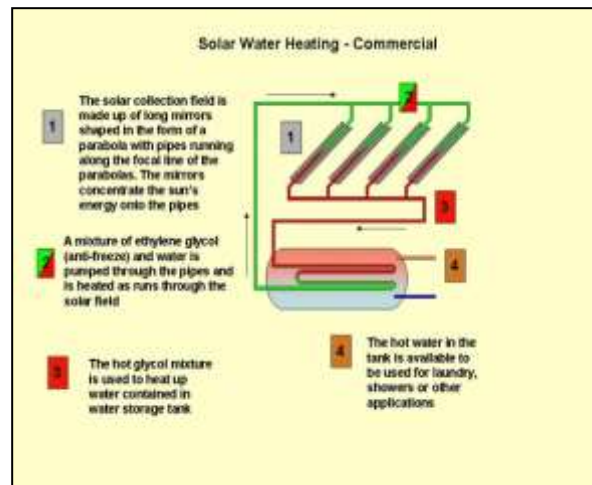


Figure 2. Solar water heating.

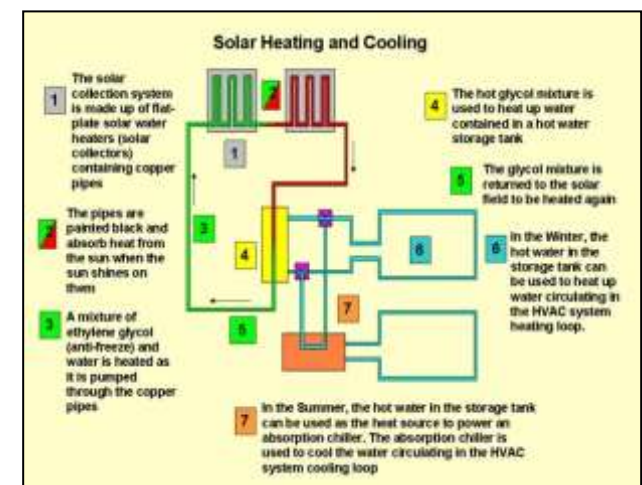


Figure 3. Solar heating and cooling.

Energy Conservation

Turning off lights when no one is in the room or allowing the room temperature to be a few degrees warmer than comfortable in the summer or cooler than comfortable in the winter are examples of energy conservation.

Energy-effective systems balance a building's electric light, daylight, heating, and cooling systems for maximum benefit. They consider the needs and schedules of occupants, together with seasonal and climatic changes.

Mechanical systems

HVAC stands for heating, ventilating, and air conditioning and is sometimes called climate control. The HVAC system is the mechanical system that affects thermal comfort for the occupants in a building. Advanced HVAC and lighting controls are the “brains” behind the intelligent operation of smart buildings.

Heating is the process of bringing heat to different spaces via hot air, hot water or steam using a boiler, furnace, or heat pump.

Ventilating is the process of removing or changing air in a space to create a different temperature or to reduce or remove moisture, odors, smoke, dust, or even airborne bacteria within a space. There are two types of ventilation, natural and forced air ventilation.

Natural ventilation, unlike forced ventilation, uses the natural forces of wind and convection to deliver fresh air into buildings, and the natural pressure differences to move fresh air through buildings. However, unlike true air-conditioning, natural ventilation is ineffective at reducing the humidity of incoming air. This places a limit on the application of natural ventilation in humid climates. Forced air ventilation uses mechanical equipment to move air through a building and can also control indoor air quality.

There are three types of mechanical systems that can be used to provide the above climate controls: air conditioners, heat pumps, and gas furnaces or electric heaters.

- Air conditioners are refrigeration units that are used for lowering the temperature and humidity of the air in a room or building.
- Heat pumps are also refrigeration units that can both heat and cool a room or building.
The primary difference between air conditioners and heat pumps is this heating and cooling capability.
- Furnaces and electric heaters use the energy contained in their fuel to heat the air in a room or building. Natural gas heating systems have a cost advantage over most electric heating systems. On a direct fuel-based cost basis, natural gas costs about one third as much as electricity. Even if an electric heating system is twice as efficient; it still costs more to operate than a natural gas unit.

The choice of heating system will depend on the seasonal weather in the area. If the temperature range rarely dips below 40°F (4.4°C), a heat pump will probably be the more affordable heating option. If in a colder area, a gas furnace can be a better choice.

The performance of the cooling and heating system is determined in a large part by the equipment's operating efficiency. The more cooling/heating a system puts out for each unit of energy consumed, the higher the efficiency rating of the system. The most common efficiency measurement is called the Coefficient of Performance, or COP. The higher the COP, the more efficient is the system. Typical COP values are:

Gas Furnace – 0.85 to 0.95

Oil Furnace – 0.60 to 0.70

Electric Furnace – 1.00

Heat Pumps – 2.50 to 3.50

Knowing the COP of an air conditioner or heat pump can give you a good idea of its efficiency compared to high-efficiency furnaces and boilers. If an electric heat pump has a COP of 3.5, this means it produces 3.5 units of heat for each kWh it uses. While a gas furnace running at 90% efficiency produces usually less than one unit of heat for each kWh.

The COP is a theoretical rating that does not take into account the outside weather conditions. For example, when the outside temperature falls below 40°F (4.4°C), a heat pump may require an additional electric heating element in order to provide sufficient heating.

The SEER rating (Seasonal Energy Efficiency Ratio) is the method used to describe the efficiency of a particular equipment system, taking into account the different outside temperature and humidity conditions. Once again, systems with a higher SEER rating, have a higher efficiency. Systems available today typically range from 10.00 SEER to 18.00 SEER.

Heating systems have a similar rating system that takes into account seasonal weather conditions. The HSPF (Heating Seasonal Performance Factor) is the efficiency measurement used to gauge the efficiency of the heating mode of heat pumps. Today's models typically have a minimum rating of 6.8 HSPF.

Lighting control methods

Different control systems can be used to control lighting where a level of luminance or particular use of lighting is required. Typical control systems include:

- Zones: lights are switched on corresponding to the use and layout of the lit areas, in order to avoid lighting a large area if only a small part of it needs light.
- Time control: to switch on and off automatically in each zone to a preset schedule for light use.
- Passive Infra-Red (PIR) Occupancy sensing: In areas which are occupied intermittently, occupancy sensors can be used to indicate whether or not anybody is present and switch the light on or off accordingly.
- Light level monitoring: this consists of switching or dimming artificial lighting to maintain a light level measured by a photocell.

Adding daylight to a building is one way to achieve an energy-effective design. Natural daylight 'harvesting' can make people happier, healthier, and more productive. In addition, by reducing electric lighting and minimizing solar heat gain, controlled daylighting can also reduce a building's air conditioning load.

Water conservation

Water conservation is the preservation, control and development of water resources. It applies to both surface and groundwater, by reducing the usage of water and recycling wastewater for different purposes.

An example is the installation of low-flow shower heads to use less water which can save approximately 300 pounds of CO₂ per year for electrically heated water, or 80 pounds of CO₂ per year for gas-heated water. Other water conservation devices are:

- Dual flush water closets
- Ultra low-flow water closets and urinals
- Waterless Urinals
- Sensor-operated, Low-flow lavatories
- Rainwater collection reuse systems
- Gray-water reuse systems

Transportation

A more holistic view of energy conservation can extend to the manner in which the building occupants travel to and from the building. Providing facilities for cyclists may encourage more occupants to use that form of transportation as opposed to regular vehicular transportation. Easy access to mass transit systems can likewise encourage occupants to take advantage of those modes of transportation thus reducing the use of petroleum fuels and their associated emissions.

Intelligent Buildings

The field of Intelligent Buildings, Intelligent Homes, and Building Management Systems (BMS) incorporates an enormous variety of technologies, including energy management systems and building controls. A growing number of companies are realizing the benefits of energy management by monitoring resources being used in buildings.

The function of a BMS is central to the concept of the Intelligent Building; the purpose is to control, monitor and optimize building services, such as lighting, heating, ventilation, filtration, and climate control. This is typically achieved by either time-based or optimized parameter-based control methods.

Time based control is where automated mechanical-based functions are important for executing mechanical functions based on necessity during certain times of the day, while optimizer parameter-based controls are used where, for example, a level of luminance or particular use of lighting is required.

Monitoring energy usage every hour by the use of a Data Acquisition System (DAQ) and comparing that usage to the previous day, week, or month, can help the building manager adjust the settings of the BMS.

Based on the system settings and the current data being monitored, the BMS can make intelligent decisions regarding the control of the building heating and lighting systems.

Distributed generation and microgrid

Distributed generation (DG), also known as on-site power, includes generation technologies such as backup diesel generators, renewable sources, cogeneration, and fuel cells. By the use of DG, the end user is able to control several key aspects of energy costs, reliability, and even power quality.

On-site renewable electricity generation is somewhat limited to solar and possibly wind. Hydro kinetic, geothermal, and wave energy sources are difficult to imagine on a building, however, they may be available if the campus as a whole is considered, and encompasses access to those resources.

Solar energy

Solar panels convert solar radiation from the sun to electrical energy. Net-zero buildings generally require solar panels to supply an adequate amount of energy for the building's uses, depending on whether it's a home, office, school or other building. Solar technology is constantly evolving with increased efficiencies and energy storage capabilities. Most zero-energy homes and buildings must remain connected to the local electrical grid (instead of going completely off-grid), and in the event of an electrical black-out, net zero buildings also lose power. Solar panels can also be used to shade parking areas, walkway areas, and windows.

Wind energy

Wind resources for ZEBs are limited because of structural, noise, and wind pattern considerations, and are not typically installed on buildings. Some parking lots or adjacent areas may be used to produce energy from wind, but this resource is site specific and not widely available. Similar to PV generation in an adjacent parking lot, the wind resource is not necessarily guaranteed because it could be superseded by future development.

Bio-energy

Renewable sources imported to the site, such as wood pellets, ethanol, or biodiesel can be valuable, but do not count as on-site renewable sources. Biofuels such as waste vegetable oil from waste streams and methane from human and animal wastes can also be valuable energy sources, but these materials are typically imported for the on-site processes.

The microgrid

Connecting several buildings and generation sources together can form a microgrid; a miniature version of the main power grid. The microgrid can be operated in several power exchange modes with the power grid, such as importing and exporting electrical energy, and can have the additional advantage of disconnecting itself from the power grid should the power grid encounter a major problem and fail. This last concept is known as “islanding,” which allows the microgrid to achieve operational energy independence from the main power grid.

The deployment of a microgrid containing intelligent buildings along with an interaction with a SMART grid takes the concept of a SMART, green campus even further.

Green buildings are more than a fashion statement

Many architects, builders and clients agree that smart, sustainable buildings are becoming a necessity. According to some estimates, buildings account for almost one-half of the world's material and energy consumption, one-sixth of fresh water use, and a quarter of all wood harvested.

A benefit to green buildings is the reduced demand on electric, gas and water utilities which mean these infrastructures can do more with less. This can result in lower municipal utility costs over the long run as utilities need not expand and can avoid passing those expansion costs onto utility customers. And in the case of energy- efficient net zero buildings and zero energy homes, these buildings actually feed electricity back into the utility grid, and result in no energy costs at the end of the year.



Logbook: Make a logbook entry - What did you learn from this narrative?

