Overview of power generation techniques

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Traditional Power Generation

Oil-fired power

Crude oil is extracted from oilfields located on land or offshore in the ocean. Crude oil is then converted to more refined products in large oil refineries. One product of this refinement is **fuel oil that can be burned to produce electricity** in oil-fired power plants.

Oil sits in deep underground reservoirs. Like other fossil fuels, this liquid is the end product of millions of years of decomposition of organic materials. Since the ultimate amount of oil is finite – and cannot be replenished once it is extracted and burned – it cannot be considered a renewable resource.

How it works

Three technologies are used to convert oil into electricity:

- Conventional steam. Oil is burned to heat water to create steam to generate electricity.
- Combustion turbine. Oil is burned under pressure to produce hot exhaust gases, which spin a turbine to generate electricity.
- Combined-cycle technology. Oil is first combusted in a combustion turbine, using the heated exhaust gases to generate electricity. After these exhaust gases are recovered, they heat water in a boiler, creating steam to drive a second turbine.

Utilization

Although relatively little change in oil-fired generating capacity is expected, oil's share of world installed capacity declines over the projection period, from 10 percent in 2003 to 7 percent in 2030 in the IEO2006 (International Energy Outlook 2006, cf. www.eia.doe.gov) reference case. Oil has more value in the transportation sector and in limited applications for distributed diesel-fired generators than in central power plant applications. Only the Middle East and China are expected to see sizable increases in oil-fired electric power capacity.

In recent years, China has shown fairly strong growth in oil-fired electricity generation, because peak electricity demand continues to outpace on-grid electricity generation, and Chinese industry has had to rely on diesel generators to cope with annual summer power shortages. That situation is expected to continue in the short term, but as planned capacity fueled by natural gas, coal, nuclear, and hydroelectric power comes on line and China's electricity grid matures, the use of oil to generate electricity is expected to moderate.

Environmental impacts

Burning oil to generate electricity produces significant air pollution in the forms of nitrogen oxides, and, depending on the sulfur content of the oil, sulfur dioxide and particulates. Carbon dioxide and methane (as well as other greenhouse gases), heavy metals such as mercury and volatile organic compounds (which contribute to ground-level ozone) all can come out of the smoke stack of an oil-burning power plant.

The operation of oil-fired power plants also impacts water, land use and solid waste disposal. Similar to the operations of other conventional steam technologies, oil-fired conventional steam plants require large amounts of water for steam and cooling, and can negatively impact local water resources and aquatic habitats. Sludges and oil residues that are not consumed during combustion became a sold waste burden and contain toxic and hazardous wastes.

Drilling also produces a long list of air pollutants, toxic and hazardous materials, and emissions of hydrogen sulfide, a highly flammable and toxic gas. All of these emissions can impact the health and safety of workers and wildlife. Losses of huge stretches of wildlife habitat also occur during drilling. Refineries, too, spew pollution into the air, water and land (in the form of hazardous wastes). Oil transportation accidents can result in catastrophic damage killing thousands of fish, birds, other wildlife, plants and soil.

Gas-fired power

See also: *Waste-to-energy: Landfill gas*.

Natural gas, because of its clean burning nature, has become a very popular fuel for the generation of electricity. In a natural gas power plant **gas is converted successively into thermal energy, mechanical energy and, finally, electrical energy** for continuous use and distribution. Almost all large fossil fuel power plants are steam-electric power plants, except for gas turbines and utility-sized reciprocating engines. The stock of natural gas, like other fossil-based fuels, is limited and is therefore not a renewable resource.

How it works

Natural gas can be used to generate electricity in a variety of ways:

- Steam Generation Units. The most basic natural gas-fired electric generation consists of a steam generation unit, where fossil fuels are burned in a boiler to heat water and produce steam, which then turns a turbine to generate electricity. These basic steam generation units have fairly low energy efficiency.

- Centralized Gas Turbines. Gas turbines and combustion engines are also used to generate electricity. In these types of units, instead of heating steam to turn a turbine, hot gases from burning fossil fuels (particularly natural gas) are used to turn the turbine and generate electricity. Gas turbine and combustion engine plants are traditionally used primarily for peak-load demands, as it is possible to quickly and easily turn them on.

- Combined Cycle Units. Many of the new natural gas-fired power plants are what are known as “combined-cycle” units. In these types of generating facilities, there is both a gas turbine and a steam unit, all in one. The gas turbine operates in much the same way as a normal gas turbine, using the hot gases released from burning natural gas to turn a turbine and generate electricity. In combined-cycle plants, the waste heat from the gas-turbine process is directed towards generating steam, which is then used to generate electricity much like a steam unit. Because of this efficient use of the heat energy released from the natural gas, combined-cycle plants are much more efficient than steam units or gas turbines alone.

Liquefied natural gas or LNG

LNG is natural gas that has been processed to remove either valuable components e.g. helium, or those impurities that could cause difficulty downstream, e.g. water, and heavy hydrocarbons and then condensed into a liquid at almost atmospheric pressure by cooling it to approximately -163°C. LNG is transported by specially designed cryogenic sea vessels and cryogenic road tankers; and stored in specially designed tanks. LNG is about 1/614th the volume of natural gas at standard temperature and pressure, making it much more cost-efficient to transport over long distances where pipelines do not exist. Where moving natural gas by pipelines is not possible or economical it can be transported by LNG vessels.

LNG offers an energy density comparable to petrol and diesel fuels and produces less pollution, but its relatively high cost of production and the need to store it in expensive cryogenic tanks have prevented its widespread use in commercial applications.

LNG is currently a booming business, but with the growing energy demand – especially in Asia – this will be a continuous upward trend, challenging the gas industry to develop cheaper and more advanced LNG technology. An important part of the supply picture is, that out of the 485 billion m^3 of gas exported around the world in 1999, approximately 25% or 124 billion m^3 was in the form of LNG, 75 % of which is transported to Asia Pacific.

Major international oil companies such as BP, ExxonMobil, Royal Dutch Shell; and national oil companies such as Pertamina, Petronas are active players. Japan, South Korea and Taiwan import large sums of LNG due to their shortage of energy.

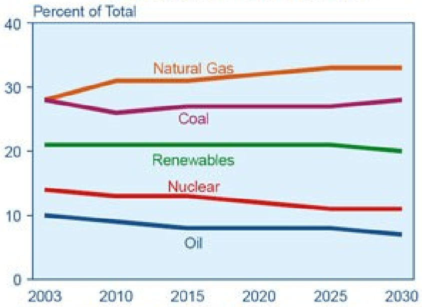
Utilization

In the IEO2006 (International Energy Outlook 2006, cf. www.eia.doe.gov) reference case, natural-gas-fired generating capacity increases by approximately 2.7 percent per year from 2003 to 2030.

In the OECD economies, natural gas and coal each accounted for 28% of installed electricity generating capacity in 2003 (cf. Figure 60). Over the projection period, natural gas capacity gains share (rising to 33 percent) at the expense of nuclear, renewables, and oil-fired capacity, while coal's share remains steady. Nearly one-half of the total increment in OECD gas-fired generating capacity is attributed to the countries of Europe, where the natural gas share of electric power generation more than doubles, from 15 percent in 2003 to 39 percent in 2030.

In the United States, both the share of natural gas capacity and the share of electricity generated from natural gas decline over the projection period. Gas-fired plants, which provided 15 percent of total U.S. electricity supply in 2003, increase their share to 20 percent of supply in 2015 before dropping back to 15 percent in 2030. Gas-fired power generation (excluding generation in the industrial sector) increases initially as the recent wave of newer, more efficient plants come online, but it declines towards the end of the projection period as natural gas prices continue to rise. A similar pattern of expanding natural gas capacity and generation shares, followed by declining shares relative to other fuels, is expected in OECD Asia. In both Canada and Mexico, natural gas capacity increases steadily, and gas-fired power generation increases by 4.5 percent per year in Canada and 6.9 percent per year in Mexico.

