Renewable energy

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PREFACE

Renewable energy has been an important political topic for a long time. 20-30 years ago there was an increasing realization that the earth's resources are limited and that the world's dependency on fossil fuel must be reduced. Today, climate problems are on the summit of the international political agenda.

Climate change created by humans around the globe is the largest challenge humanity is currently faced with. EU and many national authorities have therefore decided to focus on a re-adjustment toward more environmentally friendly energy production and consumption. Norwegian authorities have set a target of 30 TWh of new electricity production, heat from renewable sources of energy and through energy efficiency by 2016 over the 2001 level.

The purpose of this compendium is to present a concise overview of the progress of technology, economy and market in relation to renewable energy. The publication will also present examples of Norwegian companies that deliver relevant technology.

The compilation of the information for this publication has been carried out by the consultancy company SWECO Grøner in close cooperation with the Norwegian Water Resources and Energy Directorate (NVE), Enova, The Norwegian Research Council and Innovation Norway, which also have financed the publication.

The booklet has been quality assured by a number of experts. In addition, the Center for Renewable Energy, which is a cooperation between The Norwegian University of Science and Technology (NTNU), Institute for Energy Technology (IFE) and The Foundation for Scientific and Industrial Research at NTNU (SINTEF), has contributed with comments and suggestions.

22 March 2007

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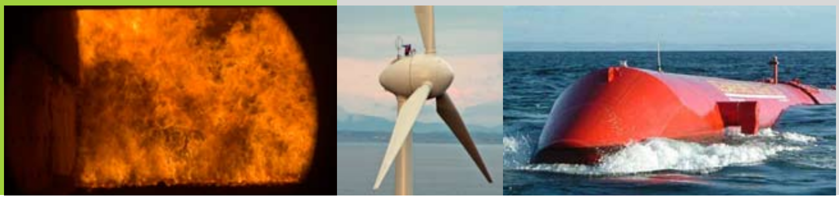


1. INTRODUCTION

All reliable examinations and analyses the last thirty years point in the same direction: The use of fossil fuels in the transport sector and the energy provision should not continue like today. The increase in greenhouse gas emissions in the same time period also gives rise to concern. In 1987, the international Brundtland Commission, led by Gro Harlem Brundtland, Prime Minister of Norway at the time, presented the report "Our common future", the first overall and all-inclusive political analysis of the international environmental challenges. The concept "sustainable development" was launched here among other things. The report recommends the countries to change the energy consumption and to base their welfare on a sustainable development.

Photo: Corbis.

In 1997, the Kyoto protocol was established on the basis of the Kyoto agreement. This means that that the global emission of greenhouse gases will be reduced by 5.2 per cent in relation to the 1990-level within 2012. Norway is among the countries that have ratified the agreement that came into force on February 16th 2005. In this agreement, we were required not to increase the greenhouse gas emissions by more than one per cent compared to our 1990-level. In 2005, emissions had however increased by eight per cent in relation to 1990.

The autumn of 2006, former Chief Economist in the World Bank, Sir Nicholas Stern, presented the report "The Stern Review". It painted a gloomy picture of the situation if the international community doesn't manage to halt the increase of greenhouse gas emissions. The report determines that this development must be turned now, and that the serious consequences will manifest themselves as early as within one generation. Stern and his analysts predict that several areas in the world will experience lack of drinking water, several hundred million people will start a migration as a consequence of a rise in the sea level of one meter or more, and what is the most serious: A global lack of food. The report also points at an increase of climatic weather phenomena as storms, floods, forest fires and drought.

At the end of 2006, the international energy agency IEA presented the report "World Energy Outlook 2006", where they describe a number of scenarios for the development towards 2030. The reference scenario describes a development with the same effort as today to change the energy use. The world will then use almost twice as much energy in 2030 compared to 2004, and the renewable energy sources will make up an even smaller share of the total production even though the volume increases.

The positive aspect, which represents our challenge, is the report at its most optimistic, but at the same time realistic, scenario, shows that the increase in the world's energy consumption can flatten out, and that the climate threat can be handled with the help of, among other things, increasing the share of renewable energy sources considerably.

Possibilities for Norwegian players

This is very convenient for Norway. We already base the main part of our stationary power production on the renewable energy source large-scale hydropower. Besides, Norway has large related wind- and wave power resources along our long coast. The autumn 2006, The Low Emission Panel presented its analysis on how Norway best can reduce its emissions of greenhouse gases. Here the great potential that lies in increasing the utilization of bioenergy was pointed out, both for district heating plants and as raw material for bioethanol, and in exploiting the enormous wind resources far at sea in the North Sea.

In the political environment as well as in trade and industry, there is broad consent that there is a great public utility in exploiting these resources. In 2006, the government notified that it will allocate 20 billion NOK in a fund, where the public company Enova has been given the task of administering the earnings. It will be used to foster renewable energy and measures to increase energy efficiency.

Norwegian scientists, professionals and trade and industry are among the best in the world at within a number of areas that concern renewable energy sources. This expert knowledge, combined with good economic framework conditions and accessible technology, should lay the ground for a healthy exploitation of those of our resources that haven't been exploited up until today, an exploitation that is based on trade and industry.

The IEA report "World Energy Outlook 2006" points out that increasing the share of renewable energy sources considerably is an important measure to handle the climate threat. Photo: Øystein Søbye/Photographica.

Norwegian companies have a long tradition in establishing activity based on society-related needs. There is a reason to expect many small and middle-sized Norwegian suppliers of equipment and services to the future wind power, wave power and bio energy industry. It's interesting to note that such industry and business activity are often located near the areas where there is most need. This means that the conditions are appropriate for growth in trade and industry along and outside the coast, where the resources are found.

It's also worth mentioning that Norwegian industry is among the largest producers of silicon for the production of solar cells. Norwegian companies are also active in the production of solar thermal collection systems.

Obstacles for further expansion of renewable energy

The international energy agency IEA doesn't only point to renewable energy sources as climate-friendly measures in a future society. In the report "World Energy Outlook 2006", they point out that it is highly likely that the consumption of fossil fuels will increase, no matter how optimistic the scenarios are. This is because the main part of the increase will come about in China and India, which will base their consumption increase mainly on coal. Therefore IEA points at the capture and depositing of CO_2 as an important method to reduce the emissions

Europe's largest land based wind farm at Smøla. Photo: Statkraft.

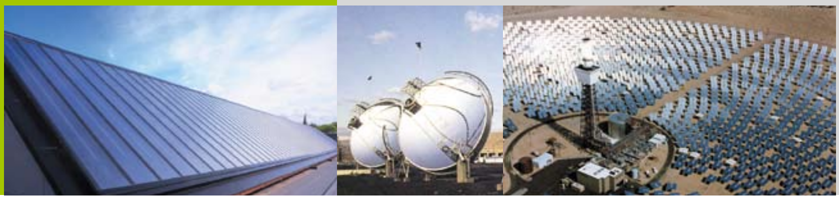
of greenhouse gases. Nuclear power will also be emphasized as a significant contribution.

Nuclear power has a number of problems however, among them the costs related to further expansion, and public scepticism in relation to the waste problems. Nevertheless, nuclear power industry is very strong in many countries, among them in France, Germany and Great Britain. It's expected that new generations of nuclear power plants will remedy many of the problems one is faced with today. In Finland, the largest power plant of the Nordic countries will be completed in 2009, and yet another is being planned.

The capture and depositing of CO_2 can be a more relevant competitor to developing the renewable energy resources. Also on this area, Norwegian players are far ahead. Since 1996, Statoil has separated CO_2 from the gas from the Sleipner field, and led the greenhouse gas back into the ocean floor. Far below the oil- and gas containing layers of sand stone lays the so-called Utsira formation. This is an enormous salt water pocket, which in theory can contain all CO_2 like the fossil driven power plants all over Europe can produce in at least 500-600 years. However, there are large costs related to the realization of such measures, not least when it comes to transporting the greenhouse gas from the power plants to the North Sea. Nevertheless, Europe has several large programs and projects that look into the possibility of realizing this. These processes can contribute to dampening the pressure from the granting authorities to develop the renewable energy resources.

A fundamental hinder to the expansion of a renewable resource is that it most often is more expensive than the fossile alternatives. However, in 2006 it seems that the prices on oil and gas will increase enough to pressure the prices on power to a stable and higher level than what we have seen the last years. This could contribute to set off the most economic construction processes within small-scale hydropower production, bio energy projects and some wind power. However, it has proven difficult to find international consensus regarding common means to develop the renewable energy resources. Several countries practice different kinds of "green certificates" and guaranteed minimum prices to give the developers of renewable resources stable framework conditions.

Environmental protests also hit developers of renewable energy sources, for example wind power. More than 100 meter high wind turbines, often in parks counting dozens of turbines are perceived as visual pollution by residents as well as people passing by. A promising technology that doesn't seem to create substantial environmental conflicts is offshore wind power far off the coast. It's free of emissions, hardly comes into contact with birdlife, can be placed outside fishing grounds and shipping lanes, and will be out of sight of the population. The technical challenges are enormous. Several Norwegian companies are leading the way in the development, based among other things on experience from the offshore oil- and gas industry.



2. SOLAR ENERGY

The sun is a prerequisite for life as we know it on our planet. With the exception of geothermal energy and tidal water, solar energy is the driving force behind all other renewable energy sources. Fossil energy carriers are even considered to be mainly stored solar energy.

The human race uses solar energy extensively and has done so throughout history. Today the most important areas of utilization are those of drying agricultural products, heating buildings and producing electric power. In the future direct use of solar energy can become common also for cooling and for running industrial production processes.

Resource base

The sun as an energy source

Outside the Earth's atmosphere, the solar radiation's intensity is relatively constant at 1 367 W/m^2±3 per cent. The variation is due to the distance between the Earth and the Sun changing throughout the year. The Sun's radiation changes because of fluctuations in the inner physical processes. This phenomenon is of such limited importance that one can disregard it in connection with the use of solar energy. On average approximately 30 per cent of the sun's radiation is reflected before it reaches the ground.

The radiation from the sun is modified by the atmosphere, which spreads the light and dampens certain wavelengths. The dampening varies, depending on the

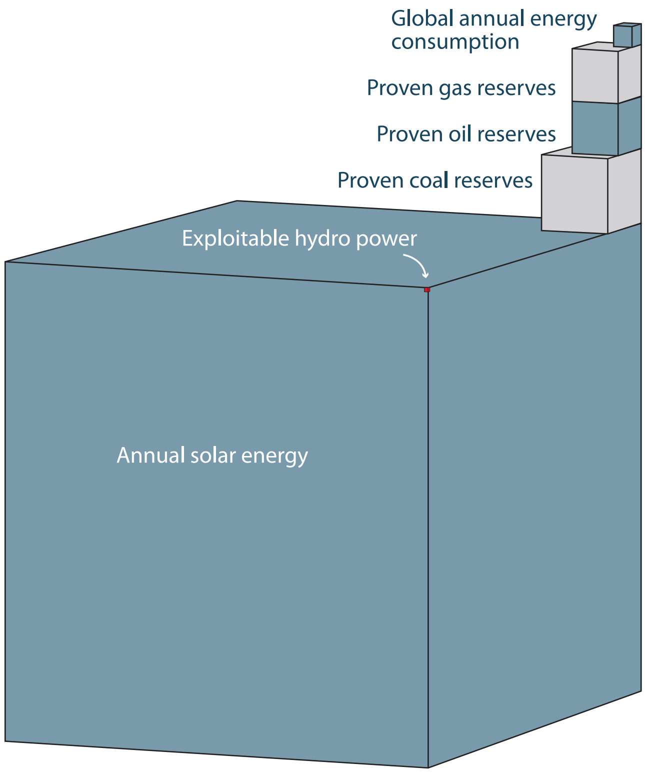


Figure 2-1 Annual solar energy radiation that reach the earth, proven fossil fuel reserves and annual global consumption of commercial energy. Source: [BP, 2006].

atmospheric content of gases. The amount of incoming radiation which is at disposal for energetic exploitation therefore depends on:

- One's location on the planet, because closer to the poles the sun is lower in the sky than at the equator. Consequently, the sun's rays have to pass through more air to reach the ground.
- The time of the year, because the sun is higher in the sky during summer than during winter, except from the tropics.
- Local circumstances, as for example local cloud formation and shadows from surrounding nature and buildings.

The solar energy that reaches the earth's surface consists of two components: direct and diffuse incoming radiation. The direct incoming radiation originates directly from the sun. The diffuse radiation consists of sunlight that is spread in the atmosphere, and it comes from all directions. Blue light is spread the most, and therefore the sky is blue. On a clear day, most of the incoming radiation is direct, and on a cloudy day there is almost exclusively diffuse incoming radiation.

Global sun energy resources

The Sun emits enormous amounts of energy. The fraction of the solar radiation which every year reaches the Earth's surface is more than 10 000 times the world's energy consumption. Distinct from other renewable sources, solar energy is available all over the planet.