* * * * *

3. Electricity

This lesson provides an introduction to electricity generation technologies and the use of renewable energy sources for electricity generation.

Electrical Energy and Power

The terms energy and power tend to be used interchangeably (and incorrectly) in many articles about electricity and energy. To understand how energy is used and how electricity is produced and used, it is important to understand the difference between these two terms.

Power plants do not produce power; they produce electrical energy or “electricity”. Referring to section 3 above, energy can neither be created nor destroyed. This applies to electrical energy and so we must be careful in using the word “produced”. In the case of fossil fuel power plants, the power plants “produce” electrical energy by converting the chemical potential energy in the fuel they burn into electrical energy.

Power is a measure of the rate at which energy can be produced (converted from some other form of energy) or used (converted to some other form of energy). For example, a 500 MW power plant is able to convert the energy contained in the fuel it burns to 500 MWh of electrical energy in one hour and a 100 Watt light bulb is able to convert 100 Watt hours of electrical energy into light and heat energy every hour that it is switched on.

Power is not something that is consumed; it is energy that is “consumed” by being converted, usually by doing some useful work, and changed, into some other form of energy.

Electrical energy or electricity is also known as an “Energy Carrier”. Energy carriers are particularly useful as they allow us to move energy from one place to another. In the case of electricity, we can move energy from one place to another using electrical conductors such as the cables that are used in transmission lines.

Electricity Generation

Electrical energy occurs naturally, but seldom in forms that can be easily used. For example, a lightning stroke contains electrical energy but lightning has not been put to practical use because of its unpredictability, and other issues. Generally, practical electric-power-generating systems convert the kinetic energy of moving parts into electrical energy.

While some electric plants derive mechanical energy from moving water (hydroelectric power), the vast majority of electric plants derive it from heat engines, which convert heat energy into electrical energy using steam. Roughly 89% of electricity in the United States is generated this way. The steam is typically generated with heat from the combustion of fossil fuels or from nuclear fission.

Fossil Power Plants

Coal, oil, and natural gas are fossil fuels we find in the earth. The fuel is burned in a boiler where water is heated and turned into steam. The steam turns a turbine connected to an electrical generator and generates electricity. If we follow the energy chain we can draw the following diagram:

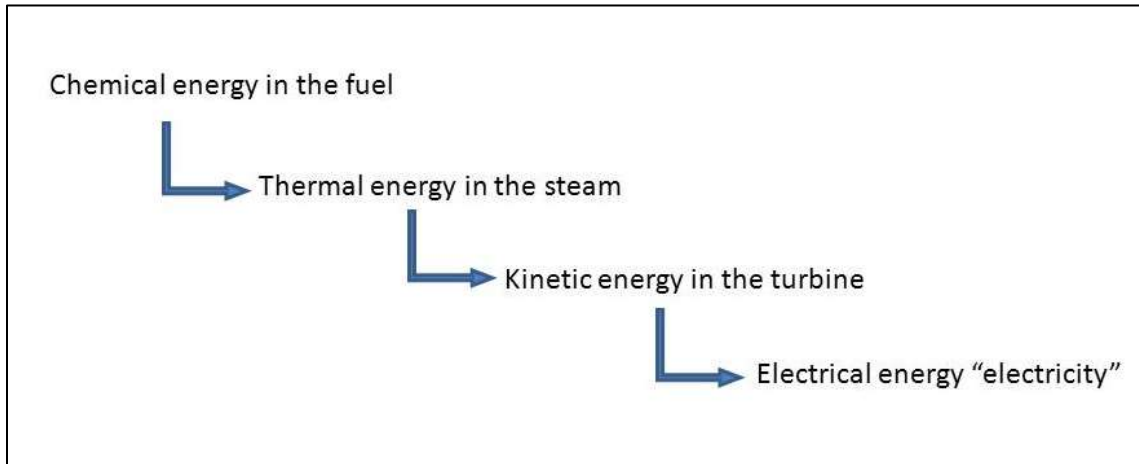


Figure 4. Energy conversion chain from fuel to electricity

Natural gas can be used as a fuel to make electricity in a power plant that does not use the steam cycle but uses large “combustion turbines”. A combustion turbine is very similar to a jet airplane engine, in fact some combustion turbines are called “aeroderivatives” as they are based on the design of airplane engines.

In a combustion turbine the fuel is burned in the combustion chamber where heat from the flame makes compressed air expand and the expanded air spins the turbine blades. The turbine shaft is connected to an electrical generator and when the turbine shaft turns, electricity is generated. Unlike a steam power plant a combustion turbine can be started very quickly and can be made to change the amount of electricity it produces very easily. A 180 MW Mitsubishi combustion turbine is shown in figure 5.

A fossil combustion power plant is not very efficient. Only 30 to 40% of the energy contained in the fuel is converted to electrical energy. The rest is converted to heat and sound which is not used to generate electricity.

In the case of the combustion turbine, a lot of heat is contained in the exhaust gases. So much in fact that the heat can be used to boil water and make steam for a steam turbine generator. This improves the efficiency of the combustion turbine power plant since the waste heat is not lost but is used to make more electricity. Such a combination is called a combined cycle power plant and can have an efficiency of more than 60%. Schematic diagrams of a combustion turbine power plant, a steam boiler and combined cycle power plant are shown in figures 6, 7, and 8.



Figure 5. Mitsubishi combustion turbine
(Courtesy Mitsubishi Power Systems)

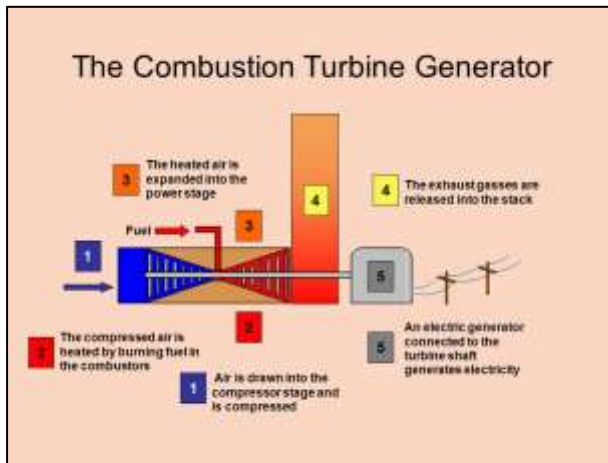


Figure 6. Combustion turbine power plant

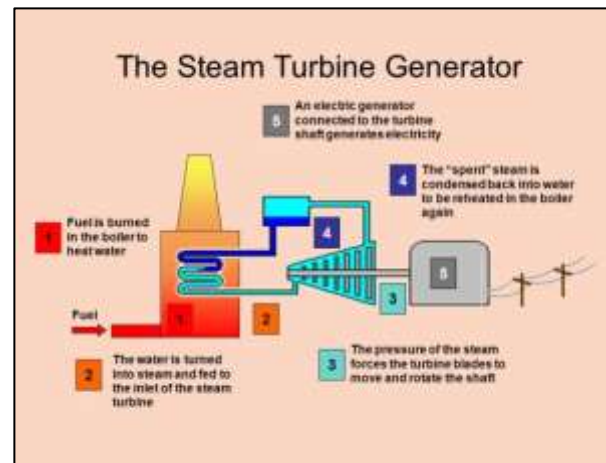


Figure 7. Steam turbine power plant

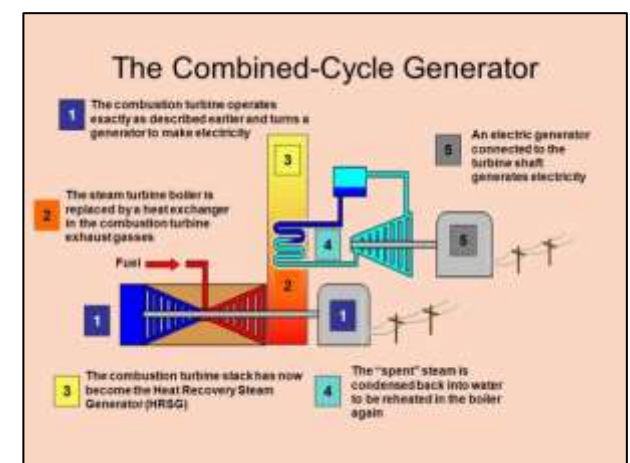


Figure 8. Combined cycle power plant

Nuclear Power Plants

A nuclear power plant is very similar to a fossil steam plant but instead of producing steam by burning a fossil fuel, the steam is produced using the heat generated when uranium atoms split during a process called nuclear fission. The rest of the electricity generation process, turbine, generator etc is identical to a fossil power plant.

Solar Power Plants

Solar power plants use either the light energy from the sun or the heat energy from the sun to generate electricity.

In a photovoltaic solar power plant, photovoltaic (PV) modules convert sunlight directly into electricity. The more PV modules in the plant the greater the power capability of the plant. PV power plants can range in size from a few kW for residential applications to hundreds of MW for utility applications. The electricity generated by a PV module is direct current (DC) and high powered electronic devices called inverters are used to convert the DC into alternating current (AC) for normal use. A PV power plant generates electricity whenever the sun is shining. On a cloudy day they work but not as well as on a sunny day and at night they do not work at all!

There are a number of different technologies that can be used to convert the heat energy from the sun into electricity. These "solar thermal" technologies typically use the heat solar power plant from the sun to boil water, or some other liquid, and use the steam or liquid vapor to drive a turbine/generator just as in a fossil fuel power plant. The two most common solar thermal technologies are the parabolic trough and the central receiver or "power tower". Schematic diagrams of these technologies are shown in figures 10 and 11.