Figure 60. Shares of OECD Installed Electricity Capacity by Fuel Type, 2003-2030



Sources: **2003:** Derived from Energy Information Administration (EIA), *International Energy Annual 2003* (May-July 2005), web site www.eia.doe.gov/iea/. **2010-2030:** EIA, System for the Analysis of Global Energy Markets (2006).

In the non-OECD nations, the natural gas share of total electricity generation rises as oil and renewables lose share. Gas-fired capacity grows most rapidly in non-OECD Asia – especially China and India – and natural gas consumption in the electric power sector increases by an average of 7.0 percent per year in China and 7.1 percent per year in India from 2003 to 2030. For non-OECD Asia as a whole, natural-gas-fired electricity generation increases by an average of 7.2 percent per year, as compared with 4.7 percent per year worldwide.

In non-OECD Europe and Eurasia, with access to rich natural gas resources, natural gas was used for 35 percent of total electricity generation in 2003. In 2030, its share of the region's electricity production is projected to be 60 percent. Africa, the Middle East, and Central and South America also rely increasingly on natural gas to produce electricity in the IEO2006 reference case.

Economics and feasibility

Electricity produced from natural gas costs around **$0.039-0.044 per kWh**. Gas-fired plants are generally quicker and less expensive to build than coal or nuclear, but a relatively high percentage of the cost per kWh is derived from the cost of the fuel. Due to the current (and projected future) upward trend in gas prices, there is uncertainty around the cost per kWh over the lifetime of plants.

Gas-fired combined-cycle generation is an attractive choice for new power plants because of its fuel efficiency, operating flexibility (it can be brought on line in minutes rather than the hours it takes for other energy sources like coal), relatively short construction times (months instead of the years that coal or nuclear power plants typically require), and lower investment costs. Natural gas burns cleanlier than coal, but the gas itself (largely methane) is a potent greenhouse gas. But still, the major drawback of natural gas capacity is the potential volatility of natural gas prices.

Coal-fired power

Electricity from coal is the **electric power made from the energy stored in coal**. Coal is a combustible black or brownish-black sedimentary rock composed mostly of carbon and hydrocarbons. Carbon, made from ancient plant material, gives coal most of its energy. This energy is released when coal is burned. Coal-fired power is not a renewable energy source because it takes millions of years to create.

How it works

The process of converting coal into electricity has multiple steps and is similar to the process used to convert oil and natural gas into electricity:

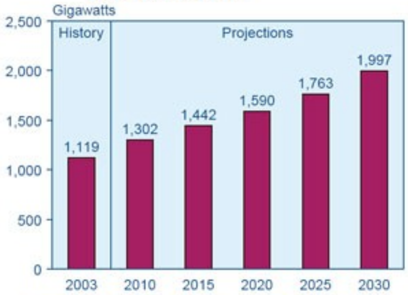
1. A machine called a pulverizer grinds the coal into a fine powder.
2. The coal powder mixes with hot air, which helps the coal burn more efficiently, and the mixture moves to the furnace.
3. The burning coal heats water in a boiler, creating steam.
4. Steam released from the boiler powers an engine called a turbine, transforming heat energy from burning coal into mechanical energy that spins the turbine engine.
5. The spinning turbine is used to power a generator, a machine that turns mechanical energy into electric energy. This happens when magnets inside a copper coil in the generator spin.
6. A condenser cools the steam moving through the turbine. As the steam is condensed, it turns back into water.
7. The water returns to the boiler, and the cycle begins again.

Utilization

Both North America and Asia have over 25% each of total coal reserves. Total coal reserves held by Europe were slightly over 30% of the world total. European reserves are dominated by two countries – Germany (21%) and the Russia (50%).

Coal retains the largest market share of the world’s electricity generation – roughly 40 percent – despite losing some of its share to natural gas. Installed coal-fired capacity, as a share of total world capacity, remains at about 30 percent. Worldwide, coal-fired capacity grows by 2.2 percent per year, from 1,119 gigawatts in 2003 to 1,997 gigawatts in 2030 (cf. Figure 62) — slightly faster than the 2.0-percent average annual increase for all electricity generation capacity. In 2003, non-OECD economies on the whole relied on coal for roughly 43 percent of generation, slightly more than the OECD economies.

Figure 62. World Installed Coal-Fired Generating Capacity, 2003-2030



Sources: **2003:** Derived from Energy Information Administration (EIA), *International Energy Annual 2003* (May-July 2005), web site www.eia.doe.gov/iea/. **2010-2030:** EIA, System for the Analysis of Global Energy Markets (2006).

Regional differences in coal use for electricity generation arise primarily from differences in coal resources. Regions with large coal resources are more likely to use coal for electricity generation, because coal has a lower energy density (energy per weight) and fewer alternative uses than oil or natural gas. These factors help keep coal prices, on an energy basis, lower than oil and natural gas prices. Coal reserves in the United States, China, India, and Australia are among the largest in the world, and those countries rely on coal to generate 50 to 80 percent of their electricity.

China and the United States lead the world in coal-fired capacity additions in the projections, adding 546 gigawatts and 154 gigawatts, respectively. In China, strong growth in natural-gas-fired capacity initially pushes coal’s share of total capacity down to 63 percent in 2010, but it rebounds to 72 percent in 2030. In the United States, coal-fired power plants continue supplying the largest share of electricity generation through 2030. Sustained high world oil and natural gas prices lead to increased reliance on coal to produce electricity in the later years of the projection. The coal share of total electricity generation in the United States increases from 53 percent in 2003 to 57 percent in 2030. In non-OECD Asia excluding China, the share of electricity generated from coal-fired capacity declines, despite continuing additions to coal-fired capacity, because additions of natural-gas-fired capacity exceed additions to coal-fired capacity. In all other regions, the coal share of electricity generation remains stable or falls.

Economics and feasibility

The mining, transportation, electricity generation, and pollution-control costs associated with using coal are increasing. However, the cost of using coal should continue to be even more competitive, compared with the rising cost of other fuels. Electricity produced from coal typically costs around **$0.048-0.055 per kWh**.

In fact, generating electricity from coal is cheaper than the cost of producing electricity from natural gas. In the United States, 23 of the 25 electric power plants with the lowest operating costs are using coal.

Note that each coal-fired power plant is a highly complex, custom-designed system. Present construction costs, as of 2004, run to US$1,300 per kilowatt, or $650 million for a 500 MWe unit.

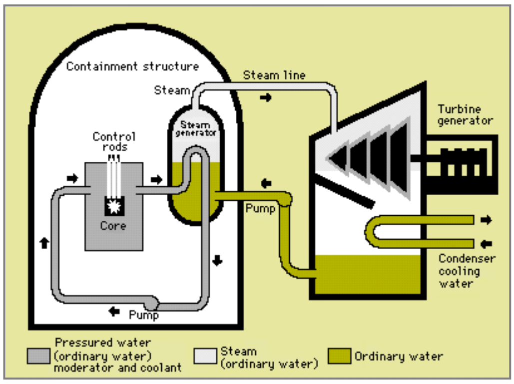
Any limit on coal use will not be imposed by a limit on the availability of physical resources of coal – but coal use could face limits and restrictions in the future which would affect the availability and price of energy. These changes in the relative market value of coal compared with other energy sources will impact on recoverable reserves when the economic impact is taken into account by individual countries when assessing their coal reserves.

It is increasingly difficult to build new coal plants in the developed world, due to environmental requirements governing the plants. The supply of coal is plentiful, but the coal-fired power generation is perceived to make a larger contribution to air pollution than the rest of the power generation techniques combined.

Nuclear power

Nuclear power is the **controlled use of nuclear reactions to release energy for the generation of electricity**. Human use of nuclear power is currently limited to nuclear fission and radioactive decay.

How it works



Nuclear energy is produced when a fissile material, such as uranium-235 (235U), is concentrated such that nuclear fission takes place in a controlled chain reaction and creates heat — which is used to boil water, produce steam, and drive a steam turbine. The turbine can be used for mechanical work and also to generate electricity.

Reprocessing can recover up to 95% of the remaining uranium and plutonium in spent nuclear fuel, putting it into new mixed oxide fuel. Reprocessing of civilian fuel from power reactors is currently done on large scale in Britain, France and (formerly) Russia, will be in China and perhaps India, and is being done on an expanding scale in Japan.