Challenges to using solar energy

Since the dawn of time solar energy has been used for several important processes, such as the production of biomass, drying of products, space heating and illumination. This has been an unconscious prolongation of processes that occur in nature. However, solar energy

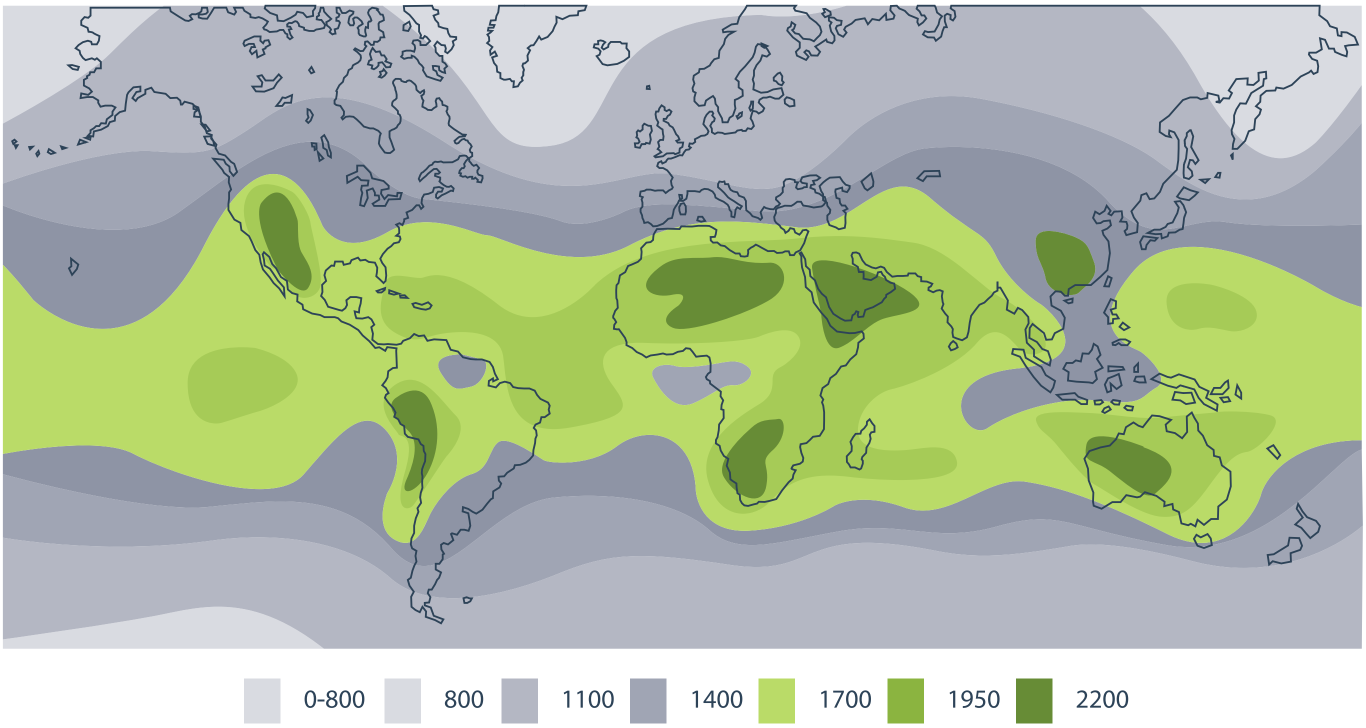


Figure 2-2 Annual solar radiation on an optimally inclined surface (kWh/m² and year). Source: NASA. Illustration. Kim Brantenberg.

has a broad spectrum of applications. Considering how fundamental the sun is as an energy source, and how widely accessible solar energy really is, it's surprising that it isn't used even more.

Solar energy is an alternative to conventional energy technologies, but other forms of energy can many times seem more practical to use. The most important disadvantage about solar energy is that the access on a short-term basis can be uncertain. The total incoming radiation normally doesn't vary much from year to year (typically ±5 per cent), but it is not easy to predict on a day-to-day basis.

Incoming radiation has seasonal variations that are in an anti-phase with the energy demand for important areas of applications, for example space heating. If one is to trust solar energy as the only energy source, either one has to adjust to the variations given by nature, store the energy, or invest in an alternative system to cover the energy demand when the sun doesn't shine. The first alternative is impractical, the latter are expensive. Energy storage makes up a substantial part of the cost for both solar heating installations and systems for the production of electricity for remote buildings and plants. Improved energy storage will therefore mean a lot for the solar energy's possibility to compete with conventional solutions. Another element that drives up the costs for solar energy is that the markets and the players in the storage sub-sector are immature.

Areas of application, value chains, technologies and market.

It is remarkable how many physical phenomena there are that can be used for the gathering and conversion of solar energy for useful purposes. Therefore we cannot go into details regarding all the technologies that have been demonstrated. Instead, the presentation will focus on the area of application itself. We emphasize examples that are relevant to Northern Europe, but also areas of application that are more suitable on other continents are mentioned.

Passive solar energy – Hydro Buildtec
Through Hydro Building Systems, Norsk Hydro has developed an advanced aluminium facade that considerably reduces energy consumption. The product has been developed mainly for office buildings and reduces the heat influence from the outside and uses ventilation and artificial illumination in a favourable way. Hydro calls this system double skin facade "TEMotion", and has looked at several different combinations of windows and aluminium frames. By optimizing the use of all building elements and electrical components, the demand for heat, cooling, ventilation and illumination in office buildings is reduced. For now, the system has been developed for countries with high temperatures and a large need for cooling. However, it can be used in all areas where there is a need for reducing energy consumption.

Because the system is modular, it is quicker to install and easier to maintain than conventional systems. Throughout the development of the system requirements of sustainability has been emphasized, thus the primary energy consumption is reduced by up to 50 per cent and more and the electrical wiring is reduced by more than 70 per cent. The Stand-by losses of the electronic devices are minimized. Active solar gaining devices like PV modules can also be integrated into the system.

Passive solar energy

The principles for passive solar space heating
Solar energy can be used directly for space heating. The sunlight passes through glass and other transparent material so that it can be absorbed in floors, walls, ceiling and furniture. Next, these materials emit long wave heat radiation (infrared radiation). The heat is not released again, because the glass is not transparent for infrared radiation. These processes occur in practically all buildings, regardless of whether they are designed for it or not.

We can increase the contribution from passive solar heat through conscious design and use of energy efficient materials and construction solutions. Passive solar heating systems are normally divided into three main groups:

- Direct systems, where the sun radiation passes into the room through apertures
- Indirect systems, where the sun radiation heats up a "solar wall". This consists of a material that stores the heat efficiently, and the living space is heated up by the warm solar wall
- Isolated systems, where the solar energy is caught up in a room that is separated from the living zone, often called a sunroom or glass yard.

Some technologies for passive solar energy

Components for passive solar heat normally serve two purposes simultaneously: the technical purpose related to building and gathering or storing solar energy. The additional costs for using solar heat are therefore low or none, and moreover one can reduce the need for technical installations for heating.

Apertures let in solar radiation if they are directed towards the sun, but they also let the heat out. To increase the net contribution it is possible to use windows with extremely low U-value (measure of thermal transmittance). Special coatings that admit visible light but block for heat radiation are now common in commercially available windows.

However, there are more advanced solutions. One area of great interest is windows with switchable coats. These can control the amount of radiation which is let in or out through a window. There are several kinds of coatings which can be regulated electrically, while other types react to temperature or radiation directly. In buildings with a cooling demand, such active systems for regulating the solar radiation entry, are often just as important for reducing the demand for cooling as for contributing to space heating.

Solar collectors for active solar heating

A solar collector gathers solar radiation and converts the energy to heat. In its simplest form, it can be a surface that is exposed to the sun. The light that is absorbed by

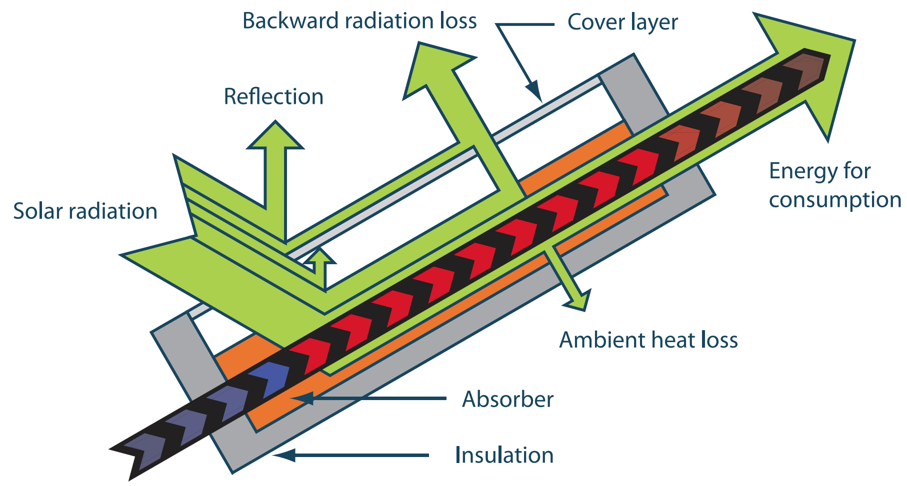


Figure 2-3 Working principle of the thermal conditions in the solar collector. A part of the solar radiation is reflected and absorbed by the glass. This is called the transmission loss and is dependent on the angle of radiation and the performance of the cover layer and absorber. The rest of the radiation goes through the cover layer and heats up the absorber. The heat loss is dependent on the temperature differential between the absorber and the ambient air. The heat loss increases with higher temperature difference. Illustration: Kim Brantenberg.

the plate is converted into heat. The plate has channels where water or another heat transfer medium circulates. The medium is then distributed to the space where heat is needed. There are several practical designs of this concept.

In order for a solar collector to function well, it must meet three requirements:

- The solar collector surface - the absorber – should be black to absorb as much radiation as possible and reflect as little as possible
- The heat in the absorber must be transmitted effectively to the heat transfer medium. Aluminium or copper are good heat conductors
- The solar collector must not have too large heat losses. In all but very simple devices, the sides and back are insulated and a transparent cover is therefore used.

A solar collector collects solar energy more or less effectively, depending on construction and the choice of materials. An effective collector with low losses can deliver heat with a high temperature, but is relatively expensive. One therefore chooses a solar collector based on the needs that the plant is to meet and the practical circumstances with regard to the installation. If one only needs moderate temperatures, an inexpensive model could be adequate.

Liquid or air as a heat transfer medium?

Water is the most common heat transfer medium in solar collectors. Water is inexpensive and gives good heat transport capacity through small pipes. The disadvantage with water is that it can freeze, and that water leakage can damage the building. Adding an antifreeze agent avoids the freezing problem but adds cost and increases the risk for environmental impact.

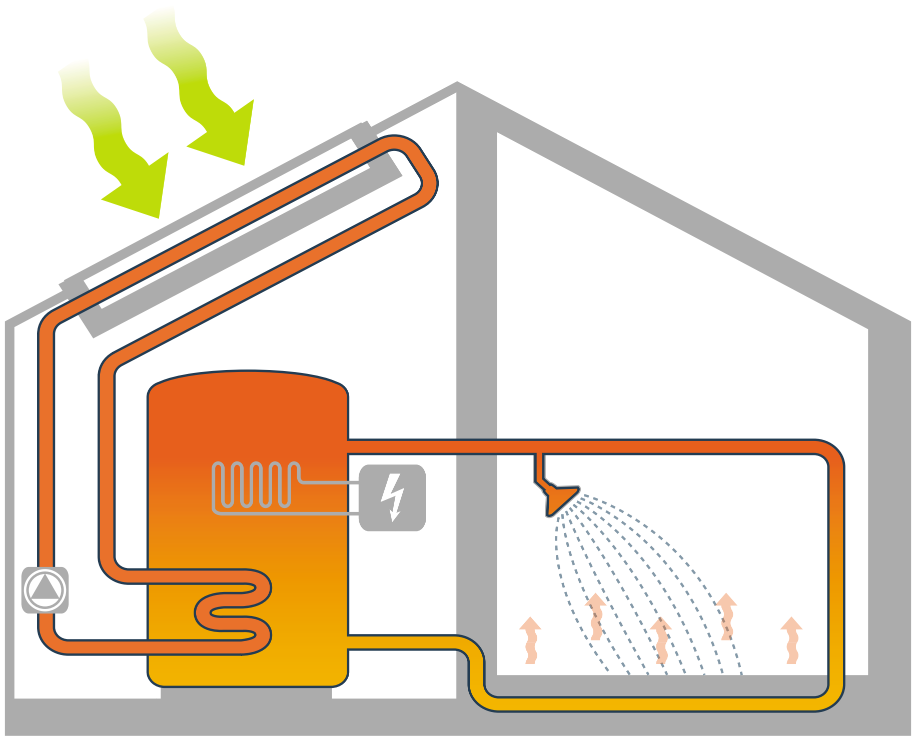


Figure 2-4 Working principle for a solar heating system. Illustration: Kim Brantenberg.

Air is even cheaper than water, it doesn't freeze and small leakages don't lead to practical problems. However, air has much poorer heat transfer properties than water. Much larger air ducts than the equivalent water pipe is required to transfer heat. Air heating collectors are therefore more expensive and less effective than water heating collectors.

For high temperature applications other heat transfer media are used such as oil or melted salt. Research has also been done on using liquid sodium.

Active solar heat in buildings and office buildings

The principles for active solar heat

In dwellings and office buildings, solar heat can contribute to room heating and heating of tap water. Larger buildings can also be cooled by solar energy.

Holographic window reflecting sunlight to the roof in order to enhance the use of daylight.

The value chain for active solar heat consists of the collection of solar energy, energy storage, and the distribution of it for space heating and/or production of hot tap water. The main components in a solar heating system are a solar collector, heating storage and heat distribution system. A working system also needs pipes, valves, pumps, an expansion vessel and regulation installation. The latter must be specially adapted for solar energy.

The heating storage is often a tall, slim water tank. Cold water is taken from the bottom and the warm water is let in at the top to obtain a stable stratification. There are, however, other types of storages as well. The storage usually stores energy for about one day's consumption.

Normally, the water in the solar collector isn't used directly. Instead, the energy required for space heating and production of hot water is transferred through heat exchange. The lower the temperature that can be held in the solar collector, the higher the system efficiency will be. Floor heating is therefore a technology that fits well together with solar heat, because the temperature level in the heating cycle is low.

The better the overlap between energy demand and access to solar energy, the better the economy of a solar energy application will be. Heating of swimming pools

Monolithic aerogel produced at NTNU in Tronheim. Monolithic aerogels may be used in windows with high insulation and visibility performance.

is a particularly favourable area of application since high temperatures aren't needed and the pool works as energy storage. For this use, solar collectors in rubber or plastic without glass covers are sufficient [Perers, 1992].

Solar collector technologies

The solar collector is the key component in the solar energy system. It is an important part of the system cost and sets limits for what the system can deliver. Therefore there are several types that are adapted to different performance requirements.

The flat plate solar collector is the most common one. It consists of a flat plate where water runs through channels. Usually, the solar collector is equipped with one or more glass covers to decrease heat loss. The more one wishes to reduce the losses from a flat plate solar collector, the more advanced and expensive materials and technologies must be used.

Solar heating is most common in single-family houses and terrace houses, but can also be used in larger systems, for instance in apartment blocks.

Status and trends

Active solar energy in buildings is a technically mature technology, and little research activity is carried out in the field. However, the technology is commercially immature, and therefore large efforts are put into making production methods, marketing channels and installation work more efficient. Increased production volumes are important in order to bring down costs.

The costs depend on where in the world the system will be used since energy consumption, solar irradiance and cost structure vary.

The European market is in rapid growth. In 2005, approximately two million square metres of solar collectors were installed in Europe, which represented a 26 per cent increase compared to the previous year. In total, approximately 16 million square metres have been installed in different types of systems. Most of them are flat plate solar collectors [ESTIF, 2006].