Figure 9. A PV

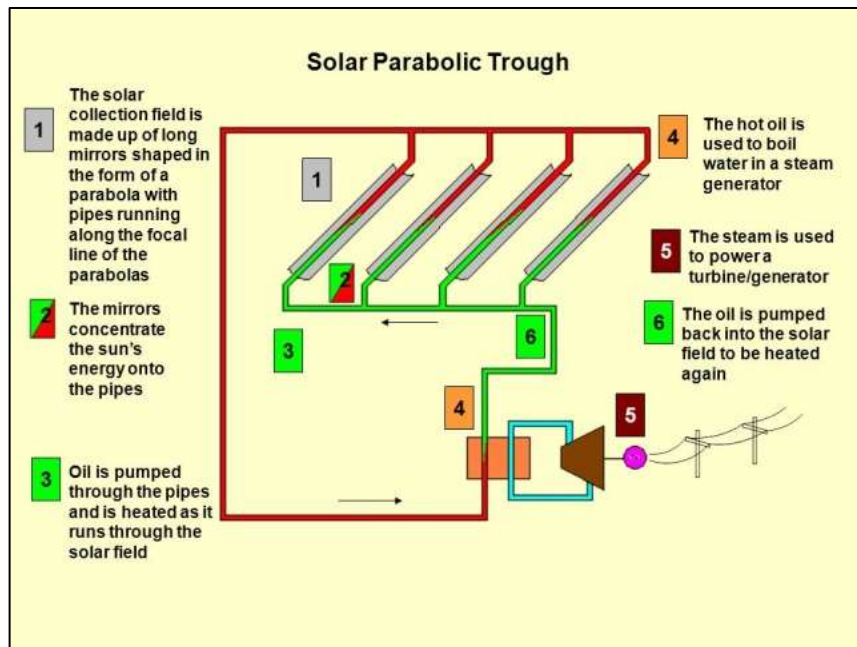


Figure 10. Parabolic trough solar power plant

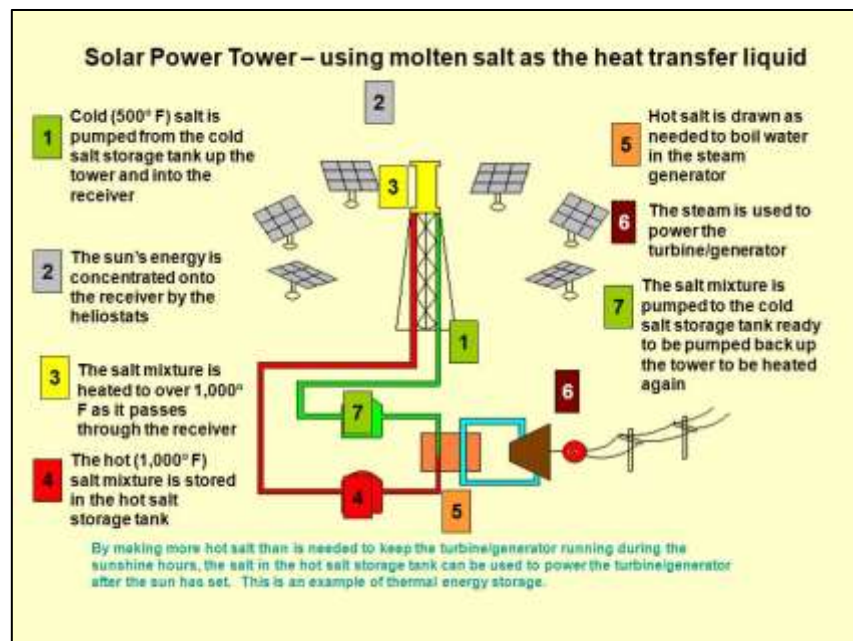


Figure 11. Power tower solar power plant

The parabolic trough solar power plant uses rows of parabolic shaped mirrors aligned in a North South direction. The mirrors “track” the sun across the sky by rotating from East in the morning to West in the afternoon and focus the sun’s energy onto oil carrying pipes running along the focal line of the mirrors. The oil is a “heat transfer fluid” and as it flows through the field of mirrors it is gradually heated until it

mirror field to be heated up again. The steam produced in the steam generator spins a turbine generator and produces electricity. The oil temperature, and therefore the steam temperature, is restricted to 750 °F to prevent the oil from breaking down or “cracking”. Parabolic trough solar power plants typically have a generating capacity of at least 50 MW and plants under construction today using this technology have generating capacities of around 300 MW. Mirrors are also used in a central receiver solar power plant. In this case thousands of computer controlled mirrors, or heliostats, surround a boiler mounted on top of a large tower. The mirrors focus the sun’s energy onto the boiler and continuously move throughout the day to keep the solar energy concentrated on the boiler as the sun moves across the sky. The central receiver typically uses a mixture of sodium and potassium nitrate salts as the heat transfer fluid. At temperatures above 500 °F the salt mixture has the appearance and consistency of water and can be heated to over 1,000 °F in the boiler. The hot salt is used to produce steam which in turn is used to generate electricity. The hot salt can be kept in a storage tank and used whenever it is needed to produce steam. This is an example of energy storage and permits electricity to be generated long after the sun has set and other solar power plants have stopped working. Central receiver power plants are usually designed to have a generating capacity of about 100 MW.

Two somewhat different solar thermal electricity generators, the dish/engine and solar chimney are shown in figures 12 and 13.

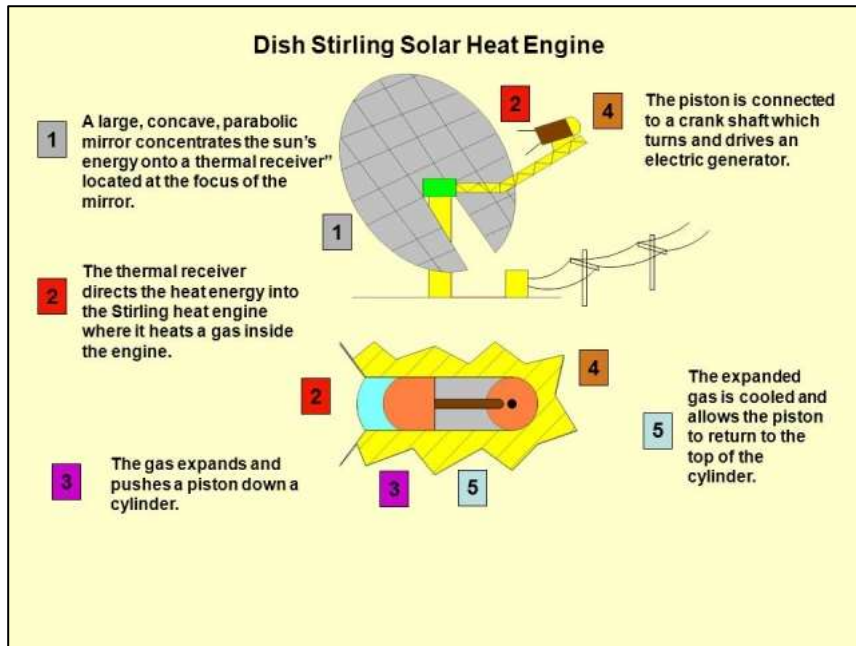


Figure 12. Dish/engine electric generator

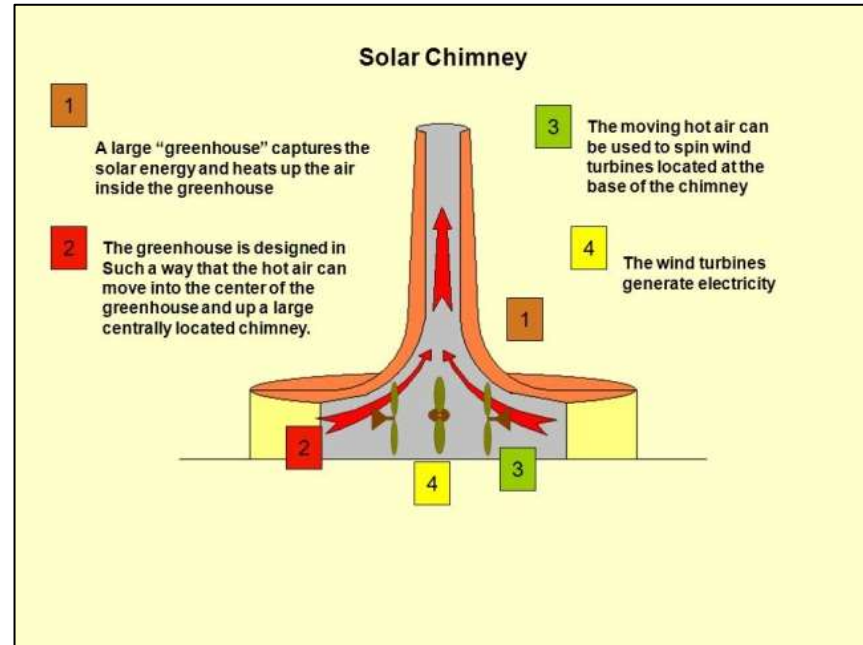


Figure 13. Solar chimney electric generator

The dish/engine uses a parabolic shaped mirror to concentrate the sun's energy onto either a Stirling engine or a small turbine. The concentrated heat is used to operate the engine which is connected to an electric generator. Dish/engine systems are much smaller than the parabolic trough or central receiver systems and typically have a generation capacity of about 20 kW. To generate larger amounts of electricity a number of dish/engine systems are used in a "solar field". Figure 14 shows a 1.5 MW dish/engine solar field in Glendale, AZ.

The concept of the solar chimney, shown in figure 11, is different yet again. The chimney is a large tower, some 2,000 feet tall, in the center of a one mile diameter glass greenhouse. As the sun heats up the air in the greenhouse the shape of the glass roof directs the warm air to the center where it rises up the chimney. The moving air can reach speeds of up to 40 mph and spins wind turbine generators located at the base of the tower. Generation capacities of 300 MW are theoretically possible but a full-size solar chimney has not been constructed anywhere as yet.



Figure 14. Dish/engine solar field

The solar resource that we enjoy amounts to about 100 Watts per square foot on a sunny day. This means that if we were able to convert all of the solar energy in a ten square foot area into electricity we could produce 1 KWh of electrical energy every hour. Solar electric technologies are not 100% efficient and although there are some new photovoltaic technologies on the horizon that can convert 40% of the solar energy into electrical energy, typically only 15% of the solar energy can be converted using today's commercially available technologies. As a rule of thumb about 6 acres of land is required to build a 1 MW solar power plant.

Wind Turbines

The energy in the wind has been used for centuries to move sail boats and to spin windmill blades to grind corn and pump water. In the 1980s serious attempts were made to construct wind turbines to generate electricity. These early machines were somewhat small having generation capacities of several tens of kilowatts. Today, these giant machines have

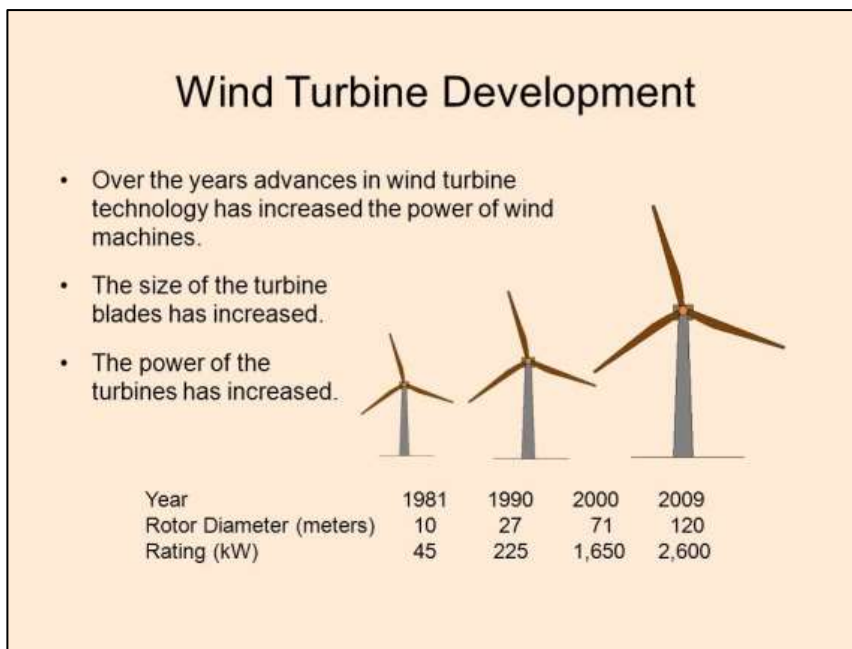


Figure 15. Showing the development of wind turbines over the years



Figure 16. A modern wind farm

capacities approaching 3 MW and are deployed in wind farms all over the world.

The concept of the wind turbine generator is still fundamentally simple; the wind moves the turbine blades that are connected to a shaft which in turn is connected to an electric generator via a gearbox. Much work has gone into the development of turbine blades and the gearboxes.