Nuclear power produces spent fuel, a unique solid waste problem. Highly radioactive spent fuel needs to be handled with great care and forethought due to the long half-lives of the radioactive isotopes in the waste.

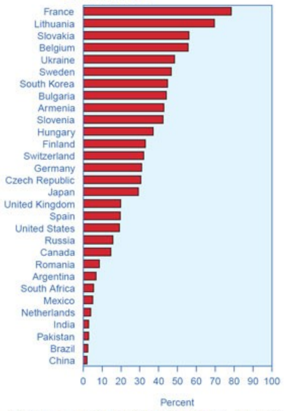
Utilization

The United States produces the most nuclear energy, with nuclear power providing 20% of the electricity it consumes, while France produces the highest percentage of its electrical energy from nuclear reactors—80% as of 2006. Nuclear power currently provides around 24% of the global electricity demand.

Prospects for nuclear power have improved in recent years, with higher capacity utilization rates reported for many existing nuclear facilities and the expectation that most existing plants in the OECD nations and in non-OECD Europe and Eurasia will be granted extensions to their operating lives. Higher fossil fuel prices, concerns about energy supply security, and the possibility for new, lower cost nuclear reactor designs also may improve prospects for new nuclear power capacity. Nevertheless, nuclear power trends can be difficult to anticipate for a variety of political and social reasons, and considerable uncertainty is associated with nuclear power projections.

Nuclear power is an important source of electricity in many countries of the world. In 2005, 16 countries depended on nuclear power for at least 25 percent of their electricity generation (cf. Figure 64). As of December 2005, there were 443 nuclear power reactors in operation around the world, and another 24 were under construction. Despite a declining share of global electricity production, nuclear power is projected to remain an important source of electric power through 2030.

Figure 64. Nuclear Shares of National Electricity Generation, 2005



Source: International Atomic Energy Agency, Reference Data Series 2, "Power Reactor Information System," web site www.iaea.org/programmes/a2/ (April 2006).

The use of nuclear power is controversial because of the problem of storing radioactive waste for indefinite periods, the potential for possibly severe radioactive contamination by accident (like the 1979 Three Mile Island accident and the 1986 disaster at Chernobyl) or sabotage.

Economics and feasibility

Opponents of nuclear power argue that any of the environmental benefits are outweighed by safety compromises and by the costs related to construction and operation of nuclear power plants. Proponents of nuclear power respond that nuclear energy is the only power source which explicitly factors the estimated costs for waste containment and plant decommissioning into its overall cost. Waste disposal remains a significant problem, and de-commissioning is costly (averaging approximately US $320MM per plant in the US). Electricity produced from nuclear power costs around **$0.111–0.145 per kWh**.

Generally, a nuclear power plant is significantly more expensive to build than an equivalent coal-fuelled or gas-fuelled plant. However, servicing the capital costs for a nuclear power dominate the costs of nuclear-generated electricity, contributing about 70% of costs (assuming a 10% discount rate). Nuclear power has lower fuel costs but higher operating and maintenance costs.

In many countries, licensing, inspection and certification of nuclear power plants has added delays and construction costs to their construction. However, the regulatory processes for siting, licensing, and constructing have been standardized to make construction of newer and safer designs more attractive to companies.

Conventional, Renewable Power Generation

Solar energy: Photovoltaic/Solar electric power

Solar energy is the technology of **obtaining usable energy from the light of the sun**. Photovoltaic modules or panels are made of semiconductors that allow sunlight to be converted directly into electricity. These modules can provide you with a safe, reliable, maintenance-free and environmentally friendly source of power for a very long time.

Utilization

Until recently, photovoltaic panels were most commonly used in remote sites where there is no access to a commercial power grid, or as a supplemental electricity source for individual homes and businesses. Recent advances in manufacturing efficiency and photovoltaic technology, combined with subsidies driven by environmental concerns, have dramatically accelerated the deployment of solar panels.

According to information compiled by the IEA PVPS, the most significant country markets for solar electric energy are Japan, the United States, Australia and Germany. In recent years, the major national incentive programs have further boosted installations in both Japan and Germany. Installed solar capacity is growing by 30% per year in several regions including Germany, Japan, California and New Jersey. Currently solar energy supplies approximately 0.8% of the global electricity demand.

Advantages

- Solar power is pollution-free during use.
- End-of-use recycling technologies are under development.
- Solar electric generation is economically competitive where grid connection or fuel transport is difficult, costly or impossible.
- Grid connected solar electricity can be used locally thus minimizing transmission/distribution losses (approximately 7.2%).
- In most places, peak generation (midday) coincides with peak demand.
- Mass production could substantially lower the production costs.

Disadvantages

- Solar cells are costly, requiring a large initial capital investment.
- Limited storage options; batteries are inadequate, inefficient, short-lived.
- Sunlight-dependent and limited power density; average daily insolation in the contiguous U.S. is 3-9 kWh/m^2 usable by 7-17.7% efficient solar panels.
- To get enough energy for larger applications, a large number of photovoltaic cells are needed. This increases the cost of the technology and requires a large plot of land.
- Solar cells produce DC, which must be converted to AC when used in currently existing distribution grids. This incurs an energy loss of 4-12%.

Economics and feasibility

Solar electricity today costs about **$0.15-0.30 per kWh**. Once the initial capital cost of building a solar power plant has been spent, operating costs are low when compared to existing power technologies. In addition, facilities can operate with little maintenance or intervention after initial setup.

Wind power

Wind power is the **conversion of wind energy into more useful forms, usually electricity using wind turbines**. Wind power is a renewable resource, which it consumes no fuel for continuing operation, and has no emissions directly related to electricity production.

How it works

Most modern wind power is generated in the form of electricity by converting the rotation of turbine blades into electrical current by means of an electrical generator. The power in the wind can be extracted by allowing it to blow past moving wings that exert torque on a rotor. The amount of power transferred is directly proportional to the density of the air, the area swept out by the rotor, and the cube of the wind speed.

Utilization

In 2005, worldwide capacity of wind-powered generators was 58,982 megawatts; although it currently only supplies approximately than 1.4% of global electricity demand, it accounts for 23% of electricity use in Denmark, 6% in Germany and approximately 8% in Spain. Globally, wind power generation more than quadrupled between 1999 and 2005. By 2010, World Wind Energy Association expects 120,000 MW to be installed worldwide.

Germany, Spain, the United States, India, and Denmark have made the largest investments in wind-generated electricity. Denmark is prominent in the manufacturing and use of wind turbines, with a commitment made in the 1970s to eventually produce half of the country's power by wind. Denmark and Germany are leading exporters of large (0.66 to 5 MW) turbines. Spain and the United States are next in terms of installed capacity.

Economics and feasibility

The cost of wind-generated electric power has dropped substantially. Since 2004, according to some sources, the price in the United States is now lower than the cost of fuel-generated electric power. In 2005, wind energy cost one-fifth as much as it did in the late 1990s, and that downward trend is expected to continue, as larger multi-megawatt turbines are mass-produced. A British Wind Energy Association report gives an average generation cost of onshore wind power of around **£0.032 per kWh**.

Most major forms of electric generation are capital intensive, meaning that they require substantial investments at project inception, and low ongoing costs. This is particularly true for wind power, which have fuel costs close to zero and relatively low maintenance costs.

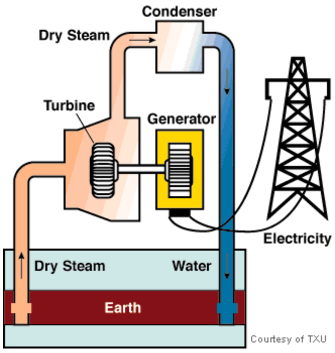
Wind energy benefits from subsidies of various kinds in many jurisdictions, either to increase its attractiveness, or to compensate for subsidies received by other forms of production or which have significant negative externalities.

It is possible to produce electricity from wind for as little as £0.02 per kWh, comparing with the cost of electricity from conventional sources. However, low cost generation is only possible on the windiest sites. Typically, electricity from wind will cost around **£0.02-0.10 per kWh** depending on scale and location.