Germany, Austria and Greece are leading both when it comes to yearly sales and total installed solar collector surface. The demand is also particularly strong in Cyprus, Spain and Italy. In most countries, the market is driven by public policy measures.

Most solar energy systems that are installed in Europe are hot tap water systems. In countries where the buildings have a heating demand, the market shares increase for combined systems that also deliver energy for room heating.

In the rest of the world, China, Japan and the U.S. have significant areas with installed solar collectors [ESTIF, 2003:2]. In the U.S., this mainly means low temperature systems for swimming pools. In China, the situation is very dynamic where more than 60 million square metres of solar collectors have been installed and the production capacity exceeds 13 million square metres of solar collectors per year. [Li Junfeng, 2005].

The rapid growth in the solar energy market, combined with increasing price on fossil energy and environmental constraints due to climate change, gives interesting possibilities for the future. Increased volumes decrease production cost through better capacity utilization and the introduction of more cost-effective production methods. To reduce cost, the solar collector can be integrated into ceilings or walls. That way the cost for alternative roofing or wall materials are saved, and the method also makes it easier to achieve aesthetically pleasing installations that appeal to the market. The Norwegian producer SOLARNOR belongs to those who go in for building integration (see fact box on SOLARNOR).

Thermal solar energy – SOLARNOR
SOLARNOR produces a solar heating system developed in Norway. The company also delivers solar collectors, heating storage and control systems. The solar collectors can either be integrated into the roof of a building or be installed in an isolated aluminium frame. SOLARNOR uses an open collector circuit. Water is pumped into the solar collector only when it can deliver heat to the storage. When the pump stops, all the water drains from the solar collector down into the heat storage, and consequently boiling or icing in the solar collector is avoided. When the sun shines on the solar collector, radiation will pass through the outer plate and be taken up into the black surface of the plate behind. The energy is transferred as heat to the water in the channels inside the plate.

SOLARNOR produces the heat storage in Norway. In addition, the solar collectors are put together to complete modules in Norway, while solar collectors and control systems are produced abroad according to SOLARNOR's specifications. SOLARNOR has installed approximately 300 solar heating systems in Norway. With regard to control systems, approximately 500 units have been delivered.

The picture shows solar collectors on the roof of Klosterenga Ecology houses in Oslo. Photo: SOLARNOR.

Active solar heat in agriculture and industry

Heat is a common contribution factor in production and refining processes. The most common areas of application are drying, washing, colouring of fabrics and heat treatment of nutrients. These processes often take place in temperatures lower than 100 ºC, which is within reach of a good solar collector. If a higher temperature is needed than a solar collector can provide at a reasonable cost, solar energy can be used to preheat the water.

In agriculture drying is an important process in the value chain. Solar energy is well suited, since there is often access to solar energy when there is a need to dry the crop. Air can be used as a heat medium, the temperature need is moderate and the systems can be of relatively simple construction. Even without special dryers, it is of course the solar energy that dries the crop, but the ability of air to take up humidity increases significantly already at a five degree increase in temperature.
In developing countries, solar drying can contribute to increased added value. Traditionally, crops are usually dried in the field, which may lead to significant losses to pests. With simple, small dryers, it is possible to dry valuable products like spices and fruit. Larger dryers for volume products such as coffee are also being tested.

Solar dryer for fruits and spices in Tanzania. Photo: Jonas Sandgren.

Industrial processes in the food and textile industry often need temperatures in the range 50 – 150 °C. Back-up systems are often necessary to guarantee production independently of the weather. Industry processes often have small seasonal variations. For temperatures below 100 °C, mainly the standard types of solar collector is used as for space heating. If there is need for higher temperatures, the sunlight must be concentrated and oil must be used as a heat medium.

Solar cooling

Cooling is used in many contexts, and can be of great value to the user. The most common examples are air conditioning and storage of food, both applications being very relevant to public health. In many cases, the need for cooling is highest when the sun is shining, and vice versa, so solar energy is well suited to this purpose. Ice production by using solar energy was demonstrated already at the world exhibition in Paris 1878 [Podesser]. In many parts of the world cooling is a significant part of peak power demand, and solar cooling therefore has a huge potential to reduce the demand for electric power at peak hours.

Solar cooling can utilize several different sorption processes. If ammonia is used as the cooler medium and water as absorption medium, temperatures below -30 °C can be achieved. A heat source that holds over 70 °C is then needed.

Many types of absorption coolers are commercially available, and suitable solar collectors are also on the market. However, it can be difficult to find suppliers that offer complete systems. The same types of solar collectors that can be used for process heat are suitable.

Solar cooking

For billions of people, the dominating energy demand is energy for cooking. Today it is met by firewood, charcoal, manure, and in cities also kerosene and propane. The latter are expensive to use for a poor population, and in densely populated areas the access to firewood is often insufficient [Sanga, 2003]. It is possible to use solar energy for cooking, and with that save people considerable expenses and use of time for firewood gathering.

Several solar cookers have been developed for households and for catering centres (for example schools). The simplest one is the box cooker. It is found in several versions, often made by simple (but not so durable) materials. It consists of an isolated box with a glass lid, and often also a plane reflector as a coverlid. The food is placed in

Parabolic solar cooker. Source: SolarCooker.Org.

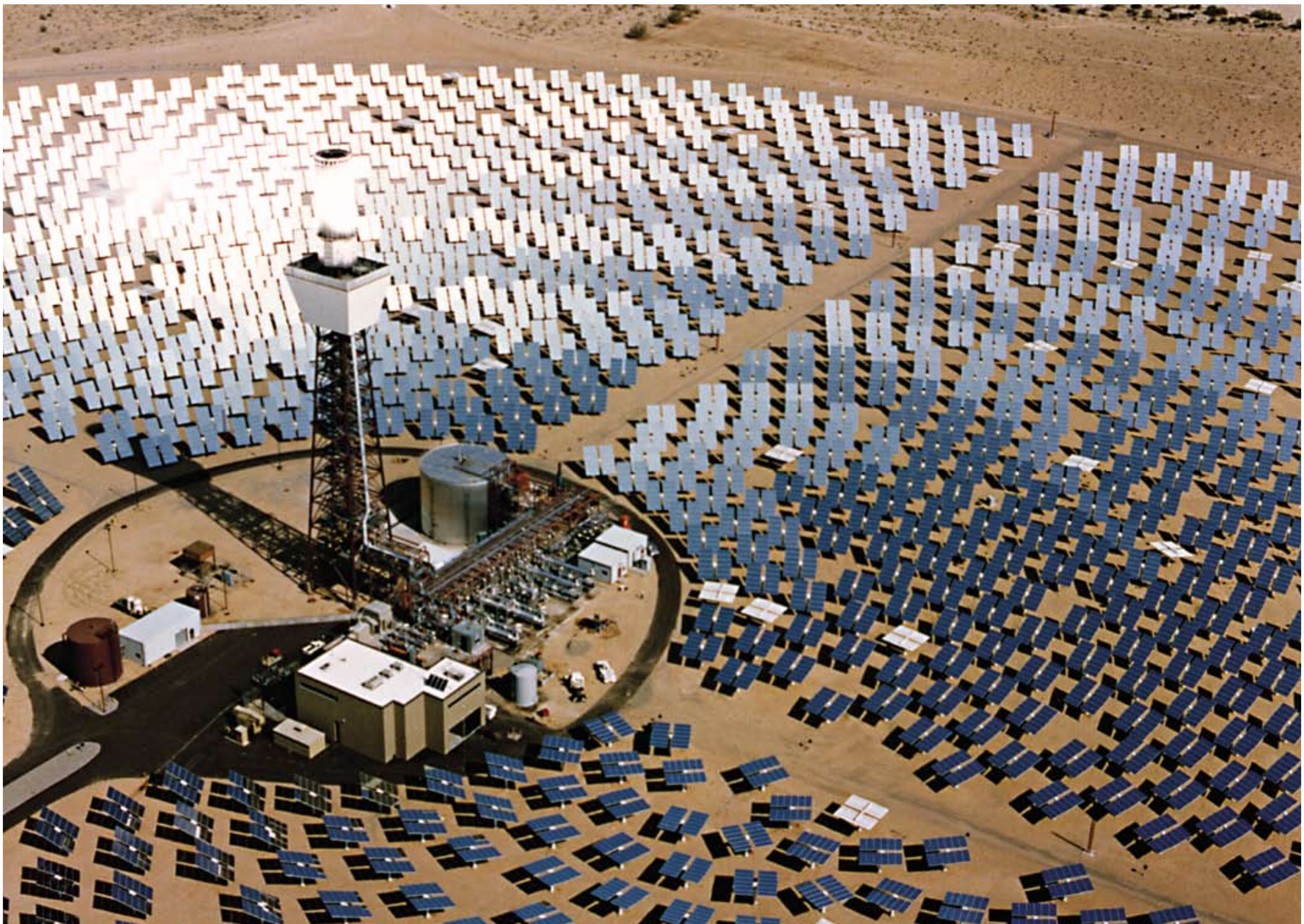
Box type solar cooker. Source: SolarCooker.Org.

a black cooking vessel with a close-fitting lid, and then placed in the box. It's possible to achieve temperatures in the area 80-130 °C, but it takes longer to prepare the food compared to cooking at a fireplace.

There are also several types where the sunlight is concentrated on black cooking vessels. These exist both for households and for catering centres. For the latter, there are solar kitchens with energy storage, so that it is possible to cook throughout the evening.

Power generation – thermal systems

Most of the world's electricity is produced by steam turbines in thermal power plants driven by energy from coal or nuclear fuel. Solar energy can also be used to generate steam for steam turbines. In order to achieve the high temperatures necessary, more than 350 °C, the sunlight must be concentrated. Systems that concentrate the light more than ten times only "see" a small part of the sky. In practice, they can therefore only concentrate direct sunlight. For that reason, solar thermal power plants must be located in areas with a lot of clear



The solar power tower "Solar Two" in the Mojave desert in California. Photo: Sandia National Laboratories, US Department of Energy/National Renewable Energy Laboratories.

weather. The optical systems that concentrate the light must be directed towards the sun all the time. Therefore, they must be equipped with a device called a "tracker" allowing them to follow the sun's movement over the sky continuously.

A thermal power plant is a complicated installation, consisting of collector or mirror field, steam generation system, turbines, cooling systems and a number of auxiliary systems. However, much of these plants consist of conventional technologies that show significant economy of scale. Therefore, large solar thermal power plants can produce electrical power at a lower cost than solar cells.

The value chain for thermal solar power plants is largely the same as the one for conventional power plants and include, besides solar specific components as mirrors, advanced solar collectors, buffer storage and related mechanics, standard components such as pipes, heat exchangers, steam equipment, turbines, control systems, etc. All full-scale plants have reserve burners to keep the power plant working when incoming radiation is insufficient.

In the 1980's, nine power plants were built in California with a total power of 354 MW, but further developments were stopped due to changes to economic incentives for solar energy. However, the interest in building solar thermal power plants has increased. In Spain, several installations are planned and under construction, and there are also ongoing projects in developing countries. In Australia, a demonstration project has been built, where solar energy is used to reduce coal consumption in a conventional coal power plant. The best solar power plants in California have achieved production costs in the range 9 – 11 c€/kWh (0,12-0,15 USD/kWh), and there are expectations that it will be able to achieve production costs of 4 c€/kWh (0,05 USD/kWh) [Stine et al, 2006], [NREL, 2003].

The production of electrical power – solar cells

The photoelectrical effect

It's possible to convert solar energy directly to electricity by means of the photoelectrical effect. It was discovered already in 1839, but it didn't have any practical application until the 1920's, when one started to use photocells made of selenide in exposure metres.

A solar cell consists of a semi-conductor where the front and reverse side have been processed (doped) so that the front side normally has a surplus of free electrons while the reverse side has a deficit. Sometimes, this is done in the opposite way. In the interface between the two areas, an electrical field is created that drives free electrons towards the front side of the cell. Bound electrons in the solar cell can absorb a photon and thereby become mobile. Most of them will be caught by the field in the interface and transported to the front side of the cells. If the front- and reverse side are connected with an electrical circuit, the electron can do useful work in a light bulb, electrical motor, computer and the like.

It's possible to produce solar cells from a wide range of materials. It's also possible to use combinations of semi-conductors and metals, and semi-conductors and electrolytes. Today, probably more than 90 per cent

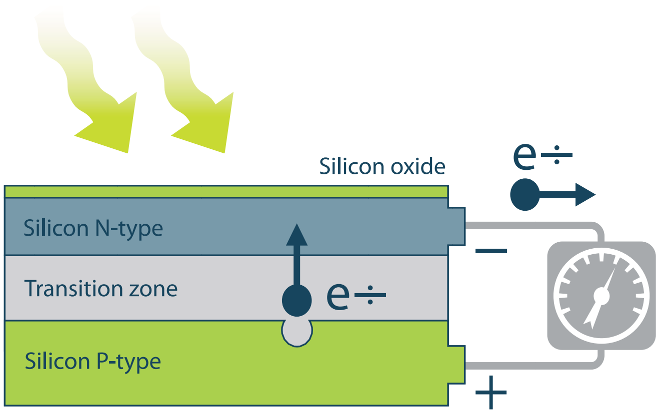


Figure 2- 5 Working principle for solar cell. Illustration: Kim Brantenberg.

of the products on the market are based on mono- or multicrystalline silicon cells.

The solar cells' value chains
One distinguishes between crystalline silicon solar cells and thin film cells. The value chain for both types is characterized by consisting of refined materials with precisely specified qualities. The requirements to raw material, production processes and quality control are very strict.

The crystalline silicon solar cell raw material is quartz sand from natural deposits. Thereafter, the raw material is purified in a metallurgical process, where the sand is melted and contamination is removed with the help of slag producing additives.