One issue with a wind machine is that when a blade passes in front of the support tower it encounters a wind “dead spot”. This produces a mechanical jolt to the machine and has been the cause of many gearbox failures. Another issue with wind turbines is their need for a continuous, strong wind to make them economically viable. There are areas where good wind resource conditions exist and these are the areas where wind farms are being constructed. Unfortunately, these areas are not necessarily in the locations where the electricity is required which has led to the construction of large power transmission lines to deliver the electrical energy to where it’s needed.

Wind turbines work best when the wind is flowing linearly, that is there is no turbulence. This is one of the reasons that wind turbine towers are tall, to escape the air turbulence that occurs close to the ground. Although there are some proponents of installing wind turbines on the top of buildings, the turbulent air flows around a building will not allow a turbine to operate as efficiently as it could in a wide open space. Care has to be taken when designing a wind farm that the turbines up-wind of others do not cause appreciable air turbulence for the down-wind machines. This is the reason wind farms require a lot of land, about 60 acres per MW of generation capacity.

Geothermal Power Plants

Geothermal energy can be accessed by drilling holes or “production wells” deep into the earth. There are several technologies available to make use of geothermal resources having different characteristics. The geothermal heat may be used by pumping water into the earth to be heated and then pumped out again to be used in an electric generating plant, or, the resource may be so hot that steam comes out of the well and can be used directly to spin a turbine/generator.

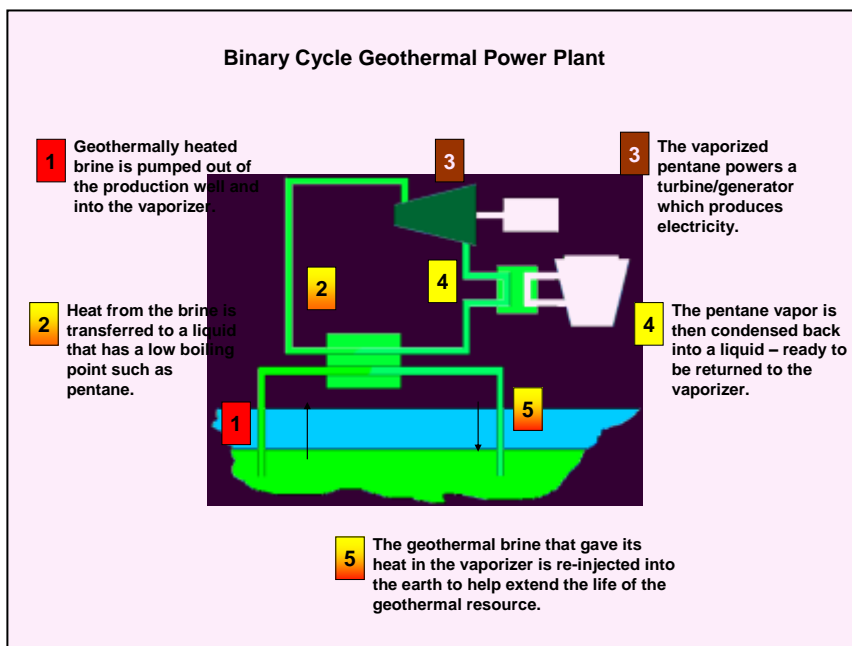


Figure 17. Binary Cycle geothermal plant.

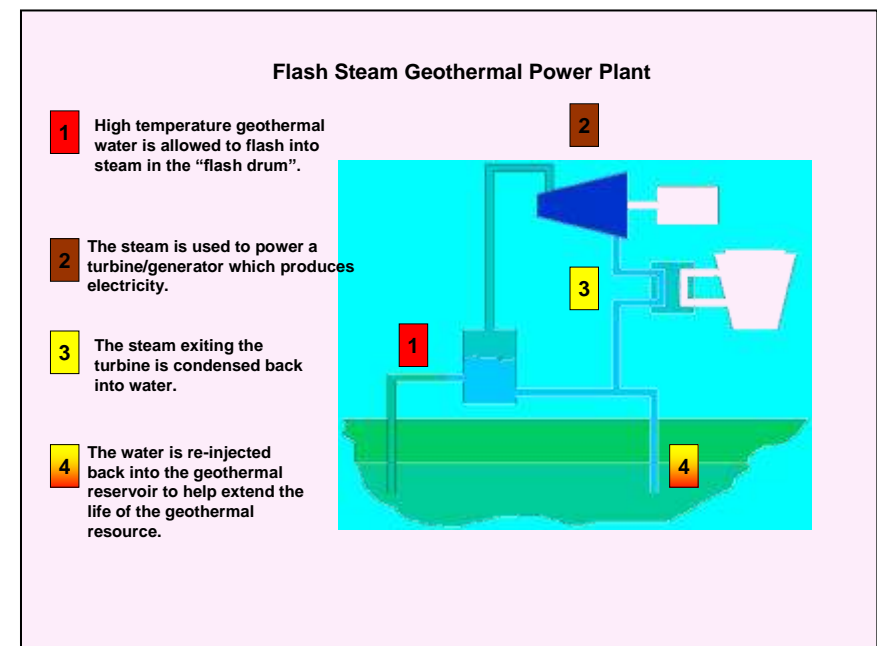


Figure 18. Flash-Steam geothermal plant

A Binary Cycle geothermal power plant uses the relatively low temperature, 300 °F, brine found in shallow geothermal reservoirs. The hot brine is pumped out of the production well and into a vaporizer where heat from the brine is transferred to a fluid with a low boiling point such as pentane (Pentane boils at 85 °F). The pentane vapor powers the turbine/generator which produces electricity. The vapor is then condensed back into a liquid to be re-vaporized in the vaporizer. The geothermal brine that was used to vaporize the pentane is re-injected into the earth in an “injection” well. Re-inserting the heat depleted liquid into the geothermal reservoir extends the life of the geothermal resource.

Sometimes the temperature of the geothermal water is higher than the boiling point of water but the high pressure that the water is subjected to under the earth prevents the water from actually boiling. As the water is allowed to reach the earth’s surface, the pressure is reduced and the water can “flash” into steam. The steam can be used to power a turbine/generator and produce electricity.

The used steam is condensed back into water which can be re-injected into the geothermal reservoir, once again to help extend the life of the geothermal resource.

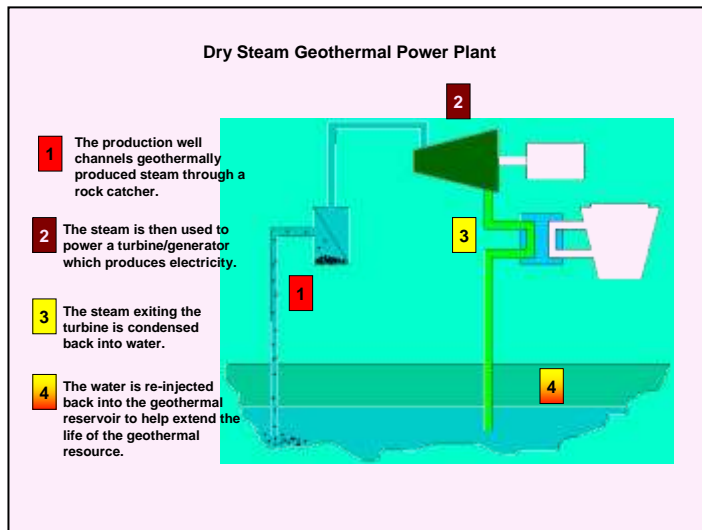


Figure 19. Dry-Steam geothermal plant.

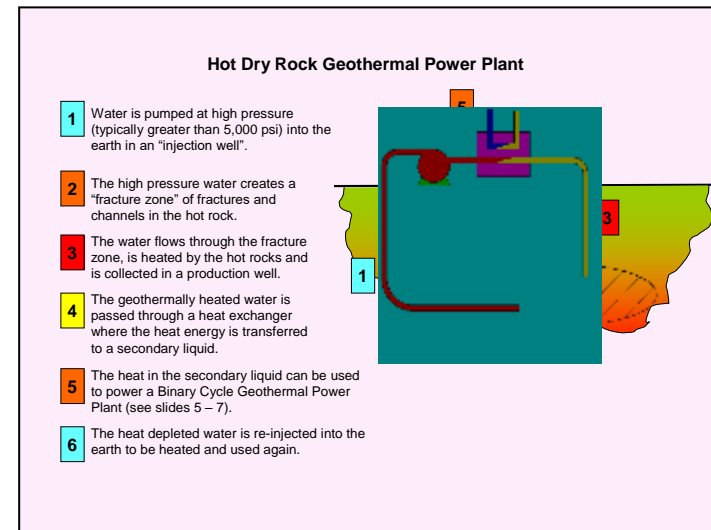


Figure 20. Hot-Dry-Rock geothermal plant

An even hotter geothermal resource can actually produce steam that can be captured to power a turbine. With this type of geothermal source the steam is channeled through a “rock catcher” to remove solid debris before being used to power a turbine/generator. The steam exiting the turbine is condensed back into a liquid which is re-injected into the earth.

Not all geothermal sources have “mobile” water to indicate their presence. A vast majority of the world’s accessible geothermal energy is found in rock that is hot but, essentially, dry. Water can be injected into the hot-dry-rock to be heated by the geothermal heat energy and pumped back out of the earth to be used in binary cycle geothermal power plants. The water used to power the plant is re-injected into the earth to be heated and used again.

Bio-Fuel

The energy contained in biomass can be used to produce electricity. The simplest method is to burn woody biomass in a boiler, produce steam, and use the steam to drive a turbine/generator. Wood for a biomass power plant is usually delivered to the plant in the form of wood chippings or sawdust in large trucks. This tends to place a restriction on where a biomass power plant can be economically operated. A general rule of thumb is that the trucks should not travel more than 50 miles to deliver their loads and so care must be taken to ensure that there is an adequate supply of biomass material within a 50 mile radius of the intended power plant location.