Geothermal power

Geothermal power is the **use of geothermal heat to generate electricity**. It is often referred to as a form of renewable energy, but because the heat at any location can eventually be depleted it technically may not be strictly renewable. Geothermal comes from the Greek words "*geo*", meaning earth, and "*therme*", meaning heat. Geothermal literally means *"earth heat"*.

How it works



A geothermal reservoir is a mass of fractured rock in the Earth's crust that is saturated with hot water or steam. To bring the water or steam to the surface, wells are drilled into them. If the fluid is hot enough steam bubbles will occur and cause the water to flow naturally to the surface, if not then the wells may need a pump. Power plants utilize the hot water or steam from the wells by directing it to a turbine and generator to produce power (electricity), working much like any conventional power plant. The hot water can also be used directly to heat buildings.

Three types of power plants are used to generate power from geothermal energy:

- Dry steam plants take steam out of fractures in the ground and use it to directly drive a turbine that spins a generator.

- Flash plants take hot water, usually at temperatures over 200°C, out of the ground, and allows it to boil as it rises to the surface then separates the steam phase in steam/water separators and then runs the steam through a turbine.
- In binary plants, the hot water flows through heat exchangers, boiling an organic fluid that spins the turbine.

The condensed steam and remaining geothermal fluid from all three types of plants are injected back into the hot rock to pick up more heat. This is why geothermal energy is viewed as sustainable.

Utilization

Geothermal power is generated in over 20 countries around the world including Iceland (producing 17% of its electricity from geothermal sources), the United States, Canada, Italy, France, New Zealand, Mexico, Nicaragua, Costa Rica, Russia, the Philippines (production output of 1,931 MW, 2nd to United States, 27% of electricity), Indonesia, China and Japan. The United States uses more geothermal energy than any place else in the world. Currently geothermal power supplies approximately 0.23% of the global electricity demand.

Economics and feasibility

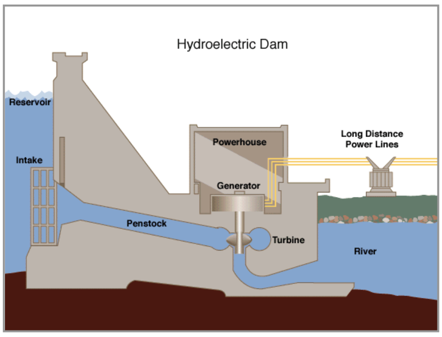
Electricity produced from geothermal energy typically costs around **$0.045-0.30 per kWh**. Generally, the bigger the plant, the less the cost and cost also depends upon the depth to be drilled and the temperature at the depth. The higher the temperature, the lower the cost per kWh.

Geothermal power is more competitive in countries that have limited hydrocarbon resources, but have plentiful geothermal sites, such as Iceland, New Zealand, and Italy. Not all areas of the world have usable geothermal resources. Some geothermal areas do not have a high enough temperature to produce steam. Other areas do not have the water to produce steam.

Hydroelectric power

Most hydroelectric power comes from the **potential energy of dammed water driving a water turbine and generator** although less common variations use water's kinetic energy or dammed sources. Hydroelectricity is a renewable energy source.

How it works



A dam is built to trap water, usually in a valley where there is an existing lake. Water is allowed to flow through tunnels in the dam, to turn turbines and thus drive generators. The energy extracted from water depends not only on the volume, but also on the difference in height between the source and the water's outflow. This height difference is called the head. The amount of potential energy in water is proportional to the head.

Hydropower produces essentially no carbon dioxide or other harmful emissions, in contrast to burning fossil fuels, and is not a significant contributor to global warming through CO_2. Recent reports have linked reservoir construction to methane, formed by decaying submerged plants growing in the dried parts of the basin during drought. Methane is a greenhouse gas.

Utilization

Hydroelectric power now supplies about 715,000 MW or 19.9% of the global electricity demand (16% in 2003). Large dams are still being designed. Apart from a few countries with an abundance of it, hydropower is normally applied to peak load demand because it is readily stopped and started. Nevertheless, hydroelectric power is probably not a major option for the future of energy production in the developed nations because most major sites within these nations are either already being exploited or are unavailable for other reasons, such as environmental considerations.

Norway produces virtually all of its electricity from hydropower, while Iceland produces 83% of its requirements (2004), and Austria produces 67% of all electricity generated in the country from hydropower (over 70% of its requirements). China is the world's largest producer of hydropower. Canada produces over 70% of its electricity from hydroelectric sources.

Grid-connected hydroelectric and other generating capacity fueled by renewable energy resources is projected to increase by 553 gigawatts from 2003 to 2030, at an average annual rate of 1.9 percent. Much of the projected growth in renewable generation results from the expected completion of large hydroelectric facilities in non-OECD Asia, where the need to expand electricity production with associated dams and reservoirs often outweighs concerns about environmental impacts and the relocation of populations. China has ambitious plans to increase hydroelectric capacity, including completion of the 5.4-gigawatt “Longtan” hydroelectric project by the end of 2007 and the 18.2-gigawatt Three Gorges Dam project in 2009. India and several other non-OECD Asian countries, including Laos and Vietnam, also have plans to increase hydroelectric capacity.

In Central and South America, many nations have plans to expand their already well-established hydroelectric resources. Brazil is the largest energy market in Central and South America, and more than 80 percent of its electricity generation comes from hydroelectric sources. As a result, Brazil is especially vulnerable to drought-induced shortages in electricity supply. In general, the nations of Central and South America are not expected to expand hydroelectric resources dramatically but instead are expected to invest in other sources of electricity – particularly natural-gas-fired capacity – that will allow them to diversify electricity supplies and reduce their reliance on hydropower.

Advantages

- Hydroelectric plants tend to have longer lives than fuel-fired generation, with some plants now in service having been built 50 to 100 years ago.
- Pumped storage plants currently provide the only commercially important means for energy storage on a scale useful for a utility.
- Low-value generation in off-peak times occurs because fossil fuel and nuclear plants cannot be entirely shut down on a daily basis. This energy is used to store water that can be released during high load daily peaks.

Disadvantages

- Large hydroelectric projects can be disruptive to surrounding aquatic ecosystems and the generation of hydroelectric power impacts on the downstream river environment.
- The reservoirs of hydroelectric power plants in tropical regions may produce substantial amounts of methane and carbon dioxide. This is due to plant material in flooded areas decaying in an anaerobic environment, and forming methane, a very potent greenhouse gas.
- Another disadvantage of hydroelectric dams is the need to relocate the people living where the reservoirs are planned.

Economics and feasibility

Electricity from hydropower typically costs around **$0.051–0.113 per kWh**. Operating labor cost is usually low since plants are automated and have few personnel on site during normal operation.

Large-scale hydropower development opportunities are limited in many countries because the best sites are either already in use or else unavailable due to economic or environmental restrictions.

Non-Conventional, Available, Renewable Power Generation Technologies

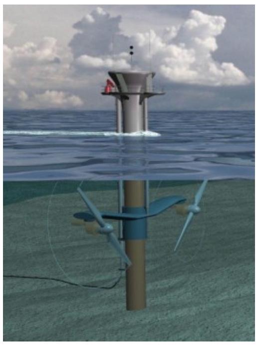
Tidal power / Marine current power

See also: *Hydroelectric power* or *Wave power.*

Tidal power is the power achieved by **capturing the energy contained in moving water mass** due to tides. Two types of tidal energy can be extracted: kinetic energy of currents between ebbing and surging tides and potential energy from the difference in height (or head) between high and low tides. Many coastal sites worldwide are being examined for their suitability to produce tidal energy.

Tidal power is classified as a renewable energy source, because tides are caused by the orbital mechanics of the solar system and are considered inexhaustible within a human timeframe.

How it works



One method of extracting tidal energy involves building a barrage and creating a tidal lagoon. The barrage traps a water level inside a basin. Head is created when the water level outside of the basin or lagoon changes relative to the water level inside. The head is used to drive turbines. In any design this leads to a decrease of tidal range inside the basin or lagoon, implying a reduced transfer of water between the basin and the sea. This reduced transfer of water accounts for the energy produced by the scheme.