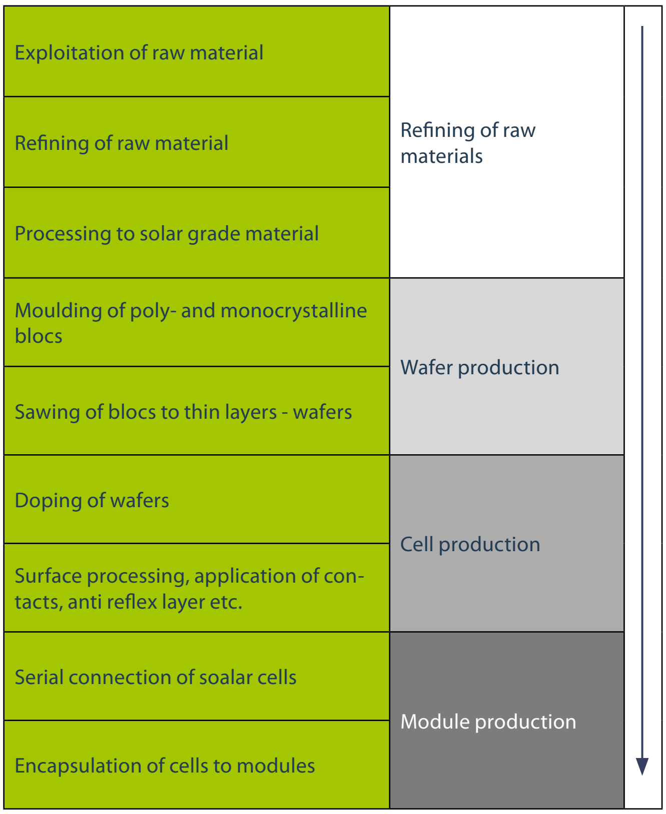


Figure 2-6 The value chain for crystalline silicon solar cells.

Typical for crystalline solar cells is that one first has to produce a material that consists of large, or preferably only one, silicon crystal. The most common is to make cylindrical (for monocrystalline cells) or square blocks (for multicrystalline cells). Thereafter, this crystal block must be sliced in thin wafers that can be processed to solar cells. Only one producer (REC) carries out all the steps itself from processing of raw material to modules ready for sale, while most other companies have specialized on one or a few of the steps in the value chain. Chemicals, crucibles and abrasive material that are necessary in the processing of silicon to "solar grade" and slicing into wafers are also important products in the value chain.

Solar cells based on thin film technologies are considerably thinner than the crystalline silicon cells, measuring only a few micrometers of active material for the thinnest types. All producers of thin film cells handle the whole chain from the purchase of raw material to the completion of modules within the same factory. For most technologies, the energy conversion efficiency is considerably lower from a thin film panel (6-9 per cent) than from a panel based on crystalline silicon (12-18 per cent).

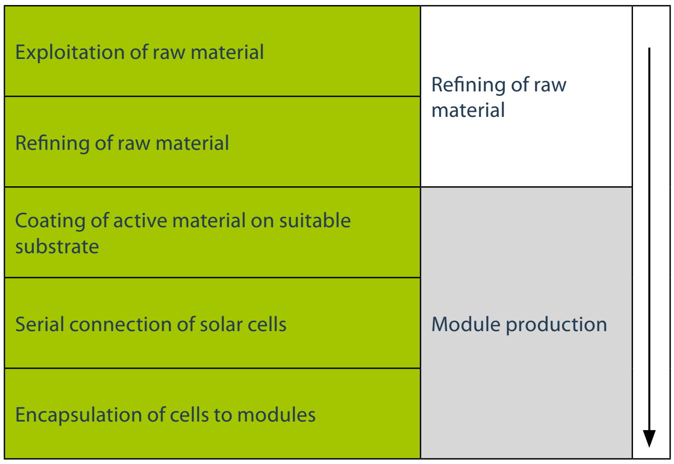


Figure 2-7 The value chain for thin film cells.

The different applications for solar panels have their own value chains, depending on the purpose of the system they are integrated into.

Solar cell technologies

Solar cells give an output voltage of approximately 0.3-0.6 V, depending on the technology. To get a practical size of the panel and an appropriate voltage, a number of cells are coupled in series in the solar panel. A typical panel with solar cells of crystalline silicon consists of 50-70 series- and parallel-coupled cells, which are encased between a cover glass and a back plate. The panel must protect the solar cells against wind and weather, thus the quality of the casing is very important. In addition, the panel must have sufficient mechanical stability to protect the fragile solar cells from handling and strain from hail and the like.

Solar panels are standardized products that have several application areas. Solar cells are also integrated directly into a number of products such as pocket calculators, watches and outdoor lights. However, systems like these make up only a small part of the solar cell market and will not be further discussed here.

A new producer of wafers – Norsun

The Norwegian Company Norsun produces monocrystalline silicon ingots and wafers. The company was founded in 2005 by Alf Bjørseth, who was also behind the establishment of REC.

Monocrystalline silicon wafers give solar cells with a higher efficiency than multicrystalline. The silicon wafers are sold to players in the international solar energy market for processing to solar cells and solar panels.

The company establishes production plants in Årdal with a production capacity of 130 MW. Norsun will also invest in the production of the raw material in itself, polysilicon, and within second generation solar energy based on thin film technology.

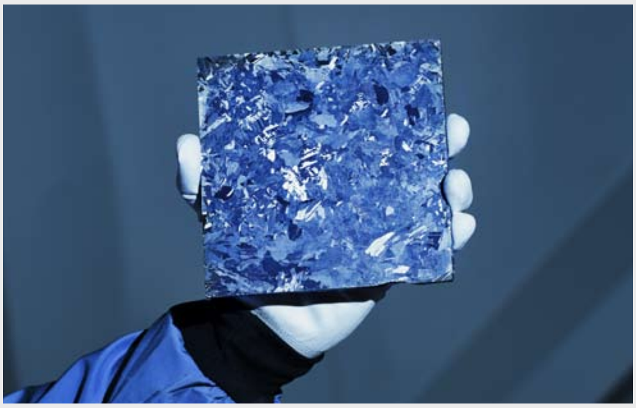
REC – fully integrated solar cell corporation

The Norwegian solar energy company Renewable Energy Corporation (REC) is unique in that it delivers goods and services in the whole value chain for solar energy. REC is the world's largest producer of "solar grade" silicon and wafers, and a considerable producer of solar cells and modules. The company has over 1 000 employees, and the activity is divided into three divisions.

REC Silicon is the world's largest producer of "solar grade" polysilicon for the photoelectrical industry. The production is carried out at two factories in the U.S., and the company is establishing a new large factory in the U.S. that will use a new and patented technology for the production of granulated polysilicon through the FBR process (Fluidized Bed Reactor), that gives a more cost-efficient production than earlier.

REC Wafer is the world's largest producer of multi-crystalline wafers for the solar cell industry. The production is carried out at factories in Glomfjord and Herøya in Norway. The company is also starting a new factory at Herøya that will double the production capacity to 550 MW_p. The company also has its own factory that produces mono-crystalline blocks for wafer-production in Glomfjord. This factory has a production capacity of 25 MW_p.

REC Solar produces solar cells in Narvik in Norway and solar cell modules at Glava in Sweden. The company today has a total production capacity of 45 MW_p, but is extending the production to 225 MW_p cells and 100 MW_p with modules. The company also has an operation for installation of small scale systems in South-Africa. Polycrystalline wafers from RECs factory at Herøya. Photo: REC ScanWafer .



Crystalline silicon cells are made of thin slices called "wafers" which are sawed out of blocks of silicon. Some years ago, these slices were 0.3-0.4 mm thick, but now the industry manages to saw wafers that aren't more than 0.12-0.2 mm thick. This allows better utilization of an expensive material. An alternative is direct pulling of thin crystal plates from a metal mass, which later on can be cut in fitting wafers.

There are a number of different thin film technologies. The first to be commercialized was amorphous silicon cells (a-Si). These have low efficiency and limited lifetime (approximately 10-15 years). The other commercial thin film technologies are cadmium telluride cells (CdTe)

Stand-alone system for private supply. Photo: Richard Cohen.

and copper-indium-gallium-diselenide cells (CIGS). The efficiency varies somewhat depending on producer and quality. The most important advantages of thin film technology as compared to crystalline silicon cells is that they use less amounts of expensive raw material, and that it's theoretically possible to make large surfaces in one operation, making possible a more efficient production process.

Independent of technology, the solar cells are assembled in panels that are delivered in many sizes. Most common are panels in the area 50-100 Wp for thin film and 50-300 Wp for crystalline solar cells. Panels with crystalline silicon cells can be obtained with a 25-year guarantee.

Areas of application

The most important advantages with solar cells are reliability in operation and that the technology can be easily adjusted to a given need in everything from very small systems (fractions of a Watt) to very large plants (MW). When solar cells are used in small systems (a few Watts or less), they are normally built into a product, for example a street light, fittings for garden lighting and the like. Normally, these systems only provide the one service they are designed for as they don't have a power outlet. Such products are getting more common, but all the same represent a small share of the solar cell market.

There are four system types for general power supply:

- Stand-alone systems for private supply, which provide electricity to cabins, households or villages that aren't attached to the transmission grid system. They're normally dimensioned to provide power for lights, radio/TV and pos sibly refrigerators, and they are used when con nection to the transmission grid system is expen sive or not technically feasible. If the distance to the system is more than two kilometres, solar cells can be an economic alternative for supplying moderate needs.

- Stand-alone systems for other purposes often supply power for specific purposes: telecommunication, water pumping and lighthouses. These systems are used when reliable power supply is needed, it is not possible to establish a grid connection, and it is expensive to provide fuel for generators.
- Distributed grid-connected systems are common in a number of countries because of generous subsidy arrangements. Japan and Germany are countries leading the way, and it is these arrangements that have led to the strong growth in the solar cell market. These kinds of systems typically have some kW_p solar cells, but can be significantly larger. They reduce the owner's need to buy electricity from the grid. A possible surplus production is sold to the grid.
- Centralized grid-connected systems can be of many megawatts and are simply a power plant that uses solar cell technology, since the electric ity is fed directly in to a transmission grid.

A solar cell system consists of more components than the solar panels. In stand-alone systems, the most important ones are batteries, charge regulators, cabling and assembling equipment and loads such as lamps and refrigerators.

Market and trends

The solar cell market has grown by 19-66 per cent annually the last ten years. In 2005, approximately 1 500 MW of solar cells were produced [IEA, 2006]. Over 90 per cent of these were mono or poly crystalline silicon cells.

Solar cells are often competitive for power supply in stand-alone systems. This part of the market therefore isn't dependent on subsidies. The main part of today's market has been driven by subsidies that have had the purpose to stimulate the industry to make production more efficient. The strong growth has led to cost reductions in the production and installation, but also to scarcity of raw material the last three years (2004-2006). Consequently, the fall in prices has stopped.

Silicon is the second most abundant element in the earth's crust. With today's technology, it is complicated and expensive to refine natural deposits to "solar grade" silicon. The industry is therefore working to develop alternative, cost-effective methods [IEA, 2006]. Elkem Solar has developed a metallurgic purification process that avoids the expensive path via $SiCl_3H$.

A new producer of "solar grade" silicon – Elkem solar

The Norwegian industry group Elkem ventures into solar energy through the company Elkem Solar. Elkem has been involved in research and technology development related to solar grade silicon since the beginning of the 1980's. Through the long experience and broad competence on metallurgic processes, the company has developed a method for producing polycrystalline silicon. The method is simpler and less costly than the Siemens-process, but doesn't provide as clean silicon. However, tests have shown that the material can be used in solar cells and achieve an efficiency of 18 per cent.

Elkem Solar has decided to invest 330 million € in a new factory at Elkem Fiskaa in Kristiansand. The plant will have an annual production capacity of 5 000 tons of clean silicon and employ some 150 people when it is completed in the middle of 2008. Illustration: Elkem Solar.

During the last ten years, Norway has become an important nation in the solar cell value chain. This position is built on an industrial past in silicon production for other purposes for the metallurgic industry. The knowledge that was gained from this industry has been instrumental for success. This has led to Norway having achieved expertise within material technology research and development. The solar cell industry has access to an industrial environment that includes broad competence in connection with production methods and understanding of the markets for these materials.

Other areas of application for solar energy

Solar energy can be used for a number of other purposes, and research is being carried out on a global level with regard to solar energy, most often for heat generation over 1 000 °C for purposes such as:

- Production of hydrogen and other energy carriers
- Reforming of natural gas to carbon monoxide and hydrogen
- Production of metals as aluminium and zinc
- Production of nano-structural materials in carbon
- Recycling of materials from waste that is hazardous to the environment
- Decomposition of organic substances in water

These areas of application are still only on a research level.

Environmental impact

The utilization of solar energy has a moderate environmental impact, but in no case will it be zero.

Solar collectors and solar panels need an external surface, with potential user conflicts as a result. Other uses of the area may be hampered, but fortunately it is often possible to integrate solar collectors and panels on roofs and walls on buildings, so that the net additional area requirement is zero. So far, there haven't been any serious conflicts, and larger solar power plants will often be located in desert-like areas, where the potential for user conflicts is small.

Large thermal solar power plants will use some water in the steam system and in cooling towers. Water is expensive in the areas of the world where such power plants are of interest, so conflicts of use could arise.

Emissions to water and air during operation will under normal circumstances be close to zero. Emissions could occur in connection with accidents.

Environmental influence from the production of the systems will naturally occur. Thermal systems are produced by completely ordinary materials and are similar to other technology that normally surrounds us. Solar cell production uses certain very aggressive chemicals, and some technologies use substances such as cadmium and tellurium. Some of these substances are extremely toxic; however solar cell production is carried out in ultra clean and very controlled environments, so this problem seems manageable. In the completed products, the substances are stable.

The energy consumption during production has been emphasized as an issue. For systems that are used in an efficient manner, this is not a problem. The payback period for the energy that is used will normally be less than two years.

Dismantled systems will come back as waste that need to be treated. This has to be done in a responsible manner, and the waste will mainly be recyclable (metals, plastics). In Japan, industrial players that wish to recycle substances from discarded solar cells have already appeared.

Products and services in the value chain

Successful use of solar energy for heating depends on the existence of:

- competent architects and engineers that can integrate the systems aesthetically and technically in buildings
- access to systems at a competitive price
- competent professionals for installation and service

Even though the prices for electrical power and fuel oil are rising, solar energy as a renewable energy source competes also with windpower, hydropower, bioenergy and heat pumps that today are more economical. Thus, it is important to continue research and development work to reduce the associated costs.

Crucibles for silicon slices – CruSiN
The Norwegian company CruSiN AS in Trondheim has as its business idea to develop and sell a new crucible concept for the production of silicon slices for solar cell purposes. Until now, crucibles like these cannot be found on the market. Today, crucibles made of quartz are used. These are expensive and only for one-time use.

With the new crucible concept, CruSiN has a goal to contribute to a significant cost reduction in the solar cell industry.