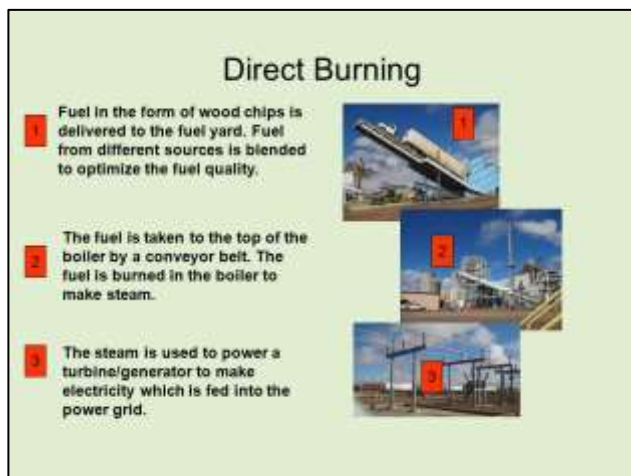


Figure 21. Direct burning

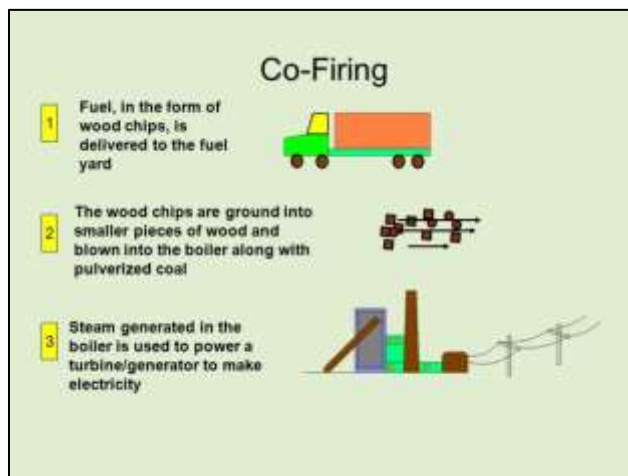


Figure 22. Co-firing

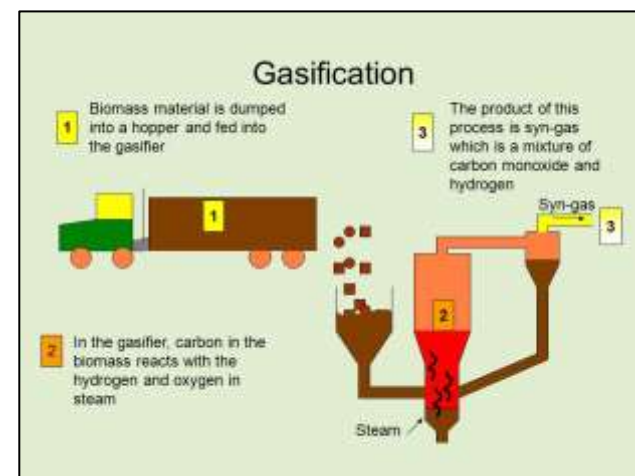


Figure 23. Biomass gasification

Woody biomass can be burned along with coal in a coal fired power plant. Some of the coal is replaced by the biomass and so the power plant actually operates a little more cleanly. If a source of biomass is available near to a coal plant, co-firing is one of the cheapest methods of producing “renewable” electricity since the power plant has already been built and the infrastructure needed to deliver the electricity into the power grid already exists.

Rather than burn the biomass directly or with coal, fuel energy can be extracted from the biomass in the form of a gas. By heating bio-fuel material in an oxygen starved atmosphere, a mixture of carbon monoxide and hydrogen called “syn-gas” can be collected. Syn-gas is a combustible fuel and can be burned in a boiler to make steam or can be used to fuel a combustion turbine.

Another form of gas that can be derived from bio-fuel is bio-gas - a methane rich gas which is created during the decomposition of organic material. Bio-gas is an approximately 50/50 mix of methane and carbon dioxide along with some other impurity gases. It can be used as a fuel to produce electricity in engine/generators or turbine/generators or the carbon dioxide and other impurities can be removed leaving the methane which can be injected into a natural gas pipeline and used in a natural gas power plant.

There are several useful sources of bio-gas, all of which rely on the decomposition of bio or organic material. Organic material decomposes through the action of anaerobic microbes, that is, microbes that exist in the absence of oxygen. Anaerobic decomposition occurs in landfills, at wastewater treatment plants and can occur at animal feed lots.

As material decomposes in a landfill, it generates bio-gas. The gas seeps out of the landfill and escapes into the atmosphere. Methane is a known “greenhouse” gas and is actually 21 times more potent as a greenhouse gas than carbon dioxide. When a landfill grows to a certain size the landfill owner is required to stop the escape of methane into the atmosphere. This is accomplished by drilling holes into the landfill and gently sucking the bio-gas out.

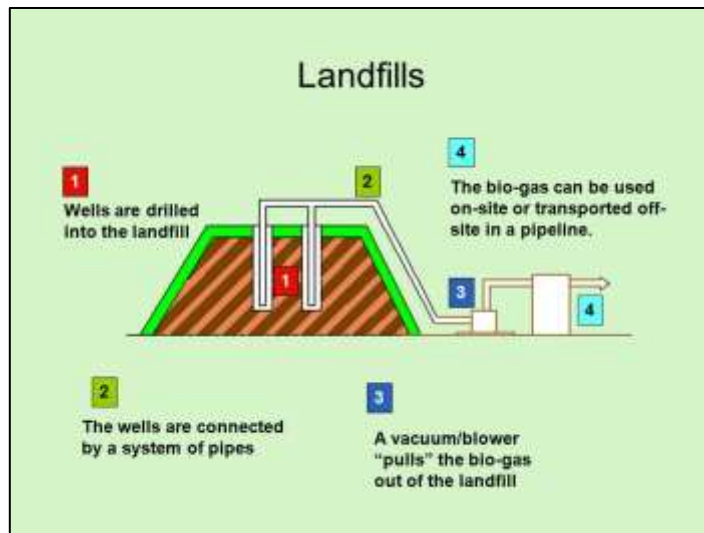


Figure 24. Bio-gas from a landfill



Figure 25. Bio-gas from a waste water treatment plant

The amount of suction must be great enough to prevent the bio-gas from escaping but small enough to prevent air from being sucked into the landfill and thereby reducing the amount of anaerobic decomposition. The amount of bio-gas collected can be sufficient to power an engine/generator or a small combustion turbine with an electricity generation capacity of around 5 MW.

In the process of treating sewage at a waste water treatment plant, anaerobic digestion tanks are used to remove the solid materials in the sewage. Depending on the size of the plant, enough bio-gas can be collected from the digesters to power electricity engine/generators having capacities of several tens of MW.

Bio-gas is a by-product of the operation of landfills and waste water treatment plants. If the gas is not used to generate electricity it must be “flared” i.e. simply burned. It is better for the environment if the methane in the bio-gas is turned into carbon dioxide by burning it than releasing the methane into the atmosphere. Bio-gas is a renewable fuel and flaring is literally fuel going up in smoke!

A by-product of the operation of an animal feed lot or CAFO (Concentrated Animal Feeding Operation) is manure. Manure is rich in organic matter and can be used in an anaerobic digester to produce bio-gas. Dairy feedlots are favored as a source of manure for a digester since the manure is collected daily and is very wet. As in the case of bio-gas collected from a WWTP, it can be used to make electricity on site to offset some of the electricity used at the dairy or it can be cleaned and piped to a natural gas fired power plant

Hydro Kinetic Power Plants

Hydro kinetic power plants use the energy in moving water to produce electricity. The water can be a flowing river, the water released from a dam, the water currents caused by ocean tides, or the up/down motion of ocean waves. There are three types of machines that can be used to convert the energy in the moving water into mechanical energy and thence, into electrical energy. These are the impulse turbine, which has a jet or a flow of water hitting the turbine blades, the reaction turbine, which operates totally submerged and has a flow of water passing through the blades just like air through a wind turbine, and wave energy converters which use the up/down motion of surface waves to pump hydraulic fluids.

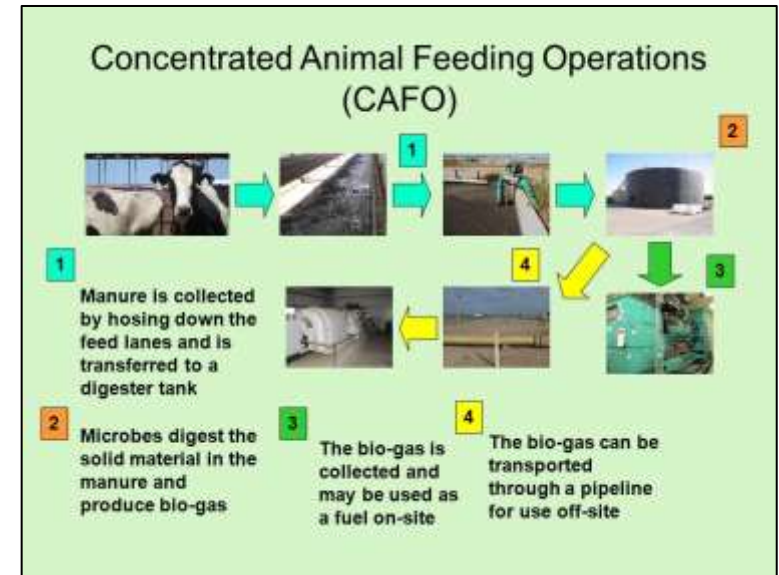


Figure 26. Bio-gas from a CAFO

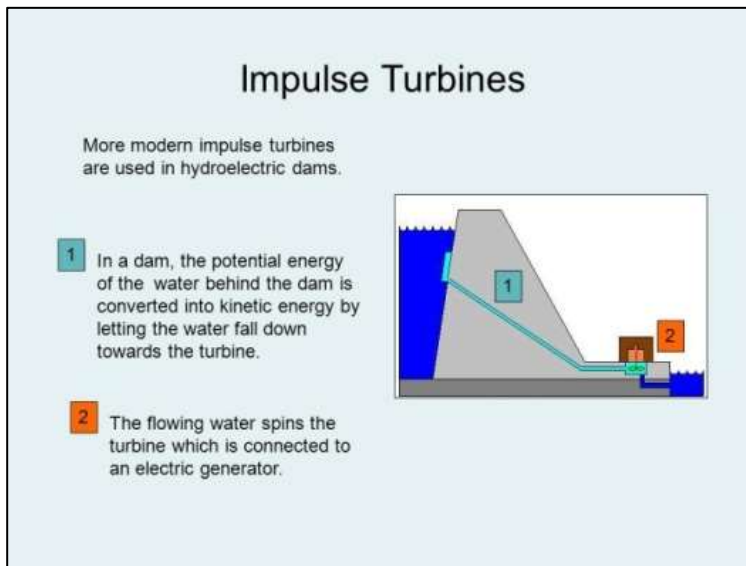


Figure 27. The Impulse Turbine

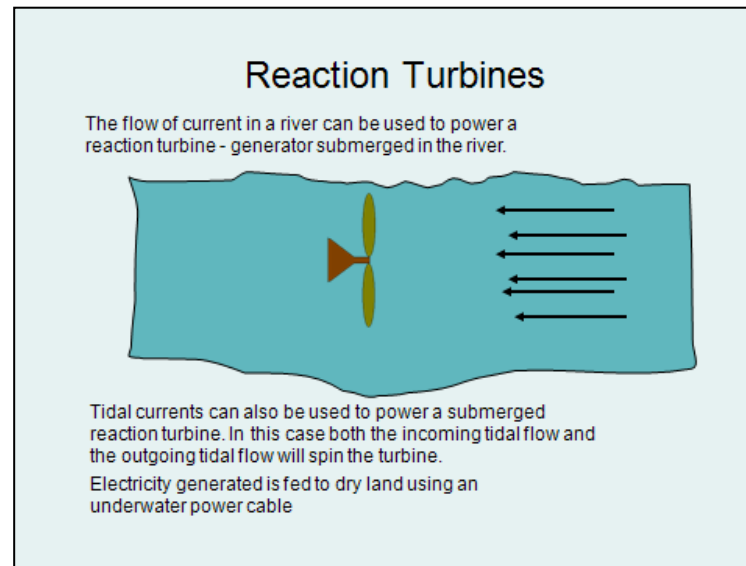


Figure 28. The Reaction Turbine

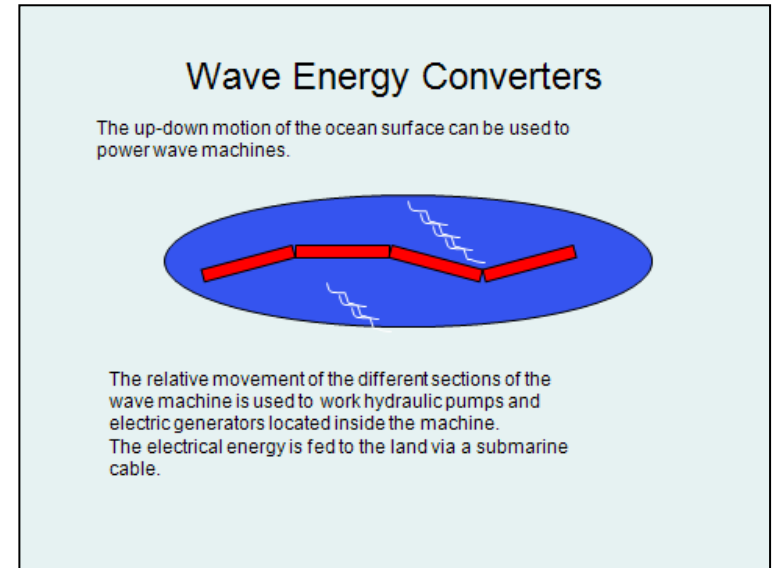
The familiar hydro-electric power plants that use dams to form reservoirs and lakes use impulse turbines to produce electricity. The old water wheels next to flowing rivers were also impulse turbines. Totally submerged reaction turbines are used in deep rivers, and tidal currents use reaction turbines totally submerged in the tidal water flow.