The root source of the energy comes from the slow deceleration of the Earth's rotation. The Moon gains energy from this interaction and is slowly receding from the Earth. Tidal power has great potential for future power and electricity generation because of the total amount of energy contained in this rotation. The amount of energy obtainable from a tidal energy varies with location and time. Output changes as the tide ebbs and floods each day. However, tidal power is reliably predictable (unlike wind energy and solar power) in both amount and timing.

A list of different techniques is available from Pure Energy Systems:
http://peswiki.com/index.php/Directory:Tidal_Power#Technologies

Advantages

- 60% of the World's human population resides near coastal areas.
- Tidal energy is around 200 times more energy dense than wind or solar.
- 14-15 knots water speed found in some tides is comparable to 700km/h wind speed in its energy.
- Water (tide) is non-compactable, in contrast to air (wind), which is compactable, making tidal energy much more predictable in terms of scalability.
- Tide phases are very predictable, unlike solar and wind phases, which only have "statistical probability", not actual probability.
- Two tidal stations just 20 kilometers apart could supplement one another so that at least one is always running.

Disadvantages

- Huge cost of additional for transmission lines from the electro-generation source to the points of use.
- Grid power vulnerability due to possible bad weather destruction and other environment-based acts.
- Tidal energy plants do not produce energy 24 hours a day. A conventional design, in any mode of operation, would produce energy for 6 to 12 hours in every 24 and will not produce energy at other times. As the tidal cycle is based on the period of revolution of the Moon (24.8 hours) and the demand for electricity is based on the period of revolution of the Sun (24 hours), the energy production cycle will not always be in phase with the demand cycle. This causes problems for the electric energy transmission grid, as capacity with short starting and stopping times (such as hydropower or gas fired energy plants) will have to be available to alternate power production with the tidal power scheme.

Economics and feasibility

Electricity produced from tidal power typically costs around **$0.02-0.05 per kWh**. Several small tidal power plants have recently started generating electricity in Norway and United Kingdom. Several prototypes have shown promise. But this technology is at the early stages of development and will require more research before it becomes a significant contributor.

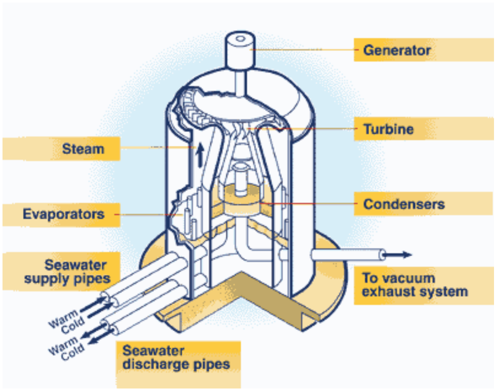
Ocean thermal energy conversion (OTEC)

See also: *Thermoelectric power.*

Ocean thermal energy conversion, or OTEC, is a way to **generate electricity using the temperature difference of seawater** at different depths. The method utilizes the temperature difference that exists between deep and shallow waters – within 20°C of the equator in the tropics – to run a heat engine. Because the oceans are continually heated by the sun and cover nearly 70% of the Earth's surface, this temperature difference contains a vast amount of solar energy, which could potentially be tapped for human use.

The total energy available is one or two orders of magnitude higher than other ocean energy options such as wave power, but the small size of the temperature difference makes energy extraction difficult and expensive.

How it works



An OTEC power plant makes use of a heat engine. The concept of a heat engine is very common in engineering, and nearly all energy utilized by humans uses it in some form. A heat engine involves a device placed between a high temperature reservoir (such as a container) and a low temperature reservoir. As heat flows from one to the other, the engine extracts some of the heat in the form of work. This same general principle is used in steam turbines and internal combustion engines, while refrigerators reverse the natural flow of heat by "*spending*" energy. Rather than using heat energy from the burning of fuel, OTEC power draws on temperature differences caused by the sun's warming of the ocean surface.

OTEC systems can be classified as three types based on the thermodynamic cycle – closed cycle, open cycle and hybrid systems:

- Closed-cycle systems use fluid with a low boiling point, such as ammonia, to rotate a turbine to generate electricity. Warm surface seawater is pumped through a heat exchanger where the low-boiling-point fluid is vaporized. The expanding vapor turns the turbo-generator. Then, cold, deep seawater – pumped through a second heat exchanger – condenses the vapor back into a liquid, which is then recycled through the system.
- Open-cycle OTEC uses the tropical oceans' warm surface water to make electricity. When warm seawater is placed in a low-pressure container, it boils. The expanding steam drives a low-pressure turbine attached to an electrical generator. The steam, which has left its salt behind in the low-pressure container, is almost pure fresh water. It is condensed back into a liquid by exposure to cold temperatures from deep-ocean water.
- Hybrid systems combine the features of both the closed-cycle and open-cycle systems. In a hybrid system, warm seawater enters a vacuum chamber where it is flash-evaporated into steam, similar to the open-cycle evaporation process. The steam vaporizes a low-boiling-point fluid (in a closed-cycle loop) that drives a turbine to produce electricity.

Detailed information on the different types of OTEC systems is available here:
http://www.oceansatlas.com/unatlas/uses/EnergyResources/Background/OTEC/OTEC2.html

Advantages

- Clean energy production. OTEC has remarkably little adverse environmental impact, especially compared with other energy sources of comparable size. OTEC is inherently not exothermic, so it does not adversely contribute directly to global warming, as do, for example fossil fueled and nuclear plants.

- Fresh water production. OTEC plants can produce fresh water as well as electricity. Open-cycled and hybrid plants can directly produce fresh water as well as electricity and closed-cycle plants can produce similar volumes by condensation from the atmosphere. This is a significant advantage in island areas or deserts were fresh water is limited.
- Continuous power. Unlike most other renewable energy sources, which vary with weather and time of day, OTEC power plants can produce electricity continuously. Since the ocean doesn't change temperature at night, the solar energy stored in the seas is always available.
- Worldwide applicability. Production of fuel, such as hydrogen, by tropical OTEC plants can provide the benefits of low-cost OTEC power to the whole world.
- Aquaculture enterprises. Deep seawater discharged from an OTEC plant is cold, rich in nutrients, relatively free of pathogens, and available in large quantity. This is an excellent medium for growing phytoplankton, which in turn can support the production of a variety of commercially valuable fish and shellfish.
- Air-conditioning/refrigeration. The deep-ocean cold water can be used as a chiller fluid in air-conditioning systems. Using the OTEC-byproduct chill-water can save 75% to 85% of air-conditioning costs.
- Mineral extraction. OTEC systems could potentially provide the opportunity to mine for some of the elements in the ocean water solution. Investigations are underway to determine the feasibility of combining the extraction of uranium dissolved in seawater with ocean energy production.

Disadvantages

- Low efficiency. The small temperature difference between the heat source (warm surface water) and the heat sink (cold deep water) temperature gives OTEC plants a typical thermal to electrical energy conversion efficiency of less than 3%. The greater the temperatures difference between the heat source and a heat sink, the greater the efficiency of an energy-conversion system. In comparison, conventional oil- or coal-fired steam plants, which may have temperature differences of 260°C (500°F), have thermal efficiencies around 30-35%. To compensate for its low thermal efficiency, an OTEC plant has to move a lot of water. That means OTEC plants have a large "hotel load." In other words, OTEC-generated electricity has a lot of work to do at the plant before any of it can be made available to the community power grid.
- Potential ecological consequences. OTEC has not been demonstrated at full scale over a prolonged period with integrated power, mariculture, fresh-water, and chill-water production. OTEC is ecologically controversial – at least untested – in large scale and over a long period.
- Siting considerations. OTEC plants must be located where a difference of at least 20°C (36°F) occurs year round - mostly limited to tropical waters. Ocean depths must be available fairly close to shore-based facilities for economic operation. Floating plant ships could provide more flexibility, serving as sources for fuel for distant regions.