Better energy storages will have great importance to making solar heating systems more competitive. Unfortunately, there are no ground-breaking discoveries on the horizon.

For solar cell systems, a continuation of the tremendous market development is dependent on the following:

- Access to raw material at moderate prices must be secured
- Production processes must be further developed so that the price on solar cells can continue to fall
- Clear rules for the sale of surplus power to the power grid must be put in place
- Sound technology and acknowledged standards for grid connection of solar cells are developed, since the grid owner must be sure of that the distribution network is without voltage when maintenance work is to be carried out.

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3. BIOENERGY

Bioenergy is a common term meaning energy related to the exploitation of biomass. Biomass exists in many different forms with different qualities. The common feature of each form is that they their energy content is derived from photosynthesis, which uses the energy of sunlight to release electrons from water molecules. The high-energy free electrons are used in the cell's metabolism to build up organic molecules in the plant by binding carbon from the air.

Forest chip during burning in grate furnace. Photo: SWECO Grøner AS.

The net reaction can be described with the following reaction equation:

$6CO_2 + 6H_20$ + (energy from sunlight) $C_6H_{12}0_6 + 6O_2$

The final products are sugars, which the plant uses as building blocks, energy storage, and oxygen which is released to the atmosphere. The combustion of biomass is the opposite of the photosynthesis:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + (free energy)

In principle, the chemical net reaction is the same, regardless of whether the degradation takes place in the digestive tract of a cow or a human or in a fireplace. In the first case, the energy is used as chemical energy in the cells that build up the organism. In the latter, the energy is released as heat.

Human ancestors mastered fire before our species saw the dawn of light for the first time. Large parts of the population in developing countries still depend on biomass in the form of wood, charcoal or dried manure as an energy source for cooking and heating. Bioenergy is the most important energy source for at least half of the world's population.

Biomass is used for a number of purposes such as fodder, building materials and paper, and can be used for processing into commercial chemicals. The use of biomass for energy purposes therefore competes for the raw material with many alternative applications. The most common area of application for bioenergy is the production of heat. It is also possible to produce electric power, liquid biofuel, biogas and hydrogen from biomass.

Resource basis

Plant and algae production of biomass is dependent on temperature and access to growth factors such as incoming radiation, nutrient salts and water. Green plants normally transform between one and four per cent of incoming radiation to energy content in biomass [Hohle (red), 2001].

Commercial bioenergy resources are mainly derived from forestry, farming and waste. It is possible to produce biomass also from aquaculture, but this has not been used for energy purposes so far.

Biomass is normally processed to a fuel before the energy is used. The simplest form of processing is cutting, chopping and drying of firewood. For more refined biofuels, the processing can be advanced and complicated.

There are many paths from biomass to fuel. Not all are equally suitable, and it is important to have good knowledge about bioenergy to choose the most suitable solution in a given situation. Currently there is a rapid technology development in the areas of thermochemical and biochemical processing.

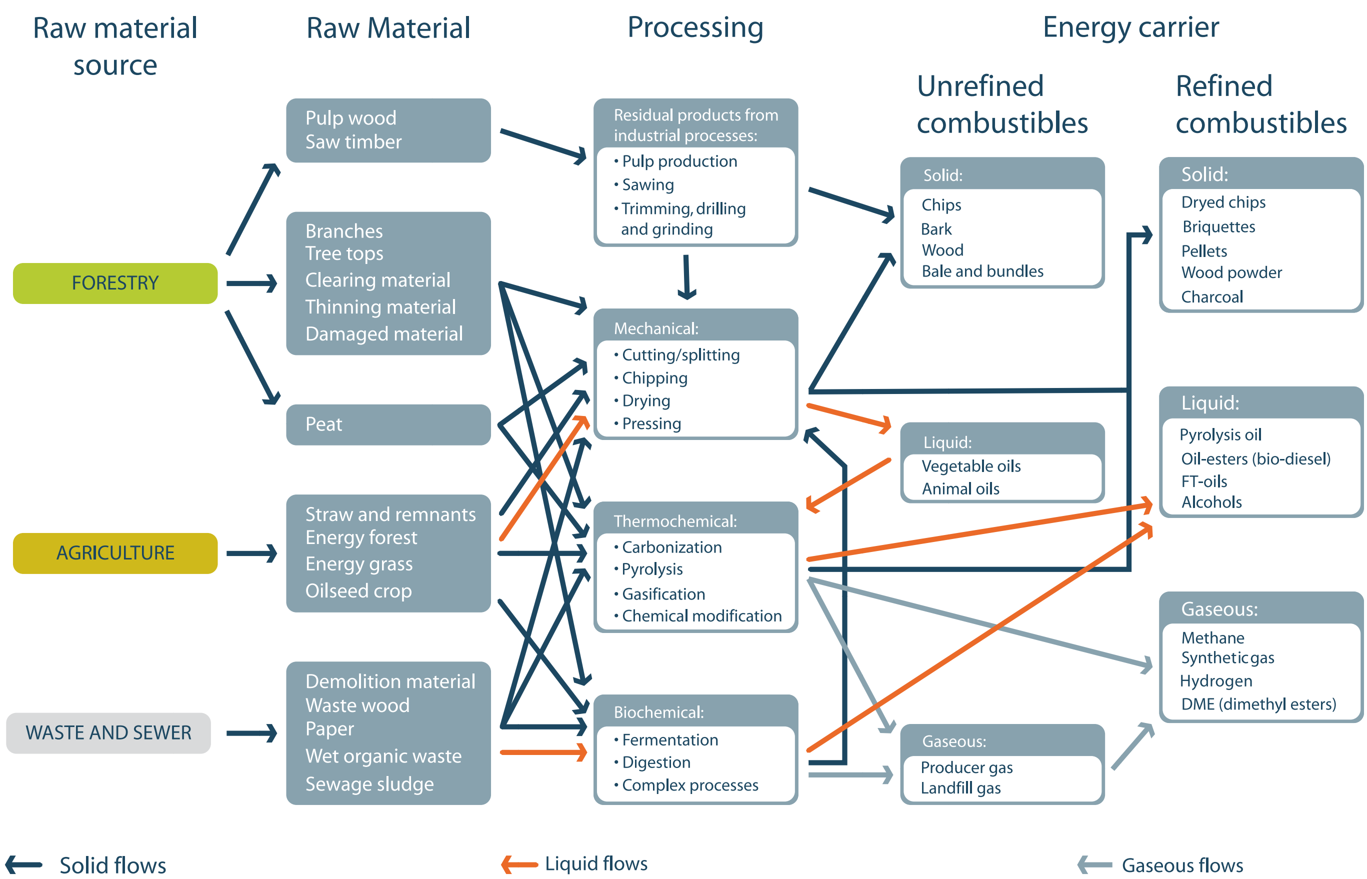


Figure 3-1 The most common processing ways for biomass to energy carriers. The terms are explained throughout the chapter. Illustration: Kim Brantenberg.

Global resources

The total growth of biomass on land corresponds to an amount of energy of approximately 660 000 TWh/year. Only a small part of this growth is used to cover the needs of the world's population, most of it is needed to maintain the ecosystem. Accessible biomass that is not processed into food or durable products can in principle be used for energy production.

The IEA estimates that the world's total bioenergy consumption in 2003 was 13 366 TWh. This represented approximately 11 per cent of total energy consumption. The statistics are not yet complete, and the real number is probably higher. For many developing countries, bioenergy is by far the most important energy carrier, often with a share of 85 per cent and more of the total consumption of energy carriers. Nevertheless, the potential for increased use of bioenergy is considerable, in part through increased production and use of biomass resources, and in part by using already exploited resources more efficiently. In developing countries, where bioenergy is the dominant fuel for cooking, boiling water and heating, the efficiency at end use could be as low as 10-15 per cent. The losses are also great in processing, such as in charcoal production. Even though the technology is better in Western countries, bioenergy resources are often poorly exploited because the resource is considered waste, and people are primarily interested in getting rid of it.

EU's white book regarding renewable energy [EU, 1997] set an objective to increase the contribution from renewable energy to the total final energy consumption from 5.4 per cent in 1997 to 12.0 per cent in 2010. In 2001, it was estimated that EU's total use of bioenergy was 660 TWh (56 Mtoe). To reach the goal in the white book, it would be necessary to increase the use of bioenergy by 870 TWh/year (74 Mtoe/year).

EU has set a number of quantitative goals that are to be reached within 2010:

- 22.1 per cent of all electrical power will be produced from renewable energy
- 5.75 per cent of petrol and diesel for transport purposes will be replaced with biofuel, equivalent to approximately 212 TWh/year
- Use of 176 TWh/year of biogas

As a consequence of EU's directive on renewable energy, several European countries have set ambitious goals for, among other things, increased use of bioenergy. This has led to an increased trade with both solid and liquid biofuels.

If a considerable share of fossil fuel in EU's transport sector is replaced with biofuel, very large volumes are needed, and most likely there will be an extensive importation of fuel. One has to assume that large quantities of biofuel will have to be produced from energy crops, both inside and outside the EU. Much of the production will probably take place in countries like Russia, Thailand, Malaysia and Indonesia. Some of these countries already today export large quantities of biofuel. Countries like Brazil and Malaysia have important rainforest resources, and there is a challenge in increasing export of bioenergy from such countries while making sure this industry does not lead to degradation of natural resources, come in conflict with local food production or nature conservation interests, or involve social dumping in countries with exploitive working conditions.

Bioenergy resources in Norway

Norway has rich bioenergy resources. The theoretical growth potential in Norway is approximately 425 TWh per year, of which 100 TWh is aquatic biomass. Today, bioenergy covers approximately 25 per cent of energy demand in the Norwegian wood processing and wood working industry.

Sawmills and the wood processing industry use most of the secondary wood, bark, black liquor and waste wood for energy production for internal use. The energy is used for the heating of buildings, as process energy, or for the production of electric power with the help of counter-pressure turbines.

The organic fraction of waste can also be used for energy purposes. In Norway, one can assume that approximately 50 per cent of the waste can be considered "renewable energy". Norway has a national goal to recycle 80 per cent of the waste, and from 2009 it will be illegal to landfill degradable waste. This will increase recycling of materials and energy from waste. The authorities set very strict demands to emissions from the combustion of mixed waste which is only burned in large plants with advanced flue gas treatment.

Chipping of branches and tree tops. Photo: SWECO Grøner AS.

Challenges in using the resource

Bioenergy is used extensively all over the world. If use is considerably increased, the resource must be exploited more efficiently than today. It must also be used in market segments where it is not used today, and it must be used for new purposes.

Much of the new bioenergy resources that are used today originate as waste products from industry and households. Therefore they have low value, and today's energy recycling plants are even paid to receive the worst waste fractions. When use of bioenergy is increased significantly, the current waste flow will not suffice as a source of low-valued energy resources, and costs will increase.

The fuel cost that the end-user has to pay is one of the most important factors that affect the competetiveness of bioenergy. Since bioenergy often has a lower energy density than alternative fuels, transport cost is a correspondingly larger share of the price that the end-user has to pay. There is a large potential for improvements in the logistic chain bringing the fuel from the forest or field to the user.

If there is a waterborne heating system in a building, heating it by bioenergy is often advantageous. In the case of district heat, the technical installations in the building are compact and simple. If a district heat connection is not possible, the building to be heated must also provide space for a heating plant and fuel storage. Many buildings lack these fundamental prerequisites, and it is expensive to remodel them.

The quality of the fuel is important for trouble-free operation. Although equipment that is capable of burning inhomogeneous fuel exists, it is expensive and can only be used at larger plants. Less costly combustion technology, that can be used in smaller plants, pose stricter demands on the fuel's properties. Standardization of the fuel's properties is therefore important to secure a problem-free operation. There are standards for some types of biofuel, and work is currently under way on additional international standards.

In order for the prices to be more competitive, technologies for most liquid and gaseous fuels must be further developed and scaled up.

Areas of application, value chains, technologies and market

The most common application area for bioenergy is heating. The heat production can be carried out in a local heating plant for supply of a single building, or a group of buildings in a neighbourhood. In densely populated areas with apartment buildings and industrial areas, it can be profitable to establish a district heat network that distributes heat over a larger area, possibly from several heating plants. The heat demand, i.e. annual need for energy and power, determines the appropriate type of fuel and combustion technology.

Biomass can also be processed into high-grade energy products. Since the production of electric power from biomass always gives considerable amounts of waste heat, this is most profitable in combined heat and power (CHP) stations, i.e. energy plants where both electricity and heat are delivered at the same time. Biomass can also be processed to fluid and gaseous energy carriers, for use in combined heat and power stations or vehicles.

Solid biofuels

The currently most important sources of raw material for biofuel is waste from the processing of sawn wood products and pulp and paper, trees and parts of trees that can not be used for products and chips from demolition waste. Even from this limited part of the biomass resource we have a broad spectrum of commercial biofuels:

- firewood
- bark
- forest chip (stem chip, green chip)
- chips from demolition waste
- briquettes
- pellets

In some countries, waste as straw from farming is an important fuel. Straw can be briquetted and energy crops can be processed in the same way.

In developing countries, charcoal is an important fuel and in some cases as an export product. Charcoal is produced through thermochemical transformation of biomass with oxygen deficiency (pyrolysis). More than half of the energy in the wood is lost in this process, but charcoal has advantages for the user as more even and cleaner combustion than fuel wood. On an industrial scale, charcoal is used among other things as a reducing agent in the metallurgical industry.

Wood powder is dry wood ground into particles smaller than 1 mm. Wood powder is burned in special powder burners in large boiler plants. 10 m^3 of wood powder has the same heating value as 1 m^3 of oil and weighs approximately 2 tonnes. Tests have also been carried out to investigate the use of wood powder as a fuel in specially adapted diesel motors.

Properties of biofuels

Biofuels have different degrees of refining. The higher the degree is, the more standardized and predictable the properties. The user has to pay for this, and in return she will get a fuel that can be burned in a combustion plant that requires less work with operation and maintenance. Other advantages with highly refined biofuels are storage capacity and a simpler regulation of the combustion process.

Firewood has a low refining degree. In addition to logging and transport, the treatment consists of cutting, chopping and drying. Firewood is poorly suited for automated plants.

Bark is considered a waste in the wood processing industry. It contains a high level of ash and is mainly used in large energy production units in connection with industrial plants for debarking of logs. The handling requires a lot of manual work.