Shallow flowing rivers can be used as a source of energy to produce electricity. Run of the river hydropower involves placing small, mini, or micro hydro turbines into waterways that do not have large dams. There are several ways of doing this. Some projects involve running a pipe down the stream. The pipe becomes a penstock that creates a head pressure, which allows an impulse hydro turbine to run efficiently. Some methods simply place a reaction water turbine in a strong current area of a river in a manner that involves no visible structure at all. The turbines lay under the surface of the water, out of sight, with minimal environmental impact, and generate electricity from the natural flow of the river.

Run of the river turbines are much smaller than those found on large dammed reservoir projects. While there is no defined standard for size, several terms are in general use. Small hydro power plants range in size from about 1 MW to 50 MW. "Mini" hydro plants cover the range 100 kW to 1MW and "Micro" projects are typically less than 100kW in capacity.

Ocean wave technologies are being researched in some coastal regions of the world. Hydraulic pumps located between the floating sections of the converter pump hydraulic fluid to hydraulic motors which turn electric generators.

The ocean is a very harsh environment for anything mechanical and it will be interesting to see how these technologies develop.



There is a fourth type of hydro technology called Ocean Thermal Energy Conversion (OTEC) which uses the ocean's natural thermal gradient – the fact that the ocean's layers of water have different temperatures – to drive an electric generating system similar to a geothermal binary cycle power plant. OTEC works best when the temperature difference between the warmer, top layer of the ocean and the colder, deep ocean is about 36 °F. These systems use a fluid with a low boiling point, such as ammonia, to rotate a turbine generator to produce electricity. Warm surface seawater is pumped through a heat exchanger where the low boiling point fluid is vaporized. The expanding vapor turns the turbine/generator. Cold deep sea water is pumped through a second heat exchanger and condenses the vapor back to a liquid, which is then recycled back through the system. The economics of OTEC systems have limited their development to date. However, there is the potential to obtain water desalination and mariculture benefits from the technology which may spur their development in the future.



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4. The Power Grid

This lesson describes how electricity is delivered to the customer from the power station via the power grid system and explains some of the issues we have with today's power grid.

The electricity produced at electric power plants needs some means of being delivered to our homes and businesses in order to work for us. Large power plants tend to be located away from population centers and may be tens or hundreds of miles away from where their electricity will be used. Electric utilities not only sell the electricity they generate to their own customers but they also sell electricity to other utilities who in turn sell it to their customers. In order to move the electrical energy around to everyone, electric utilities are tied together in large systems called power grids. In the USA there are three power grids, the Western Interconnect, the Eastern Interconnect, and the Texas Interconnect.

A power grid system is an amazing piece of technology. The power companies provide just the right amount of energy to supply cities hundreds of miles away. This energy is distributed so efficiently most of the time that we take it for granted. However, every time we turn on a light we are transferring some energy from the grid into our home. When this happens the entire grid compensates for our small use of its energy.

Figure 30 shows the major components that are used to transfer electricity from an electrical power plant to our homes and businesses.

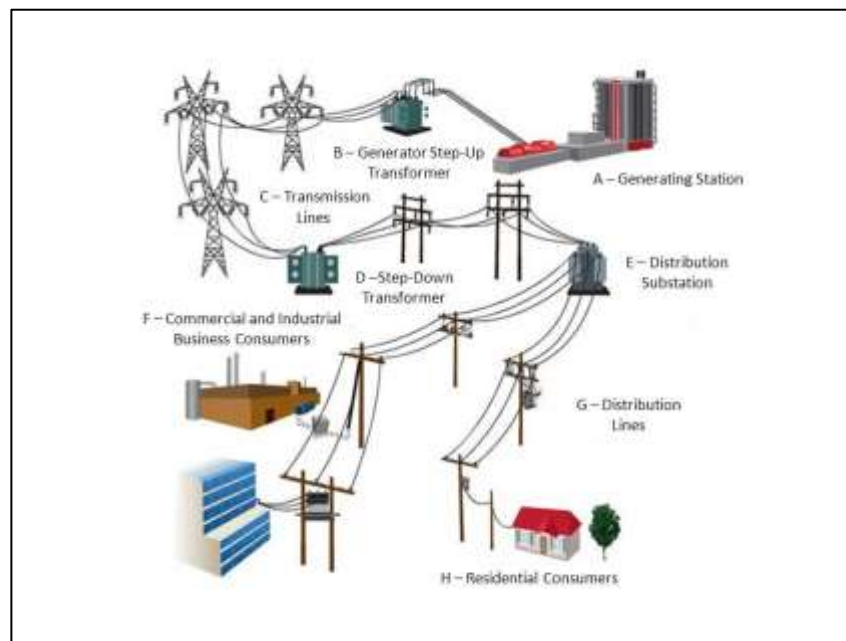


Figure 30. The major components of today's power grids (Courtesy Oncor.com)

The following is a description of these components:

A – Generating Station

Generating stations produce electricity by the methods described in the previous lesson.

B – Generator Step-Up Transformer

Electricity from generating stations is stepped up to higher voltages by means of a generator step-up transformer (GSU) for transfer over transmission lines. Operating the transmission lines at high voltage typically between 138,000 Volts and 765,000 Volts (138 kV to 765 kV) reduces electricity losses from conductor heating and allows electricity to be transferred economically over long distances.

C – Transmission Lines (138 kV, 230 kV, 345 kV, 500 kV, 765 kV)

Electricity is normally transferred by overhead transmission lines, which consist of aluminum conductors with a reinforcing steel core suspended from metal towers by porcelain insulators. Underground transmission circuits can also be used, but are used less frequently than overhead circuits due to the higher costs involved.

D – Substation Step-Down Transformer.

Most customers receive electricity at voltages much lower than those used for transmission. Substations at the end of the transmission line use transformers to step the voltage down to sub-transmission levels between 35 kV and 69 kV. Some customers who use large amounts of electricity such as chemical plants take electricity at these sub-transmission voltages.

E – Distribution Substation and local transformers.

The distribution substation uses transformers to step down the voltage further to between 2.4 kV to 13 kV.

F – Commercial and Heavy Industrial consumers.

Commercial and heavy industrial customers use electricity at voltages between 2.4 kV and 13 kV.

G – Distribution Lines.

The distribution system delivers the electricity into neighborhoods.

H – Residential Consumers.

Pole or pad mounted transformers reduce the distribution level voltages even further to 120 Volts for residential customers.

The original power grids were designed and built to allow electric utilities to generate electricity and distribute it to their customers. Over the years the demand on the grids increased as utility to utility energy sales began to emerge as an additional source of revenue

for those utilities that had excess generation capacity over and above their own customer needs, and the interconnections with other utility grids led to the system we have today.

While the original intent of the power grid remains a fundamental requisite for society today, new, additional, requirements of the grid are emerging that call into question the ability of today's grid to provide all of the functions that are being demanded of it. The grid is being challenged to integrate new energy resources, such as wind and solar and new demands such as plug-in electric vehicles and customer choices of generation energy sources and a desire to self-generate at the customer level.

There are perhaps six main issues challenging today's grid:

1. Reliability
2. Security
3. Economy
4. Environment
5. Power Quality
6. Customer choice

Reliability

Like any other piece of equipment or machinery, the components that make up the power grid are prone to fail at some time. Even with intensive preventative maintenance procedures failures will occur. As the power grids have grown to the sizes they are now, there is the potential for what should have been a local failure incident to spread into neighboring utility territories. This can have substantial impacts on commerce, security and life in general as evidenced by the blackouts that occurred on the east coast in 2003 and more recently in the 2011 Yuma incident that affected several million people in Arizona, Mexico and Southern California.

Although new power plants are being constructed to meet the growing demand for electricity, the power grid is not being updated or expanded at anything close to the rate it needs to be to keep up with the growing fleet of power plants. This can cause severe stress to the components of the power grid at times of high peak energy demand and lead to widespread power quality issues.

Utilities themselves were created to provide service to the local communities, it was never conceived that they would be required to provide the level of integration that they are expected to provide today.

Security The fact that minor faults can lead to widespread power outages suggests that deliberately caused faults could have even greater consequences. Both hardware and software attacks on the power grid could have long lasting effects especially if long lead time equipment is damaged.

The threat is not only to the power grid itself but also to infrastructure that supports it such as fuel delivery systems. Most of the energy in the power grid comes from large, “base-load” power plants that operate at full capacity as close to 100% of the time as possible. Losing the energy from several of these could cause rolling blackouts if the peak energy demand could not be met by the remaining power plants.

Military bases are beginning to recognize the potential effects of power grid insecurity. The Department of Defense recently announced a \$7B program aimed at installing electricity generation systems at military bases so that they would remain mission-ready even in the event of a terrorist attack on the grid.

Economy

Almost 10% of the energy generated at power plants is lost before it reaches consumers due to resistance losses in the transmission and distribution lines and transformers. Fuel was used to generate this energy and of course utility customers end up paying for it!

Not all electric utilities own sufficient generating capacity to feed their customers at times of peak demand and so they purchase energy from other utilities that have excess capacity. This works well when energy demand is as expected and falls within the limits of long term energy contracts that are drawn up between the utilities. Where this falls down, however, is when demand is greater than anticipated and utilities have to make spot purchases from the energy market. These purchases come at a high price and, again, the utility customer ends up paying for them.

The reverse of this situation occurs when a utility has excess generating capacity and not enough customers and contracts to use it. The excess generating assets remain idle. In addition, 20% of generating capacity in the country exists purely to meet peak demand, so it operates only 5% of the time and provides a mere 1% of the electricity supply.

Blackouts are also expensive, especially for high-tech companies such as those located in Silicon Valley. A blackout would cost Sun Microsystems an estimated \$1 M each minute, and Hewlett-Packard has estimated a 20-minute power outage at a circuit-fabrication plant would cost \$30 M.