Economics and feasibility

An OTEC facility requires a substantial initial capital outlay (in the range of $50 to $100 million for a “small” 10 MW plant. All OTEC plants require an expensive, large diameter intake pipe, which is submerged a mile or more into the ocean's depths, to bring very cold water to the surface. About 75% of the capital cost of current OTEC designs will be for the deep seawater pipeline.

Some energy experts believe that if it could become cost-competitive with conventional power technologies, OTEC could produce gigawatts of electrical power. Bringing costs into line is still a huge challenge, however. For OTEC to be viable as a power source, it must either gain political favor (i.e. favorable tax treatment and subsidies) or become competitive with other types of power generation already subsidized today. Because OTEC systems have not yet been widely deployed, estimates of their costs are uncertain. According to Cold Energy LLC, electricity produced from OTEC would cost around **$0.06-0.25 per kWh**.

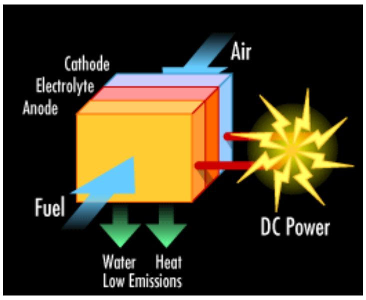
Hydrogen power / Fuel cell

Fuel cells are devices that **produce electrical power using the chemical properties of hydrogen and oxygen**. In some ways they can be considered to be a continuously fuelled battery, although, unlike a battery, they do not store energy - they convert it from one form to another.

Fuel cells are significantly more efficient than equivalent internal combustion engines because they convert chemical energy directly to electrical current rather than via an efficiency sapping mechanical intermediate phase. In addition, the modular design allows the fuel cells to be stacked in such a way to match the specific output power needs without significant additional design work or capital requirements.

The simple nature of their design and operation makes them highly reliable. They operate quietly and can operate on a variety of fuel types. If pure hydrogen is used as a fuel then the only outputs are electricity, heat and water vapor. In this way fuel cells are seen as being significantly more environmentally friendly than other hydrocarbon fueled power sources.

How it works



The combination of the materials used to make the fuel cell components, the type of fuel used and the operating temperature allow electricity to be generated via a chemical reaction rather than burning the fuel.

On one side (the anode side) of the fuel cell is fuel in the form of hydrogen gas, and on the other side (the cathode side) is oxygen (in air). Sandwiched between the anode and cathode is the very thin, gas tight, electrically insulating but ion conducting, electrolyte layer. An electrical circuit connects the anode to the cathode and provides the mechanism to power electrical devices.

The reaction starts with the oxygen on the cathode side being ionized at the cathode and generating negatively charged oxygen ions that then flow through the cathode and across the electrolyte. At the anode side the oxygen ion combines with a positively charged hydrogen ion and releases an electron that then, because of the charge imbalance and the electron-impermeable electrolyte, flows around the electrical circuit to the cathode side generating direct current. This high quality, direct current will continue to be produced as long as there is a supply of fuel and air to the fuel cell.

Challenges

- Costs. In 2002, typical cells had a catalyst content of $1,000 per kW of electric power output. This is expected to be reduced to $200 per kW by 2007.
- Water management. In this type of fuel cell, the membrane must be hydrated, requiring water to be evaporated at precisely the same rate that it is produced. Methods to manage water in cells are being developed by fuel cell companies and academic research labs.
- Flow control. Just as in a combustion engine, a steady ratio between the reactant and oxygen is necessary to keep the fuel cell operating efficiently.
- Temperature management. The same temperature must be maintained throughout the cell in order to prevent destruction of the cell.
- Durability. Stationary applications typically require more than 40,000 hours of reliable operation at a temperature of -35°C to 40°C.

Utilization

Fuel cell technology has been used as an efficient and lightweight energy source for space exploration. Fuel cells were carried aboard the Gemini and Apollo spacecraft and also aboard NASA's space shuttles.

In recent years, numerous carmakers have been developing Hydrogen vehicles, which use hydrogen as their primary source of

power for locomotion. These vehicles generally use the hydrogen in one of two methods: combustion or fuel cell conversion. In combustion, the hydrogen is "burned" in engines in fundamentally the same method as traditional gasoline cars. In fuel cell conversion, the hydrogen is turned into electricity through fuel cells, which then power electric motors.

Over the next few years, technological advances and cost reductions will likely lead to widespread use of fuel cells in a number of different applications. Fuel cells may someday be as common in residential households as refrigerators or dishwashers are today, producing clean and reliable electricity.

Economics and feasibility

Fuel cell technology offers the potential to revolutionize electricity generation. This technology is well suited for ushering in a new, decentralized energy production and delivery system.

A number of companies are actively developing fuel cell technology for commercial applications. Fuel cells can serve a number of niche markets from on-site generation to transportation. In addition to the size and performance of fuel cells, their cost will determine the applications and locations that make economic sense in the near term.

Currently, fuel cells are costly to produce and fragile. However, technologies currently under development may eventually result in robust and cost-efficient versions. One company currently markets fuel cells that use natural gas as a fuel for $3,000 per kW. At this price, fuel cells only make sense in certain niche markets where electricity prices are very high and natural gas prices are very low. A recent study suggests that fuel cells with a $1,500 per kW price would achieve market penetration nationwide in a number of different applications.

Waste-to-energy: Landfill gas

See also: *Gas-fired power* and *Waste-to-energy: Municipal solid waste*.

Large municipal or industrial **landfills produce gas that can be tapped to generate electricity**. Microorganisms that live in organic materials such as food wastes, paper or yard clippings cause these materials to decompose. This produces landfill gas, typically comprised of roughly 60% methane and 40% carbon dioxide.

The US Environmental Protection Agency (EPA) requires all large landfills to install collection systems at landfill sites to minimize the release of methane, a major contributor to global climate change. Though not a renewable resource, landfill gas will be in great supply absent major innovations in solid waste management systems and could supply up to 1% of the United States' energy demand.

How it works

Landfill gas is collected from landfills by drilling "wells" into the landfills, and collecting the gases through pipes. Once the landfill gas is processed, it can be combined with natural gas to fuel conventional combustion turbines or used to fuel small combustion or combined cycle turbines.

Landfill gas may also be used in fuel cell technologies, which use chemical reactions to create electricity, and are much more efficient than combustion turbines. See also: *Hydrogen power / Fuel cell*.

Utilization

Each person in the United States generates about 4.5 pounds of waste per day, or almost 1 ton per year most of which is disposed in municipal solid waste landfills. Landfill gas is generated by the anaerobic decomposition of organic refuse deposited in landfills. Landfill gas consists primarily of methane and carbon dioxide. The EPA Landfill Methane Outreach Program reports that Pennsylvania has 20 current landfill-gas-to-energy projects generating 30.3 million cubic feet per minute (cfm) per day of methane.

The EPA has estimated that 1 million tons of waste typically generates 300 cfm of landfill gas. This amount of gas could generate 7 million kWh per year, which is enough energy to power 700 homes for a year. Utilizing 300 cfm/year of landfill gas has the same greenhouse gas reduction as removing 6,100 cars from the road for one year or planting 8,300 acres of trees.

Waste-to-energy: Municipal solid waste

Waste-to-energy (WtE) in its strictest sense refers to any **waste treatment that creates energy in the form of electricity** or heat from a waste source that would have been disposed of in landfill, also called energy recovery. MSW power plants, also called WtE plants, are designed to dispose of MSW and to produce electricity as a byproduct of the incinerator operation.

The term MSW describes the stream of solid waste ("trash" or "garbage") generated by households and apartments, commercial establishments, industries and institutions. MSW consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint and batteries. It does not include medical, commercial and industrial hazardous or radioactive wastes, which must be treated separately.

MSW incinerators and WtE plants are generally considered not to produce renewable energy as a large fraction of the power which is generated comes from plastics (derived from fossil fuels) and other non-renewable sources. It could be debated that the energy generated from the biodegradable waste fraction is renewable however many countries do not credit this.

The potential of electricity generation using incineration and other non-thermal methods of waste-to-energy such as anaerobic digestion are being increasingly looked at as a potential energy diversification strategy.