Wood chips and chips from demolition wood can have a varying degree of refinement. Chip quality will therefore depend on the type of wood, the equipment used for making the chips, sorting techniques and moisture content. Wood chips can be used in all plant sizes, but chips as fuel will normally require more attention and total investment compared to more refined biofuels. Dry chips are a fuel that can be stored, but moist chips start to compost if left too long.

Demolition wood and treated wood will often end up as a waste fraction that can only be burned in approved waste incinerators. If wood waste is not contaminated, for example with paint, sealants or chemicals used as preservatives, it can be refined to chips or briquettes that can be used in normal incinerators. This fuel is normally crushed and passed through a sieve, as opposed to wood chips, which are chopped.

Briquettes are compressed, dried chips from wood or demolition wood. The chips are pressed to logs or cylinders with a diameter of 25-70 mm. The length varies up towards 20 cm, depending on the raw material qualities and production processes. Briquetting reduces the volume and makes the fuel more suitable for transport and storage. Briquettes are mainly used in heating plants larger than 1 MW, but also burn well in a wood stove.

Steam coming up from the chips in a storage for combustibles. Photo: Jonas Sandgren.

Chips from waste wood. Photo: SWECO Grøner AS.

Briquettes. Photo: Kirkenær Varmesentral.

Pellets are the solid biofuel that has the highest refining degree. In the same way as briquettes they are compressed chips, but based on a more finely ground raw material and with lengths smaller than 25 mm. Standard diameters are 6, 8 and 12 mm. Pellets are suitable for smaller plants and are normally used up to 1 MW, but in some cases pellets are also used in larger plants. Pellets have properties similar to those of oil with regard to transport, storage and combustion control. Oil-fired plants can often be converted relatively easily for pellet firing.

Statoil – Biodiesel and wood pellets

Statoil is Norway's largest producer of wood pellets. The pellets is produced in a factory in Brumunddal with a production of 15 000 tons of pellets per year. In addition to this, Statoil is a part owner of a factory in Sykkylven and has its own factory in Sweden. The pellets are sold to both the private and professional market.

Based on Statoil's competence and position in the fuel market, the company has also started production and sale of biodiesel. At present, this is mainly marketed in Sweden, but also in certain places in Norway. Photo: SWECO Grøner AS

Standards and requirements on fuel

The better defined and more uniform quality a biofuel has, the higher price it will fetch. It is not useful to discuss "good" or "bad" fuel qualities. Which quality is most favourable for a user depends on a number of factors such as:

- size and type of energy centre and combustion equipment
- what kind of fuel types and qualities the are locally accessible
- local fuel competency
- access and available space for storage
- local sensitivity to noise, dust and smell
- environmental requirements to fuel and emissions

Fuel standards are important tools for a buyer when specifying a fuel quality that is adjusted to his or her needs. On a European level extensive work with regard to standardization in the area of bioenergy is being carried out.

The value chain for solid biofuels

There are many solid biofuels, and therefore there it is not only one but several value chains that partly overlap each other.

One way to categorize the value chains is according to how the heat is produced in the last link since this has consequences for how the sale of heat is organized. One can differentiate between:

- spot heat/central heat - heat is produced at the property that is to be heated up
- neighbourhood heat - heat is produced centrally and is distributed within a limited area
- district heat - heat is produced in one or more heat stations and is distributed over a large area in a district heat network

In neighbourhood heat systems, heat producers cooperate with users to establish the heat system because everyone has an interest in cooperation. In a district heat system, the heat supplier is a company with production and sale of heat as a business idea, often having a special concession awarded by the authorities.

Technology for bioheat

A complete combustion plant consists of fuel storage, equipment for handling and feeding of fuel, a furnace or boiler and control systems. Larger plants usually have an accumulator tank in addition to this, for storage of heat, and equipment for flue gas treatment and ash handling. Smaller combustion plants can also have this, but installations smaller than 100 kW seldom have equipment for flue gas treatment.

The design of the different process units depends on the choice of fuel, size of the plant and technical solutions from the suppliers. Technical function is mainly the same for each process unit. The furnace or boiler will have a different design depending on the size. The smallest equipment, intended for detached houses, are wood stoves or pellets stoves which are a more comfortable alternative to traditional wood stoves. Pellets ovens achieve clean combustion by using a homogeneous fuel and even feeding and combustion,. For houses with waterborne heat distribution both wood and pellet boilers are options.

For smaller plants combustion control is the only way to control the emissions. For incinerators over 200 kW, removal of particles from the flue gas can be considered.

Combustibles	Ash	Water	Specific weight	Effective heat value	Effective heat value
	% of dry weight	% of total weight	(kg/lm^3)	(MWh/ton)	(MWh/lm^3)
Wood, birch	0,8	20	430	4,1	1,76
Wood, spruce	1,3	20	345	4,1	1,41
Wood chips, pine	1,5	55	390	1,9	0,73
Wood chips, spruce	2	55	355	1,9	0,69
Industrial chips, raw	1,8	55	300	1,9	0,55
Industrial chips, dry	0,3	20	200	4,1	0,82
Planer chips	0,5	15	100	4,6	0,46
Sawdust	0,5	44	230	2,7	0,63
Bark, coniferous wood	3	50	280	2,3	0,65
Return logs	15-20	20	265	3,8	1
Pellets	1	8-12	650	4,8	3,1
Briquettes	0,7	10-12	600	4,3	2,6
Wood powder	0,5	5	280	4,9	1,4
Bark	2,5-3,0	55	280	2,1	0,6

Table 3-1 Typical data and qualities for different biofuels.

The ash is the solid residue remaining after the combustion, mainly consisting of incombustible material.

Technology for bioheat is technically mature. A number of qualified equipment suppliers and contractors offer complete plants. However, there is continuous development to increase regularity of operation and reduce costs. Figure 4-3 indicates typical investment costs for different types of combustion plants.

Heating with solid fuel requires more effort to operate than heating with oil, gas or electricity. Experience shows that sound operation of a plant is as important for plant economy as the investment cost.

Electricity production

Production of electricity with biofuel has long traditions in countries like the USA, Sweden and Finland. Increased use of bioenergy for this purpose in the future is also a very relevant issue in both the USA and the EU, and the World Bank has financed several large biopower projects in developing countries.

During power generation waste heat is always created. The most advantageous is if both electricity and heat can be sold from a combined heat and power plant. Biopower plants are therefore often located close to companies with a large heat demand or connected to a district heating plant.

The value chain for electricity generation is the same as for bioheat, and in addition electrical power is also produced. In most cases, the opportunity to sell both the power and the heat is very important for the economy of the plant.

Traditionally, the production of electricity from biomass has been carried out through the production of high pressure steam that is used to generate power in a conventional steam turbine (see figure 4-3). In the turbine, the steam expands from a high to a lower pressure as it drives the turbine. In order to optimize the conversion efficiency to electricity, it is desirable with as high temperature and steam pressure as possible.

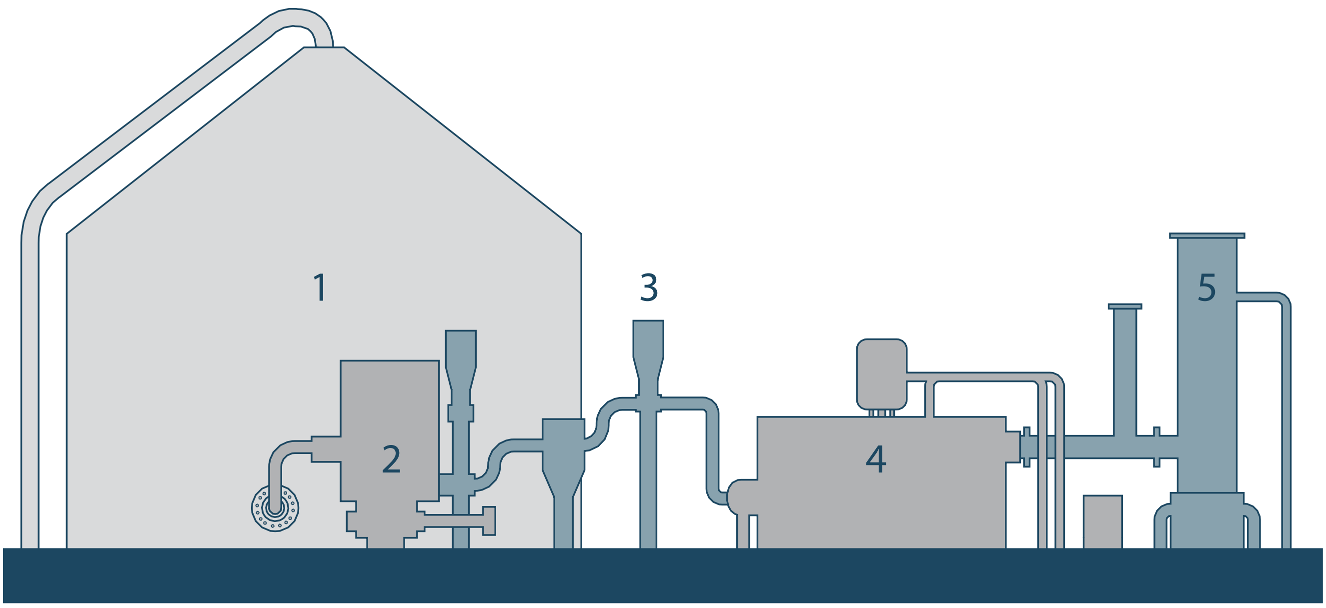


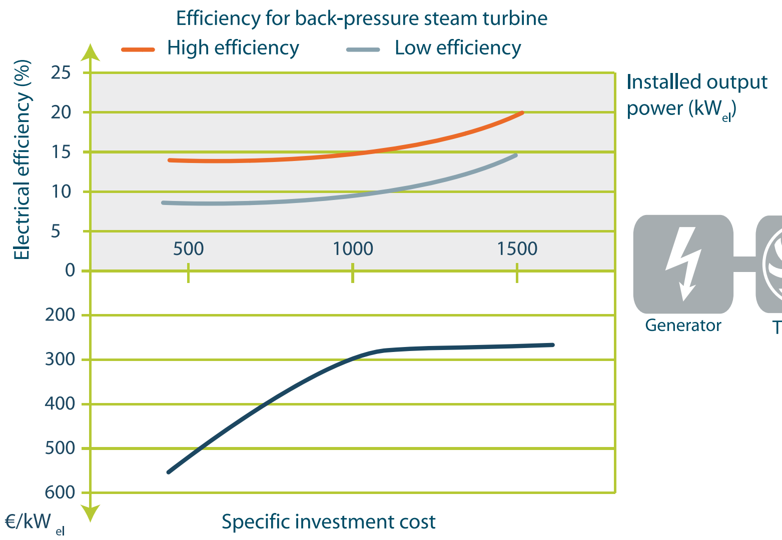
Figure 3-2 A simple way to convert oil and gas burners to bio energy is by using a carburattor. 1 pellets storage, 2 carburattor, gas purifier, 4 gas burner, 5 chimney. Source: Puhdas Energia. Illustration: Kim Brantenberg.

Today traditional steam turbine plants that are operated on biomass do not achieve higher efficiency than approximately 30 per cent since biofuel contains substances such as chlorine, sodium and potassium, which create fouling and corrosion on the heat transfer surfaces. These problems rise with increasing temperatures. The problems can be avoided by using very "clean" fuels, but these are also more expensive.

Today electricity production from biomass is almost exclusively carried out in situations where there is a residual product originating from biomass that is burned to produce steam. Using waste heat in a district heat system or in a large industrial plant is often necessary to ensure sound operation economics. In these cases one therefore does not wish to condense the steam, because then the temperature of the waste heat would be too low to be used. Instead a counter-pressure turbine is used. Counter-pressure turbines with less than 1MW mechanical power have low efficiency and high investment cost. In practice, they are therefore used almost exclusively at large plants (tenths of MW in thermal power). The size of the plant will determine which combustion technologies are relevant for steam production. The dominant combustion technique is combustion on a grate in different varieties. Bubbling fluidized beds (CFB) are relevant in bigger plants.

Gasifying biomass transforms a solid biofuel to a gas that can be used in many different ways. The technology has a potential to produce electric power both on a smaller scale and with higher efficiency than simple steam cycles. Through gasification, the fuel is decomposed by heating a combustible gas mixture consisting of carbon monoxide (CO) hydrogen (H_2), carbon dioxide (CO_2), methane (CH_4) and small amounts of heavier hydrocarbons and tar.

The gas can be used for a number of purposes. In the case of power production, it is normally used as fuel in combustion engines or gas turbines. It can also be processed to gaseous and liquid fuels with well-defined



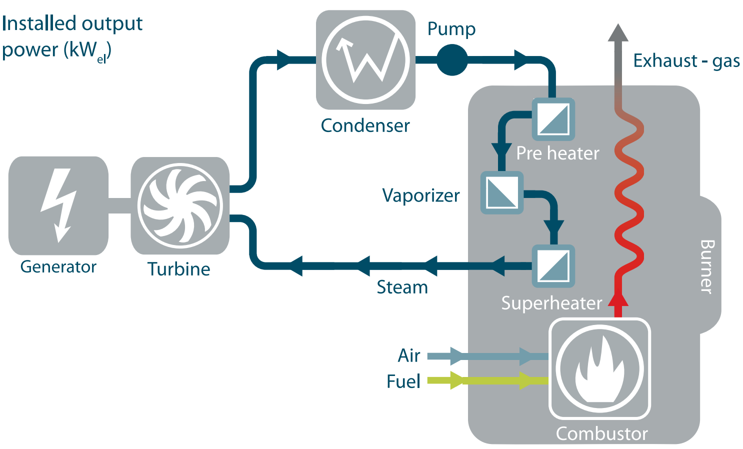


Figure 3-3 Example of investment costs and efficiency for a back-pressure steam turbine, 16 Bars pressure. Based on [NVE, 2004]. Working principle of a back-pressure steam turbine power station. Illustration: Kim Brantenberg.

qualities, or simply be burned to generate heat. However, the technology is most interesting for production of electricity and processing of high value fuels.

The gasification technology is well known, and for heat production, the technology is commercially available. On a global scale, there are around eighty large plants in existence, and many producers of such plants. An interesting possibility for gasification technology is co-burning of the gas with fossil fuel in conventional CHP or power plants. Gasification can also be used for combined heat and power production in smaller plants through the use of gas engines.