Environment

Climate-change has become a topic of general discussion and concern. The emission of carbon dioxide and other “greenhouse” gasses has resulted in the scrapping of plans to construct many new coal burning power plants. More stringent pollution controls are being called for on those coal burning power plants currently operating which will either result in power plants being shut down or very expensive retrofit controls being installed. The call to capture and sequester carbon dioxide is growing louder, but unfortunately the technologies required to provide this service are not fully developed and the potential effects and consequences of carbon dioxide sequestration are not yet fully understood.

There is a growing interest in using renewable energy sources and solar and wind electricity generation power plants in particular are being constructed at a speedy pace. While being environmentally friendly, these generation sources bring their own set of issues and primarily among them is the issue of intermittency. A solar power plant will be affected by clouds and wind farms are dependent on the wind blowing to produce electricity. Neither sunshine nor wind can be 100% guaranteed at the moment that electricity is needed! Some means of dealing with this will be required if solar and wind power plants are going to amount to a significant portion of the country’s generation mix.

Power Quality Modern electronic devices demand high quality electricity in terms of voltage and frequency in order to function properly. Generally, the power grid does a reasonable job at providing that high quality, however, glitches do happen and if the voltage “sags” for a second or

so digital equipment will react – usually going into that nuisance “flashing” mode! Electrical loads at the end of long feeders are even more susceptible to power quality issues.

Utilities try to keep voltage and current in phase with each other. Electric motors and other inductive electrical loads tend to force them out of phase which results in the utilities supplying “reactive” power. This is expensive because currents are higher than they need be and resistive losses in the power lines increase. Utilities use power factor correction capacitor banks at strategic locations in the distribution system in order to try to keep everything in phase.

Customer Choice

Until relatively recently customers had no choice when it came to purchasing electricity. The utilities provided the energy and that was that! Then customers began to have some choices, initially in the choice of their electric rate. Time of use utility rates allowed customers to manage some of their energy costs by purchasing electricity off-peak when it was a little cheaper to generate and therefore cheaper to purchase.

Information on environmental issues has become more accessible and widespread with the advent of the internet and electronic news gathering and so electricity consumers are more aware of these issues, and the steps that might be taken to address them, than they might have been in the past. The use of renewable energy sources to produce electricity is one such step and some consumers now have the choice of accessing “green pricing” programs where their utility guarantees to produce electricity using renewable resources.

Even more personal is the possibility of producing their own electricity from solar panels mounted on their rooftops. The cost of solar PV modules has fallen dramatically over the last three years and this coupled with some incredible utility, state, and federal government financial incentives has put self-generation within the reach of many homeowners and companies. Electric utilities have traditionally made their profit from the sale of electricity and so this new concept of their customers providing their own energy is somewhat alien to them. Remarkably, some utilities are embracing this change and offering help and advice to customers who wish to self-generate, while others are resisting it and producing barriers, which can be overcome, but are still a nuisance to those customers who wish to self-generate.

The power grid has served its original purpose well but for reasons including those listed above the time has come for a change.



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5. The SMART Grid and Campus Micro-Grid

This lesson introduces the concept of the smart grid and how it can be used to address today's power grid issues. It also demonstrates how a micro-grid can serve a local group of consumers or buildings.

The Smart Grid

The power grid is the network that carries electricity from power plants where it is generated to consumers. Today's grid includes switches, transformers, substations and the giant power lines and transmission towers that snake across our landscapes. It operates much like a system of interconnected rivers and streams. Power flows through the transmission system along the path of least resistance, finding multiple paths between the power plants and the areas that are demanding the power.

Power grid operators actually have very little control over today's system. Their primary task is to ensure that as much power is being generated as is being used. Without this energy balance, the grid's voltage could drop, causing the grid to become unstable. Operators generally know which lines are in service and when relays have opened to protect lines against faults such as phase to ground short circuits, but they have limited control capabilities.

Today, a local electricity disruption can have a domino effect, through a series of failures that can affect commerce, communications, and security. A smarter grid will add resiliency to the electric power system by making it better prepared to address emergencies.

Other than the consumer demanding more or less electrical power from the grid, and the utility attempting to respond, there is no communication between the consumer and the utility in the management of today's power grid. In a Smart Grid environment, there will be continuous two-way communication between the utility and the grid, and between the grid and the consumer. Because of this two-way interactive communication, the Smart Grid will allow for automatic rerouting when equipment fails or outages occur. This will minimize outages and minimize the effects when they do happen.

Today's grid has difficulty accommodating variable sources of power like wind and solar energy, the fastest-growing sources of renewable power on the grid. As these resources begin to supply increasing percentages of power to the grid, integrating them into grid operations will become increasingly difficult.

The Smart Grid will be able to make better use of these energy resources. It will give grid operators new tools to reduce power demand quickly when wind or solar power dips, and it will have more energy storage capabilities to absorb excess wind and solar power when it isn't needed, then to release that energy when the wind and solar power dips. In effect, energy storage will help to smooth out the variability in wind and solar resources, making them easier to use.

The Smart Grid will consist of millions of pieces and parts – controls, computers, power lines, automation, and new technologies and equipment working together with the electric grid to respond digitally to our quickly changing electric demand.

When a power outage occurs, Smart Grid technologies will detect and isolate the outages, containing them before they become large-scale blackouts. The new technologies will also help ensure that electricity recovery resumes quickly and strategically after an emergency, routing

electricity to emergency services first, for example. In addition, the Smart Grid will take greater advantage of customer-owned power generators to produce power when it is not available from utilities. By combining these "distributed generation" resources, a community could keep its health center, police department, traffic lights, phone system, and grocery stores operating during emergencies.

Smart meters provide the Smart Grid interface between the consumer and the energy provider. Installed in place of the old, mechanical meter, these meters operate digitally, and allow for automated and complex transfers of information between consumers and the energy provider. For instance, smart meters will deliver signals from the energy provider that can help consumers cut energy costs. Smart meters also provide utilities with greater information about how much electricity is being used throughout their service areas.

This energy information coming to and from the smart meter can be run through a Building Management System (BMS), which will allow viewing it in an easy-to-understand format on a computer or hand-held device. For instance, building managers can see the energy impact of various appliances and electronic products simply by monitoring the BMS while switching the devices on and off. In a smart building, many appliances will be networked together, allowing building managers to access and operate them through the BMS.

The BMS can choose settings that allow specific appliances and equipment to turn off automatically when a large demand threatens to cause an outage, avoid peak demand rates, help balance the energy load, and prevent blackouts. Some utilities may provide financial incentives for doing so.

Smart appliances will also be able to respond to signals from energy providers to avoid using energy during times of peak demand. This is more complicated than a simple on and off switch. For instance, a smart air conditioner might extend its cycle time slightly to reduce its load on the grid; while not noticeable to the individual consumer, millions of air conditioners acting the same way could significantly reduce the load on the power grid.

The Campus Microgrid

Rooftop solar electric systems and small wind turbines are now widely available, and people in rural areas may even consider installing a small hydropower system on a nearby stream.

Companies are also starting to roll out home fuel cell systems, which produce heat and power from natural gas.

A potential feature of the Smart Grid will be to allow communities to use individuals' solar arrays to keep the lights on even when there is no power coming from a utility.

This is called "islanding," it will allow a consumer to obtain power from "distributed resources," such as local rooftop solar, small hydropower, and wind projects, until utility workers can bring the grid back online.

Microgrids are integrated energy systems consisting of distributed energy resources and multiple electrical loads operating as a single, autonomous grid either in parallel to, or islanded from, the existing utility power grid. In many ways, a microgrid is really just a small-scale version of the traditional power grid. Yet the smaller scale of microgrids results in far fewer line losses, a lower demand on transmission infrastructure, and the ability to rely on more localized sources of power generation. Smart microgrids are an ideal way to integrate renewable resources on the community level.

The Smart Grid, with its system of controls and smart meters, will help to effectively connect all these mini-power generating systems to the grid, to provide data about their operation to utilities and owners, and to know what surplus energy is feeding back into the grid versus being used on site.

Much has been written about the characteristics and benefits the Smart Grid will provide these characteristics and benefits include:

- **Intelligent.** Capable of sensing system overloads and rerouting power to prevent or minimize a potential outage; working autonomously when conditions require resolution faster than humans can respond.
- **Efficient.** Making better use of existing infrastructure and capable of meeting increased consumer demand without the need for additional infrastructure.
- **Enabling.** Enabling real-time communication between the consumer and utility so consumers can manage energy consumption based on individual preferences, such as price and/or environmental concerns.
- **Power Quality.** Capable of delivering the power quality necessary for the digital economy, data centers, computers, and electronics, free of voltage sags, voltage spikes, service disturbances and interruptions.
- **Security.** Increasingly resistant to attack and natural disasters as it becomes more decentralized and reinforced with Smart Grid protocols.
- **Green.** Accelerating the use of renewable energy resources.



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6. Energy Storage

This lesson describes how electrical energy usage typically varies throughout the day and the need to continuously match electricity generation to the daily load profile. The concept of energy storage is introduced and how it can help with the matching process. Different energy storage technologies are described and a closer look at battery technologies is provided together with how they can be used to help reduce the consumer's electricity bill.

Load Profiles

As we look more closely at power grids and SMART micro-grids, the inclusion of renewable energy generation sources, such as wind and solar, with their unpredictable and uncontrollable intermittency, creates an increasing problem to the balancing act that needs to be continuously managed to ensure that as much electricity is being generated as is being used.

An additional burden imposed on the balancing act is the rate at which energy is used by customers at different times of the day. Depending on the type of customer (residential, commercial, school or church etc.) and their location in the country (cool northern states or the desert southwest for example), their energy usage throughout the day will be different. A picture of a customer's energy usage is called a load profile and a typical load profile for a residential customer in the South West is shown in Figure 31. This shows an increase in energy usage in the morning, probably as a result of the family using electrical appliances for breakfast and bathing, a decrease in usage during the late morning and early afternoon when the

family is at school or at work and not using much electricity in the home, and another rise in usage in the late afternoon and evening as a result of using more electrical appliances for cooking dinner, watching TV and entertainment, and using the air-conditioning to cool the house.

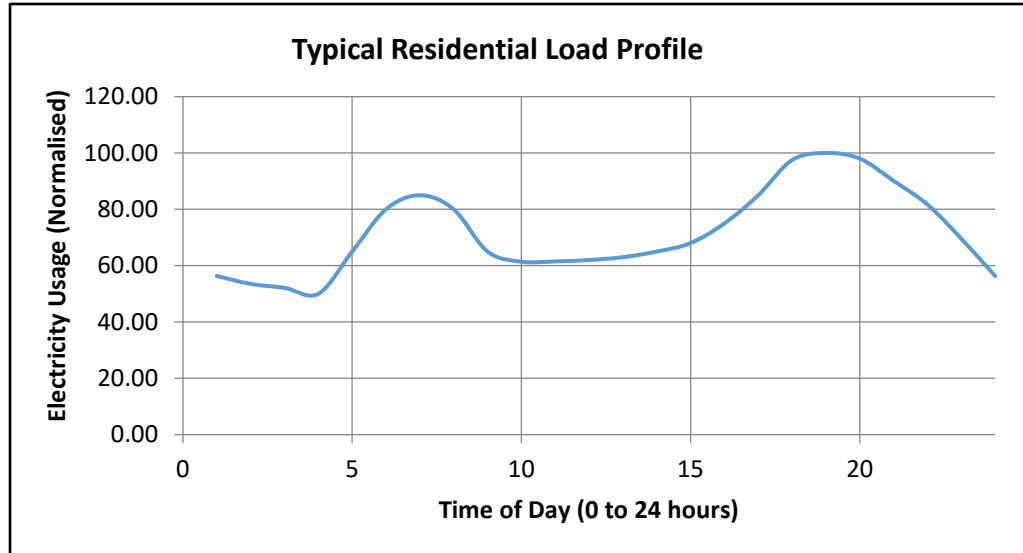


Figure 31. A typical SW Residence load profile.