How it works

Incineration is a solid waste treatment technology involving combustion of waste at high temperatures. Incineration and other high temperature waste treatment systems are described as "thermal treatment". In effect, incineration of waste materials converts the waste into heat (that can be used to generate electricity), gaseous emissions to the atmosphere and residual ash.

Incineration functions as an alternative to landfilling and biological treatment methods such as composting and anaerobic digestion.

Incineration has particularly strong benefits the treatment of certain waste types in niche areas especially for clinical wastes and certain hazardous wastes where pathogens and toxins must be destroyed by high temperatures.

Modern WtE incinerators are very different from the incinerators that were commonly used until a few decades ago. Unlike modern ones, those plants usually did not include materials separation to remove hazardous or recyclable materials before burning. These incinerators endangered the health of the plant workers and the nearby residents, and most of them did not generate electricity.

Utilization

In the United States, there are currently two main WtE facility designs:

- Mass Burn is the most common WtE technology, in which MSW is combusted directly in much the same way as fossil fuels are used in other direct combustion technologies. Burning MSW converts water to steam to drive a turbine connected to an electricity generator.
- Refuse-derived fuel facilities process the MSW prior to direct combustion. The level of pre-combustion processing varies among facilities, but generally involves shredding of the MSW and removal of metals and other bulky items. The shredded MSW is then used as fuel in the same manner as at mass burn plants.

The EPA estimates that in 1998 17% of the United States' MSW was burned and generated electricity (e.g. 14% in Pennsylvania, 2% in New Jersey and 2% in California), 55% was disposed in landfills, and 28% was recovered for reuse.

Incineration is particularly popular in countries such as Japan where land is a scarce resource. Sweden has been a leader in using the energy generated from incineration over the past 20 years and Denmark also extensively uses incineration in localized combined heat and power facilities supporting district-heating schemes.

Environmental issues

Burning MSW can generate energy while reducing the volume of waste by up to 90 percent, an environmental benefit. Ash disposal and the air polluting emissions from plant combustion operations are the primary environmental impact control issues.

MSW contains a diverse mix of waste materials, some benign and some very toxic. Effective environmental management of MSW plants aims to exclude toxics from the MSW fuel and to control air pollution emissions from the WtE plants.

Toxic materials include trace metals such as lead, cadmium and mercury, and trace organics, such as dioxins and furans. Such toxics pose an environmental problem if they are released into the air with plant emissions or if they are dispersed in the soil and allowed to migrate into ground water supplies and work their way into the food chain. The control of such toxics and air pollution are key features of environmental regulations governing MSW fueled electric generation.

Generally, WtE plants produce comparatively high rates of nitrogen oxide emissions. The on-site land use impacts are generally equal to those of coal or oil fueled plants.

Non-Conventional, Emerging, Renewable Power Generation Technologies

Solar thermal energy: Updraft tower

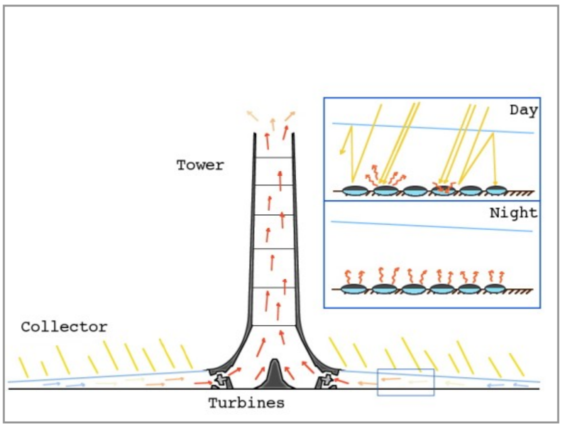
Solar thermal energy refers to the idea of **harnessing solar power for practical applications from solar heating to electrical power generation**. The solar updraft tower is a proposed type of renewable-energy power plant.

There are no solar updraft towers in operation at present. A research prototype operated in Spain in the 1980's, and EnviroMission Ltd. proposed to construct a full-scale power station using this technology in Australia. The company claims to intend to begin construction in early 2007.

How it works

Air is heated in a very large circular greenhouse-like structure, and the resulting convection causes the air to rise and escape through a tall tower. The moving air drives turbines, which produce electricity.

The generating ability of a solar updraft power plant depends primarily on two factors: the size of the collector area and chimney height. With a larger collector area, more volume of air is warmed up to flow up the chimney; collector areas as large as 7 km in diameter have been considered. With a larger chimney height, the pressure difference increases the stack effect. In fact, chimneys as tall as 1,000 m have been considered. Further, a combined increase of the



collector area and the chimney height leads to massively larger productivity of the power plant.

Heat can be stored inside the collector area greenhouse, to be used to warm the air later on. Water, with its relatively high specific heat capacity, can be filled in tubes placed under the collector increasing the energy storage as needed.

Utilization

In 1982, a medium-scale working model of a solar chimney power plant was built under the direction of German engineer Jörg Schlaich in Manzanares, Ciudad Real, 150 km south of Madrid, Spain; the German government funded the project. The chimney with a collection area (greenhouse) of 46,000 m^2 can obtain a maximum power output of about 50 kW. This pilot power plant operated successfully for approximately eight years and was decommissioned in 1989.

Economics and feasibility

With a very large initial capital outlay, no costs for consumables and relatively constant income over the life of the project, a solar updraft tower would be placed in the same asset class as dams, bridges, tunnels, motorways and other similar large infrastructure projects. Financial viability would be assessed on a similar basis. For example, the solar updraft tower being planned by EnviroMission is expected to cost AUD$250 million (US$189 million) to construct and will service 50,000 homes.

There is still a great amount of uncertainty and debate on what the cost of production for electricity would be for a solar updraft tower and thus whether a tower (large or small) can be made profitable. It was claimed, in 2002, that a solar tower in Australia would be an expensive way of generating electricity as compared to a conventional wind farm. However, a 2006 study claims that a large tower in the southwestern United States could not only outperform wind farms on a cost basis but also compete directly with current conventional gas-fired, and some coal-fired, plants.

No reliable electricity cost figures are available until such time as engineering models are available for finalized tower designs and construction has begun on a production tower.

Solar thermal energy: Power tower / Solar furnace

The solar power tower **converts sunshine into clean electricity**. The power tower (also know as “Central Tower” power plants or “Heliostat” power plants) is a type of solar furnace using a tower to receive the focused sunlight to produce heat (up to 4,000°C). The heat can be used to generate electricity, melt rock or steel or make hydrogen fuel.

How it works

A solar power tower uses an array of flat, moveable mirrors (called “heliostats”) to focus the sun's rays upon a collector tower (the target). The high energy at this point of concentrated sunlight is transferred to a substance that can store the heat for later use. The most recent heat transfer material that has been successfully demonstrated is liquid sodium. Sodium is a metal with a high heat capacity, allowing that energy to be stored and drawn off throughout the evening. That energy can, in turn, be used to boil water for use in steam turbines. Water had originally been used as a heat transfer medium in earlier power tower versions (where the resultant steam was used to power a turbine).

Utilization

Examples of heliostat-based power plants are the 10 MW Solar One, Solar Two, and the 15 MW Solar Tres plants. Neither of these is currently used for active energy generation. In South Africa, a solar power plant is planned with 4,000 to 5,000 heliostat mirrors, each having an area of 140 m^2.

The scientific solar furnace at Odeillo, French Cerdagne.

Solar One is a pilot solar-thermal project in the Mojave Desert near Barstow, California. Built by FPL Energy Inc.

Wave power

See also: *Tidal power / Marine current power*.

Wave power refers to the **energy of ocean surface waves and the capture of that energy** to do useful work including electricity generation, desalination, and the pumping of water. Wave power is a form of renewable energy. Though often co-mingled, wave power is distinct from the diurnal flux of tidal power and the steady gyre of ocean currents.