Refined liquid biofuels

Liquid fuels have great advantages compared with solid and gaseous ones. They are easy to store, transport and handle, and normally have higher energy density. Alternatives to petrol and diesel that do not contribute to the greenhouse effect have been subject to large interest in recent years. Much attention is therefore paid to developing commercial liquid biofuels based on biomass.

All biofuels can give large reductions in emissions of greenhouse gases from the transport sector, but other environmental effects and costs can show strong variations between different alternatives. When biofuels are discussed, one is often concerned with how much fossil fuel they replace. In principle they can replace 100 per cent of the fossil fuel needed to carry out a given transport task, but in practice some amount of fossil fuel is used today throughout the harvesting of resources, production of chemical fertilizers, refining of raw material to fuel, and distribution of fuel. When used, the

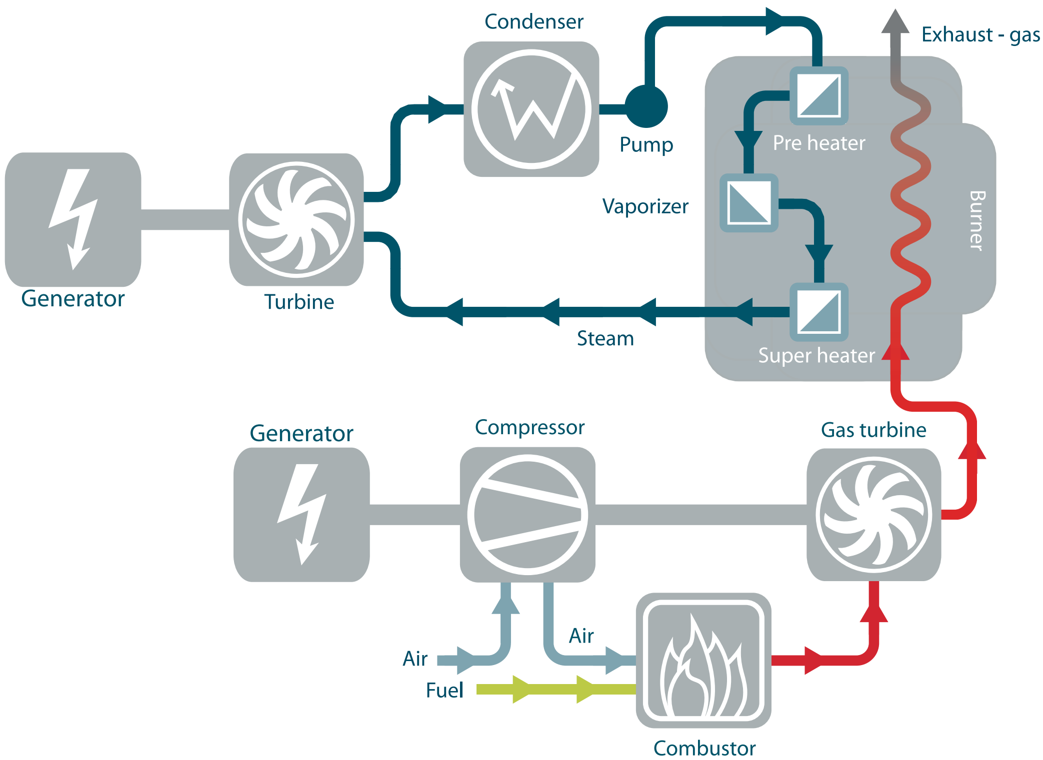


Figure 3-4 Working principle for a combined cycle power plant, which combines a gas and a steam turbine. Source: Dick Nordberg. Illustration: Kim Brantenberg.

biofuel can also be mixed with fossil fuels. In these ways, biofuels therefore become "polluted by" fossil fuels.

It is a fact that there are significant differences between biofuels with regard to how much feedstock energy is needed in the production of a given amount of biofuel, and how much fossil fuel is used in the production, harvesting and refining of the biomass. However, it has been documented that in most cases biofuel give a reduced use of fossil fuels and reduced emissions of greenhouse gases [Quirin et al, 2004].

Alcohols

Ethanol and methanol are alcohols that have practical importance as engine fuels. Ethanol is today produced through fermentation of different types of sugar. A large number of different plants can be used, for example sugar cane (most important), sugar beets, potatoes, maize, wheat and all kinds of fruits. Today, the largest volume of pure alcohol comes from the fermentation of by-products from the production of sugar.

__EnviroArc Technologies AS__ was established in 1999. The company has, among other things, developed a process that is capable of treating biomass and all types of waste, except from radioactive waste. With the help of the gasification process PyroArc the most difficult waste fractions can be treated thermally. Metallic constituents of the waste are melted and collected either as elementary metal or as an oxide. The remaining components (mainly organic) gasify, and the gas' components are completely broken down to simple compounds in a plasma reactor with extremely high temperature. After removal of particles, the produced gas, which is now a combustible gas with CO and H_2 as the combustible components (synthesis gas), are used for heat production or for electricity generation in a gas engine. Thermal energy from the plant, including residual heat from the gas engine, is used to produce steam and/or hot water. As an alternative to using the gas for energy production, it can be a raw material for several products.

The first plant for treatment of tannery waste was delivered in 2001 to Osterøy Miljø. The plant was designed to process 700 kg of dried waste per hour, which is equivalent to 3.1 MW. The company has in principle a licence to treat all types of waste. The plant at Osterøy has permission to test, for example, treatment of waste with bromated flame retardents and electronics with PCB.

Since the 1970's Brazil has developed alcohol as a transport fuel, and today there are over three million cars in Brazil that can drive on alcohol. All petrol in Brazil consists of a minimum of 25 per cent of ethanol. The production costs in Brazil are less than production costs for petrol, but the world market price is presently pushed up by a high demand in the EU and USA, where the use of alcohol as an engine fuel is stimulated as a result of legislations. The largest volume of fuel alcohol goes to admixture in normal petrol (up to 5 per cent), but now the fuel E85, that consist of 85 per cent ethanol, is gaining popularity. In the long term, ethanol can be relevant as a clean engine fuel on a large scale. The energy content in ethanol is 6.2 kWh/litre, which is approximately 65 per cent of the energy content in petrol.

Ethanol can be mixed with petrol and has good properties as a motor fuel, both with regard to performance and emission of harmful substances. It is also easy to convert petrol engines to ethanol operation.

Methanol can in principle be produced through a fermentation process. However, most of it is produced

Norwegian producers of biofuel – __Uniol AS__ is a Norwegian company that is going to produce and sell biofuel in Norway. The company's goal is to produce and sell 100 million litres of biofuel to the Norwegian and Scandinavian market. Initially, vegetable oils will be used in the production that will conform to the quality standard EN 14214. When production starts in 2008, the production plant will be supplied with rapeseed oil from Poland and soybean oil from Denofa. Animal fats extracted from slaughterhouse waste may be considered in the future.

Several other Norwegian companies, for example Statoil, are also active in production of biofuels.

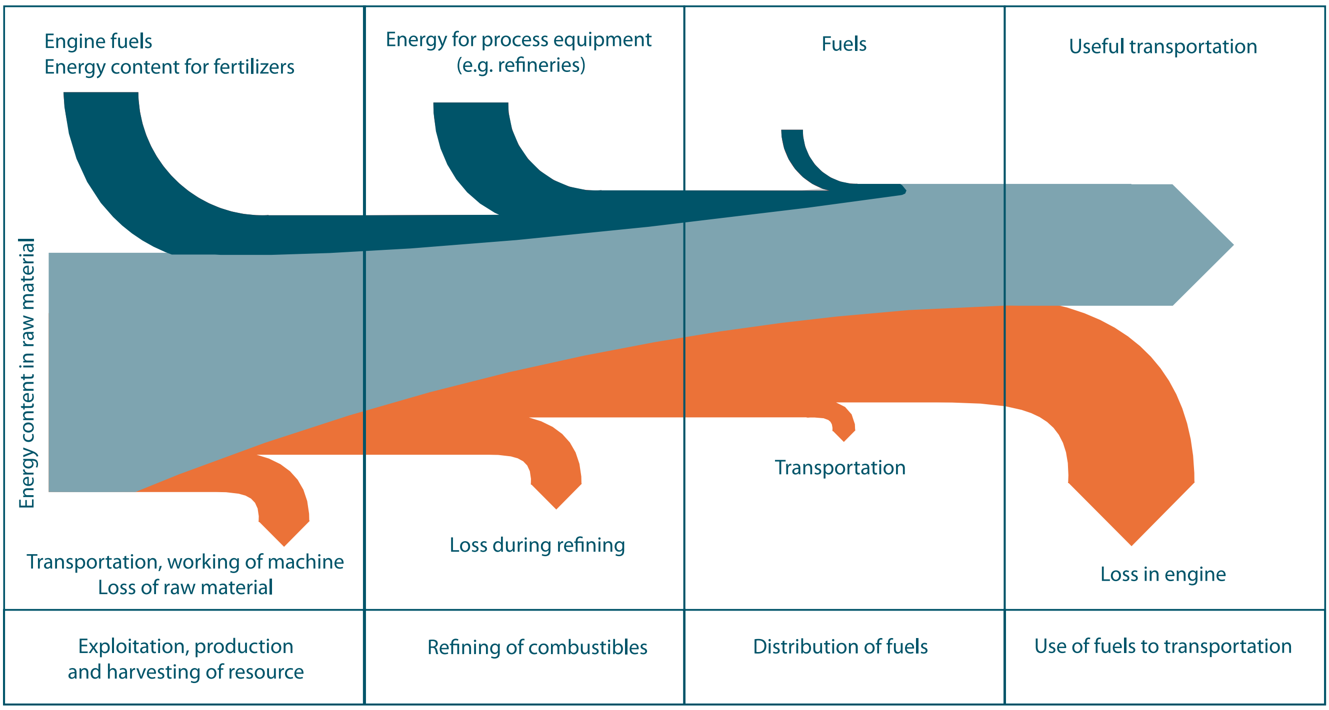
through reforming of natural gas. Methanol is harder to use in petrol cars without extensive replacement of materials in motors and infrastructure for fuel distribution since it is more corrosive. It may have potential in the future, for example as a fuel in fuel cells (see chapter 8).

Vegetable oils and biodiesel
Many plants and animals produce large amounts of fat. The combustion properties of these substances vary considerably, but through esterification they can be transformed into fatty acid methyl esters (FAME) with more homogeneous properties. FAMEs have an energy content of approximately 9.2 kWh/l which is at about the same level as diesel, and are marketed as biodiesel. Biodiesel can be used directly in diesel engines that are designed for this and can also be mixed into normal diesel oil. Biodiesel has comparable or marginally better properties than normal diesel with regard to engine performance and emissions to air.

Pyrolysis fuel oil
If small particles of biomass are heated up (wood, straw, and the like) quickly, they will disintegrate. This process is called flash pyrolysis , and occurs at temperatures in the range 700-900 ° C. the result is a mixture of charcoal, ash, oils and other organic liquids and gases (CO_2, CO, H_2, water vapor).

With the right choice of raw material and process parameters, the liquid output can reach about 70 per cent. The resulting liquid is very different from petroleum products and can not be mixed with them. It is possible to use pyrolysis oils as fuel in oil burners, but many challenges must be overcome before they can be considered as substitutes for petrol and diesel.

Synthetic fuels from biomass
The gas from gasification of biomass is suitable for further refining if air is not used as an oxidant. The gas can

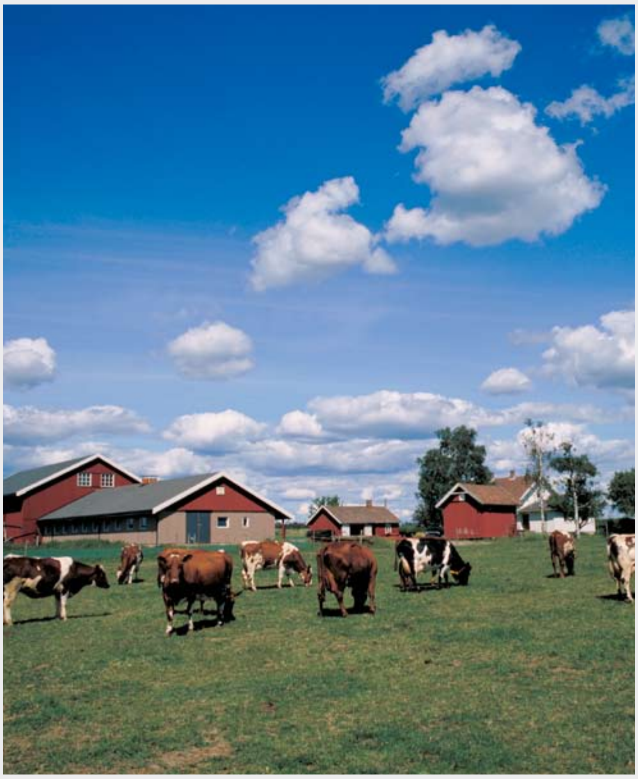


Figur 3-5 The principle for the flow of energy in the different phases from resource to performed transportation for fuels. The figure is valid for both fossil and bio fuels. Note that not all energy flows are physically mixed with the fuel. Illustration: Kim Brantenberg.

__Biowaz__
The Norwegian company NRQ AS is developing a new turnkey biogas plant for farms under the trademark BiowazTM (www.biowaz.com). High-quality PVC fabric is used in as a membrane containing the process instead of a reactor of steel or concrete. The reactor is buried in the ground and transforms organic waste (cow manure, food waste etc.) to methane gas that can be used for heating, cooling and electricity production. This technology will give considerably lower investment- and operation costs than conventional plants.

It has been estimated that the waste from 60 cows can give an energy production of approximately 86 000 kWh per year. This will cover the farmer's own energy demand for heat, cold, and electricity, and possibly yield surplus energy for sale.

The project is supported by Enova, The Research Council and Innovation Norway. A full-scale test plant was set up the autumn of 2006, where the technology was tested and approved by Norwegian University of Life Sciences at Ås.
The biogas plant is also tested in a test plant at a farm. Photo: Biowaz



be refined to a mixture of CO and H_2, also called syngas or synthetic gas. This gas can be treated in a number of ways, among others it can be processed to liquid fuel.

Several processes have already been developed to convert both coal (coal to liquid – CTL) and natural gas (gas to liquid –GTL) to liquid fuel. Conversion of biomass to liquid fuel via syngas (BTL) therefore does not presuppose new developments. However, there is a need for further development of catalysts to reduce production costs and to optimize the process for using gas originating from biomass.