The load profile for other customers, a school for example, would look very different. A typical load profile for a school is shown in Figure 32 in which it can be seen that energy usage is fairly constant throughout the school day and is otherwise very low. There may be an increase in usage in the evening for air-conditioning and lighting, for example, to support athletic activities.

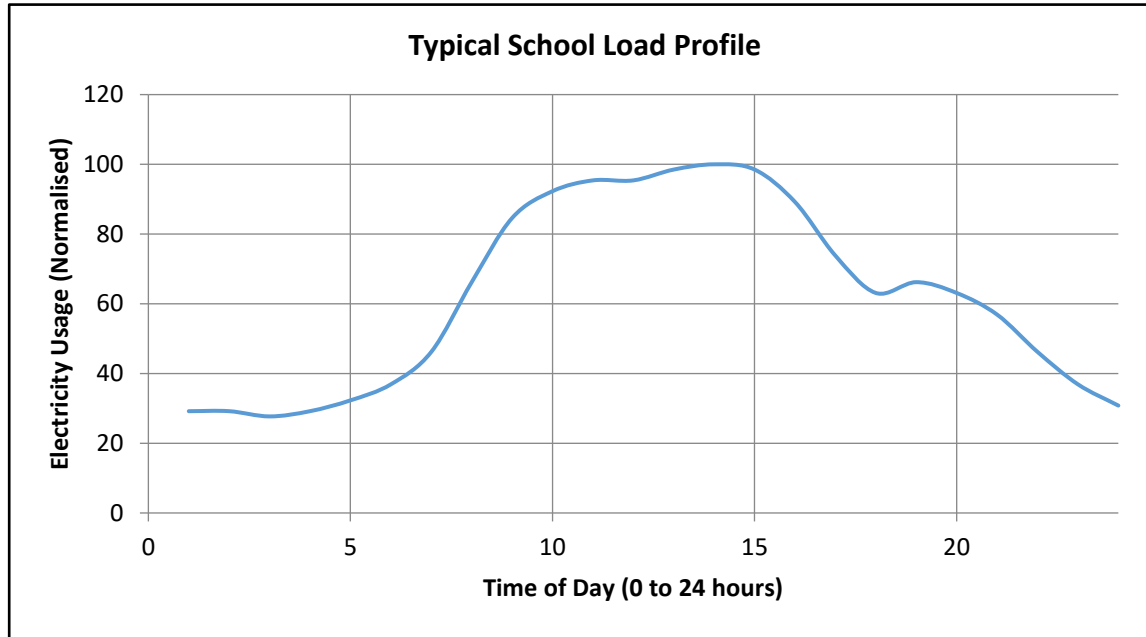


Figure 32. A typical school load profile.

It is important for an electric utility or the designer of a micro-grid system to know the overall load profile for the system in order to ensure that there is always enough electrical generation capacity available to feed the total load. In the event that sufficient generation is not available to feed the load, then brown-outs and black-outs can occur in which power to some customers is curtailed in order to continue providing electricity to others. This is not a desirable situation.

Returning to our grid that includes wind and solar generation, other (controllable and presumably non-renewable) generation sources could be included in the generation mix to ensure that the available generation capacity is sufficient at all times. However, this would defeat the object of including the renewable sources.

Another consideration that needs to be addressed is the demand for electricity in the evenings. If we look at using solar generation for example, not only do we have to deal with its intermittency during the day, due to transient cloud coverage, but we have to accept the fact that after, say 6:00pm, there is no significant solar generation at all because the sun is setting. In order to make up for the loss in solar generation capacity, a non-solar controllable generator, again, presumably non-renewable, will be needed to be included in the generation mix and since it is only required to be used for a few hours in the evening each day, this will be a very expensive source of electricity.

Another solution could be the use of energy storage to ensure that sufficient energy is always available to feed the system load and therefore not require additional generation sources to be constructed.

During periods of low energy usage, the different active generation sources can be used to charge energy storage systems. The stored energy can then be released and used at times when energy demand exceeds the currently available generation capacity. This is particularly useful for the solar and wind generation systems which are essentially “use-it or lose-it” sources. For example, if the wind is blowing but there is no requirement for all of the wind generated electricity, the wind turbines are feathered to reduce their output or are shut down completely, effectively wasting the available wind energy resource that was available at that time.

Energy Storage Technologies

With, perhaps, the exception of Super-cooled electro-Magnetic Energy Storage (SMES), electricity cannot be stored. To store electrical energy it has to be converted into some other form of energy which can be stored. The most common methods are listed below:

- Capacitors store electricity in an electrostatic charge.
- Batteries store electricity in the form of chemical energy.
- Hydrogen can be used to store the electrical energy by using electricity to split water into hydrogen and oxygen. These gases can be stored in a tank or pressure vessel. A fuel cell can then be used to recombine the hydrogen and oxygen and generate electricity.
- Pumped-hydro storage facilities use electricity to pump water uphill and then let it flow back down through a turbine to generate electricity at a later time. The energy is stored as the potential energy of the water in the elevated reservoir.
- Compressed-air storage facilities use electricity to compress air and then expand it through a turbine to generate electricity later.
- Flywheels use electricity to spin up a weighted disc. The angular momentum (rotational inertia) is used to drive a generator to generate electricity later.
- Thermal energy storage uses heat sinks like molten salts to store heat energy, and then use that energy to either generate electricity or provide heating later. Alternatively, electricity can be used to freeze water into ice, and then the ice can be used to provide air conditioning later. (This is a way of time-shifting electricity consumption more so than "storing" it.)
- Various other schemes exist, such as driving large electric trains uphill and then using regenerative braking as they roll back down. All of these have significant limitations. Each system has its own challenges:
- Inductors, capacitors, and batteries can only store direct current (DC), so additional equipment is necessary to use them for the alternating-current (AC) electric grid. They're also extremely expensive relative to the amount of energy they can store.
- Hydrogen is very corrosive to most common engineering metals (e.g. mild steel) so it requires expensive alloys for containment and transport.
- Pumped-hydroelectric and compressed-air storage require specific geography/geology and therefore are limited by the number of available construction sites.
- Flywheels can't store much energy and slowly lose energy to friction.
- Thermal energy storage requires large, expensive systems of heat exchangers and heat pumps/engines, and slowly lose energy to the environment. Another major issue is round-trip efficiency. Energy is lost during both the storage and extraction phases. The total losses are usually more than half of the energy input (depending on the type of storage). The rest goes to waste heat.

Most of the technologies described above have either small, very short-term, or large, long term storage capabilities and can be used for applications such as microsecond power quality control or major power grid energy storage. For storage applications in a micro-grid environment, batteries and fuel cells present the most effective solutions since they are modular, have a manageable size and can be distributed around a micro-grid circuit.

Batteries

For smaller, residential and commercial, energy storage applications the battery is currently the technology of choice. Batteries are modular, easy to maintain and exhibit a long life if the energy storage system is designed correctly.

The most common battery technologies are listed in the table below. In addition to the pros and cons of the different technologies, the main parameters to consider when selecting a battery technology are the cycle life – how many times can the battery be discharged and recharged, and the depth of discharge (DoD) – how far can the battery be discharged (100% DoD means the battery is fully discharged) without damaging the battery or reducing the cycle life.

Type	Cycle Life	Depth of Discharge	Pros	Cons
Flooded Lead Acid	200 – 300	50%	Low cost, reliable, tolerant to abuse, tolerant to overcharging, low internal impedance, delivers very high currents, indefinite shelf life if stored without electrolyte, can be left on trickle or float charges for long periods of time, wide range of sizes and capacity	Contains lead and sulfuric acid. Generates hydrogen during charging
Absorbent Glass Mat (AGM) VRLA	3 – 5 years, 6 – 8 years if properly maintained	80%	Spill-proof, lighter than lead acid, delivers high currents, long service life, maintenance free, less prone to discharge in storage, does well in cold temperatures, lower internal resistance	Lower specific energy and high manufacturing costs, sensitive to overcharging, capacity has gradual decline, does not like high heat
Gel Valve Regulated (VRLA)	400 – 600 cycles	80%	Can be oriented in any direction, oxygen recombination efficiency up to 99%	Contains lead, sulfuric acid and cadmium, will generate some gas during overcharge
Lithium Ion*	1900	80%	High specific energy, long cycle and extended shelf-life, maintenance free, High capacity, low internal resistance, efficient, simple charge and short charge times, low self-discharge	Requires protection circuit to prevent thermal runaway if stressed, degrades at high temperature and stored at high voltage, No rapid charge at freezing temps, transportation regulations
Salt Water	3000	100%	Fire resistant, operate from -5° to 40°C, long life	Overcharging can create hydrogen and oxygen, slow to charge and discharge, power is low and inconsistent, very heavy
Sodium Sulphur	>4200	89 – 92%	Made from inexpensive materials,	Operates at high temperature 245-350°C (473-662°F) sodium will burn on contact with air and moisture, corrosion of insulators gradually become conductive and self-discharge rate increased, dendritic-sodium growth can occur
Nickel Iron	Repeated deep discharge does not reduce life	<65%	Deep depth of discharge, high rate of discharge, long cycle life, long shelf life, high efficiency, high maximum operating temperatures, high safe storage, no lead, no acid	Poor low temperature performance, high self-discharge of 20-40% per month, high manufacturing cost
Nickel Metal Hydride	180-2000	66 – 92%	Long service life, low corrosion, minimal self-discharge, temperature performance of -28°C to 54°C (-20°F to 130°F)	Loses capacity after the 300 cycle mark, decrease in internal resistance of 700 cycle and rise in self-discharge after 1000 cycle
Zinc Air	180	50%	Similar to a fuel cell, uses oxygen to fuel the positive electrode, manufacturing cost is low, 2% self-charge per year in a sealed state	Specific power is low, sensitive to hot and cold temperatures and high humidity, affected by pollution

- Lithium Ion batteries can be made using many different ionic elements. The information presented here is an average of the overall family of technologies.

Peak Shaving

All of the above batteries can be used to store wind and solar generated electrical energy when the demand is less than the generation rate and release the energy when it is needed or store utility electrical energy during times of low demand and releasing the energy at times of peak demand.

The latter application is known as peak shaving and can be used to reduce a utility customer's electric bill.

To recover the cost of providing electricity at peak times of the day, the cost to the customer of peak demand-time electricity is usually significantly higher than the cost at times of low demand, resulting in a "time-of-use" electrical rate structure. Releasing stored energy during the peak demand time can reduce the utility electric bill by reducing the amount of electricity drawn from the utility grid at times of peak demand.

Such an application will invariably result in a customer taking a larger amount of energy from the grid at a different time of the day, hopefully when electricity is cheaper, and is known as Peak Shifting.

When designing an energy storage system it is essential to understand the local utility's rate structure so that optimum energy storage and release times can be incorporated into the system operation.



Logbook: Make a logbook entry - What did you learn from this narrative?

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