How it works

Existing wave power devices are categorized by the method used to capture the energy of the waves, by the intended location, and by the power take-off. These are descriptions of some wave power systems:

- A pontoon lying in the water is driven by wave action to push or pull an electrical generator. Wave action compresses air in a tunnel, which drives the vanes of a generator.
- A device called CETO, currently being tested off Fremantle, Western Australia, has a seafloor pressure transducer coupled to a high-pressure hydraulic pump, which pumps water to shore for driving hydraulic generators or running reverse osmosis desalination.
- Waves overtop the side of a reservoir, and the water in the reservoir runs hydroelectric generators.

Wave power generation is not a widely employed technology, with only a few experimental sites in existence. More detailed information on other related or similar techniques is available here: http://www.freeenergynews.com/Directory/Wave/index.html

Challenges

- Efficiently converting wave motion into electricity. Generally speaking, wave power is available in low-speed, high forces and motion is not in a single direction.
- Constructing devices that can survive storm damage and saltwater corrosion. Likely sources of failure include seized bearings, broken welds, and snapped mooring lines.

Economics and feasibility

Wave power will only be competitive if total cost of generation (cost per kWh) is reduced. While the industry has suffered many failures, it has benefited in recent years from increases in support from governments, universities, and angel investors. Several promising prototypes are now in operation.

According to the US Environmental Protection Agency, "*levelized cost of wave-generated electricity is less than wind-generated electricity at any equal cumulative production volume under all cost* *estimating assumptions for the wave plant*" and the EPA suggests that the cost of energy would be around **$0.09-0.112 per kWh**.

Wave power could yield much more energy than tidal power. Tidal dissipation (friction, measured by the slowing of the lunar orbit) is 2.5 terawatts. The energy potential of waves is certainly greater, and wave power can be exploited in many more locations. Countries with large coastlines and strong prevailing winds – notably, Ireland and the UK – could produce five percent or more of their electricity from wave power.

Non-Conventional, Experimental, Renewable Power Generation Technologies

Atmospheric Cold Megawatts (ACM)

The Atmospheric Cold Megawatts, or ACM, technology is capable of **generating power by leveraging the differences in atmospheric pressure at geographically separated locations**; wind speeds approaching sonic levels can be generated within ACM pipelines. This energy may then be converted to a variety of desired forms using existing technology.

No fuel is required or consumed to produce the power. No pollutants are introduced into the atmosphere as the result of the generation process.

How it works

ACM is a system for the generation of energy based upon differences in the atmospheric pressure at geographically spaced sites, and comprises at least one long conduit - in the order of many miles long. In operation, the air flow in the conduit will accelerate to a high velocity wind without the consumption of any materials and without the use of any mechanical moving parts. A power converter, such as a wind turbine, in the conduit converts the high wind velocity generated by even small pressure differences into energy of any desired type.

The opposite open ends of the conduit are located at geographically spaced sites, selected on the basis of historical information indicating a useful difference in barometric pressure. A plurality of conduits, each having open ends in different geographically spaced sites, may be interconnected to maximize the existing pressure differences, and will produce higher and more consistent levels of energy production. The ACM conduit configuration of the invention can transform even barometric pressure differences in the order of one-tenth pound per square inch into wind velocities in the sonic range.

Economics and feasibility

At present, Cold Energy LLC is the only company that is developing, marketing, and implementing the Atmospheric Cold Megawatts technology. The company claims that the electricity production using ACM costs around **$0.0003-0.01 per kWh**.

Typical installation requires 1–2 pipelines approximately 300 km in length. Endpoints are placed to maximize historical atmospheric pressure differentials. After construction is complete, however, maintenance is minimal, no raw materials are required, and no environmental externalities are produced. In addition, the projected lifespan of installations is considerably longer than any other generation method.

Blue energy / Reverse electro dialysis

Not to be confused with a leading tidal energy company named "Blue Energy". See also: Tidal power / Marine current power.

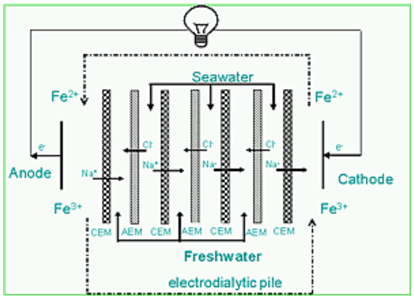
Blue energy is the **energy retrieved from the difference in the salt concentration between seawater and river water** with the use of reverse electro dialysis (abbreviated “RED”) (or osmosis) with ion specific membranes. The only waste product in this process is brackish water.

In principle, sustainable energy can be derived from the difference between the chemical potentials of concentrated and diluted salt stream.

Blue energy can be produced using devices based on a natural process – when a river runs into the ocean a huge amount of energy is unleashed because of the difference in salt concentration.

How it works

RED utilizes the electric potential which arises when permselective membranes separates electrolyte solutions of different concentrations. Electricity can be generated where a concentrated salt stream (seawater) mixes with less concentrated (fresh) water. The technology of reversed electro dialysis has been confirmed in laboratory conditions.



Utilization

In the Netherlands, for example, more than 3,300 m^3 fresh water runs into the sea per second on average. The energy potential is therefore 3,300 MW, based on an output of 1 MW per m^3 fresh water per second.

A 50 kW plant is located at a coastal test site in Harlingen, the Netherlands. The focus is on prevention of fouling on the anode, cathode and membranes and increasing the membrane performance.

Challenges

At present many aspects of RED remain unknown. A major factor that needs to be investigated to optimize the RED performance is the prevention of (bio-) fouling of the membranes. This research consists of three main activities:

- Literature study on the fouling behavior of electro dialysis membranes and the effect of pre-filtration to reduce fouling.
- Experiments identifying the fouling behavior of electro dialysis membranes and spacers with seawater and fresh water (and also with brine and sea water).
- Test concepts to reduce the fouling behavior.

Economics and feasibility

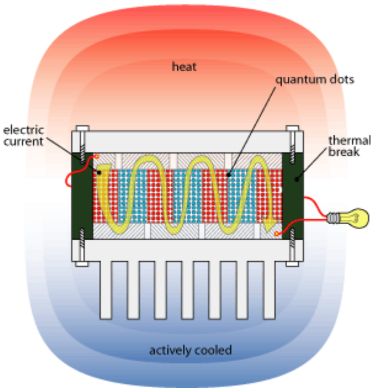
Although RED seems to be a promising concept, the amount of research performed is very limited and outdated. A few decades ago, researchers have stated that RED is not economically feasible because of the high membrane price. However, recent developments show these costs can be reduced considerably.

The production potential in Europe is estimated at 200 terawatt hours a year, or nearly twice the electricity consumption of a country like Norway. The potential in Norway alone is estimated at 10% of its annual power needs. The river Rhine, for instance, could deliver 3,000 MW of power where it flows into the sea in the Netherlands – the equivalent of five big coal-fired plants.

Thermoelectric power

See also: *Ocean thermal energy conversion (OTEC).*

Thermoelectric modules **use environmental heat engine designs** and theories, which violate the second law of thermodynamics, **for the purpose of practical power generation**.



How it works

Fuel cells convert the chemical energy of a fuel directly to electrical energy. In contrast, the thermal electric chip converts heat directly to electrical energy. Fuel cells and thermal chips both convert one form of energy directly to another, but the technology is entirely different.

Using a principle known as the "*Seebeck effect*" a temperature differential between the two sides of a thermoelectric module, electricity can be generated. Because this type of system depends upon a consistent temperature differential to provide electricity, the modules are often combined with a known heat source such as natural gas or propane for remote power generation or waste heat recovery.

They are often used in remote locations, where power is required but solar energy is unreliable or insufficient, such as offshore engineering, oil pipelines, remote telemetry and data collection.

According to Pure Energy Systems, Honda has received a patent on an exhaust heat exchanger that harnesses the heat energy from the exhaust through a thermal exchange, which can then be converted into electrical energy through a thermal electric process or to drive a turbine/generator.

Economics and feasibility

Thermal chips are far more efficient than any other known technology for power generating capacity up to about 10 kW. Thermal chips have the added advantage of working efficiently using any fuel source. They may in the future be used as primary power source for personal, portable, transportable, and small-scale applications. For waste heat/low grade heat conversion thermal chips offer an economically viable solution.

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