The future for biofuels
Extensive work is being carried out to develop new and improved technologies, and the picture we have today of relevant biofuels will change. The development of technology will entail a convergence where some biofuels and some production processes will appear as superior in terms of economy and environment. However, a great diversity of raw materials will be used in the future stimulated by local circumstances.

Biogas

When organic material is decomposed by microorganisms in the absence of oxygen, a gas consisting of methane (approximately 40-50 per cent), carbon dioxide and other gases in smaller amounts is generated. This process called anaerobic digestion, occurs spontaneously in nature, for example at a landfill. The product gas is often called landfill gas. If nothing is done to collect the gas, it leaks out into the atmosphere and contributes to the greenhouse effect.

The anaerobe decomposition process can be used and perfected in a reactor. The product gas is then called biogas. In addition to this, one will get waste heat and a residual solid substance that can be used as fertilizer. Unprocessed manure can be used as raw material for the biogas process. An advantage with controlled anaerobe fermentation is that it is possible to achieve temperatures that kill most pathogenic micro organisms. What comes out of the reactor will then be safe to handle.

The composition of the biogas depends on which raw materials and micro organisms are used. The biogas can be burned directly to produce heat, but can also be used as an alternative to natural gas, or simply be added to a natural gas network. In these cases, the gas must be cleaned in order to meet the standard for natural gas.

Hydrogen for biomass

The product gas from gasification of biomass can be optimized with respect to hydrogen production by transforming carbon monoxide into carbon dioxide and hydrogen with the so-called shift reaction (see chapter 8, the section regarding hydrogen). It will be necessary to separate the hydrogen from the other gases which is expensive.

It is also possible to produce hydrogen directly by means of biomass. Under certain circumstances, algae can produce hydrogen through photosynthesis. If there is a lack of sulphur, the algae will go from producing oxygen to producing hydrogen.

Fuel production from waste at Veolia Miljø at Haraldrud in Oslo. Photo: Veolia Miljø.

Environmental impact

An important advantage with bioenergy is that its use is neutral with regard to greenhouse gases. The carbon dioxide that is created through combustion has been previously taken up by the plant, and therefore does not represent a net emission as long as the standing biomass stock is not exhausted. However, a complicating factor is the effect on carbon that is bound in the ground below the plant. There is a need for much research on this subject before we have a complete understanding of processes and system effects.

The environmental impact due to the use of bioenergy is in many ways more complicated than for other renewable energy sources. The most extensive and serious environmental consequences can arise in connection with the production and harvesting of the resource. There is a risk for reduced biodiversity and deterioration of productive land through erosion in connection with large scale production of biomass if such issues are not given sufficient importance. There is also a danger of extensive user conflicts, for example with regard to food production and the protection of natural resources. In a time when international trade with biofuel seems to gain considerable importance, it is important establish an international set of rules and systems that can document the environmental conditions at the production site.

At the same time, cultivation of energy crops can open the door for a larger biodiversity than food production, and they can often be cultivated in areas that are not suitable for food production. Properly managed, increased use of bioenergy can therefore give more sustainable agriculture and increased income for rural communities and developing countries.

Today, a lot of bioenergy is produced with a basis in residual products that have a low alternative value. These also give little marginal environmental impact through production of the resource, since the biomass resource is produced and harvested anyway. It is not unusual that the exploitation of the residual product for energy purposes gives an environmental gain, since it otherwise would pollute in different ways. If bioenergy is to take over for fossil fuels on a large scale, the share of energy coming from residual products will decrease. If for example 10 per cent of the world's petrol consumption is to be replaced with alcohol from sugar canes, Brazil must increase its production 40 times [Nature, 2006]. In such a scenario, residual products from sugar cane production will make up a small share of the raw material. It is therefore important to improve the knowledge on the total consequences of large scale exploitation of bioenergy.

Combustion and gasification of biomass often give lower emissions of nitrogen oxide than combustion of fossil fuels. The emissions of sulphur dioxide are also low, because the wood normally contains little sulphur. Nevertheless, larger plants must have cleansing of flue gas and/or product gas in order to control harmful emissions to air. Most gas treatment processes are designed not to give discharge to water.

Combustion of solid fuels also generates bottom ash and fly ash. Fireplaces are an important source to particle emissions, but modern fireplaces for wood or pellets give low emissions. The development of combustion technology that minimize the formation of fly ash and flue gas treatment technology that effectively can handle this problem are important components to improve the economy for bioenergy.

Bioenergy technologies also contribute in a positive way to the solution of environmental problems by final treatment of waste in connection with waste combustion, gasification of harmful waste and the production of biogas from wet organic waste.

Products and services in the value chain/technology gaps

The most important products in the diverse value chains are described in connection with the different areas of application. The main areas are equipment for fuel management, combustion and flue gas treatment. An increased demand for knowledge about design of bioenergy plants, environmental assessments and operation of district heat plants can also be expected in the future.

Signs are already showing that there will be competition for many biomass resources. The development technology that can use the least attractive bioenergy fractions without damage to the environment can have a great potential for value creation.

Chip powered thermal power plant. Photo: Jonas Sandgren.

The production of liquid biofuel will lead to increased demand for chemical process equipment and process competence. Refining of wooden raw material for biofuel will be of particular interest to Norway because of the important forest resource, and as a result of good competence in the field of chemical processes that can be used for refining of this resource.

The most important task for the development of bioenergy is improving the logistic chains in the forest and in agriculture. Biomass has a relatively low energy density, and in order to turn bioenergy into a competitive alternative for high-volume uses, a rational and efficient apparatus for primary production, transport, refining and distribution of bioenergy will be of paramount importance. This calls for development of new technologies, new organization forms and new business concepts. This development has begun, but we will probably see many more changes regarding logistics for bioenergy in the future.

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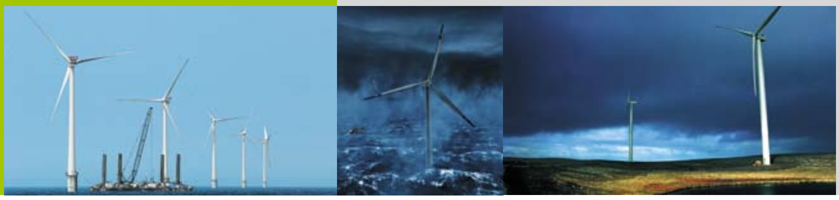


4. WIND POWER

Man has harnessed the energy in wind for thousands of years, both for sailing boats and powering wind mills at land. Of all renewable energy sources, wind power is the most mature in terms of commercial development. The development costs have decreased dramatically in recent years, however most projects are still dependent on public subsidies in order to be profitable. This energy source is interesting because of its renewability and its availability. Potential for development is huge, and the world's capacity is far larger than the world's total energy consumption. World wide, a total capacity of about 60 000 MW have been installed, with a yearly production of about 100 TWh. The major challenges for further development are connected to economy, land usage, environment and grid capacity.

Norwegian companies have extensive experience from offshore oil and gas activities and can utilise this in developing offshore wind technologies. Norwegian companies also have unique experience in operating wind turbines in harsh arctic climate.

How does wind power work?

A wind turbine consists of tower, blades, and a nacelle containing the generator, gear and control system. The wind puts the blades in motion in the same way that an airplane wing gives lift to a plane. Energy is transferred from the turbine via the drive shaft to the generator inside the nacelle. The generator transforms the kinetic energy to electric energy, which is in turn transferred to the grid via a transformer.

A modern windmill produces energy when the wind speed is in the range of 4-25 m/s (gentle breeze to storm). Maximum output is achieved at 12-15 m/s, whilst the power production normally is stopped at wind speeds above 25 m/s (blade pitch is adjusted, brakes are applied) to protect the wind mill against damage.

The energy output of wind increases exponentially in the third degree of the wind speed. Thus, even small changes in wind speed will have large effects on the energy production, and therefore the profitability of the project. A location with a mean wind speed of 8 m/s will produce twice as much energy as a location with a mean of 6 m/s. The wind properties of an area is therefore of prime importance.

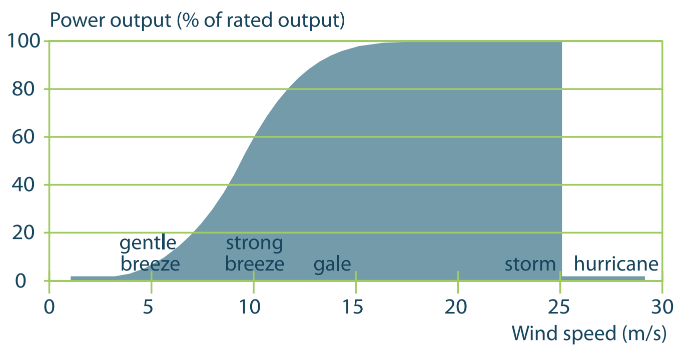


Figure 4-1 Normalized output curve for a wind turbine. Source: SINTEF Energy Research.

Resource base

About 1 percent of solar influx propels the global motion of air. For the world at large, this equals an amount of energy 100 times the current world energy consumption. Of this, only a small amount can be utilised for wind energy production.

Wind resources in Norway

Norway has excellent wind resources. On the exposed strip of the Norwegian coastline, annual mean wind speed 50 m above ground can be as high as 7-9 m/s. At sites of local acceleration (hills, crests etc) wind speeds above 9 m/s are common. Common capacity factors are around 34 per cent, generating 3000 MWh/year with the same installed capacity. At optimal sites in onshore Norway as well as offshore sites, a capacity factor of 46 per cent MWh/year is possible.

In continental Europe, capacity factors of about 23 per cent are common, thus 1 MW of wind power will generate 2000 MWh/year of electric power.

Development status

At the end of 2006, a total of 320 MW wind power was installed in Norway, with wind turbines numbering 155. This amounts to a production capacity of about 1 TWh/year.

Global wind resources

Scientists at Stanford University have calculated wind speeds at 80 m above ground for the globe. The calculations illustrate a global potential for wind power of 72 TW, translating into a production of 144 000 TWh/year [Archer & Jacobson 2004]. If only a fifth of this potential is developed, the world's entire current energy consumption would be covered. For EU-25, the potential found was 600 TWh/year onshore, and 3000 TWh/year offshore.

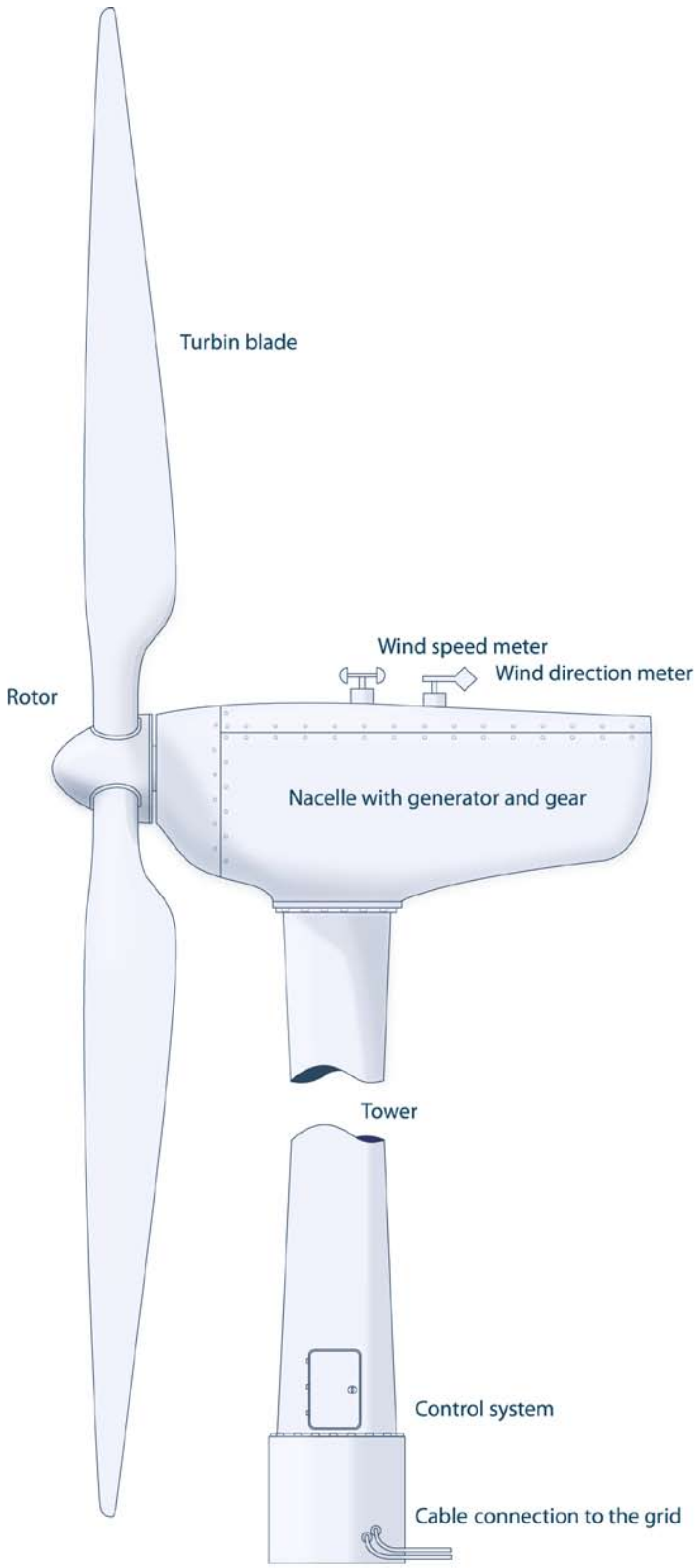


Figure 4-2 Overview of a wind turbine. Illustration: Kim Brantenberg.

Development status

Globally, installed capacity increased from 2500 MW in 1992 to 59 200 MW at the end of 2005. This corresponds to an annual growth of about 30 percent. More than 75 percent of this new capacity has been installed in Europe. [IEA 2006]

Even though the best wind conditions are to be found in Northern Europe, Germany and Spain have had the largest growth in recent years. In Denmark the wind power share of total electricity production is 20 percent, whilst in Germany and Spain the share is 5 percent.

The European wind energy organisation EWEA recently increased their estimates for wind power generation in 2010, as capacity has increased much faster than previous estimates. The current target is an installed capacity of 75 GW within 2010 for EU-15 with a production of 168 TWh/year. For 2020, the target is 180 GW [EWEA 2004].

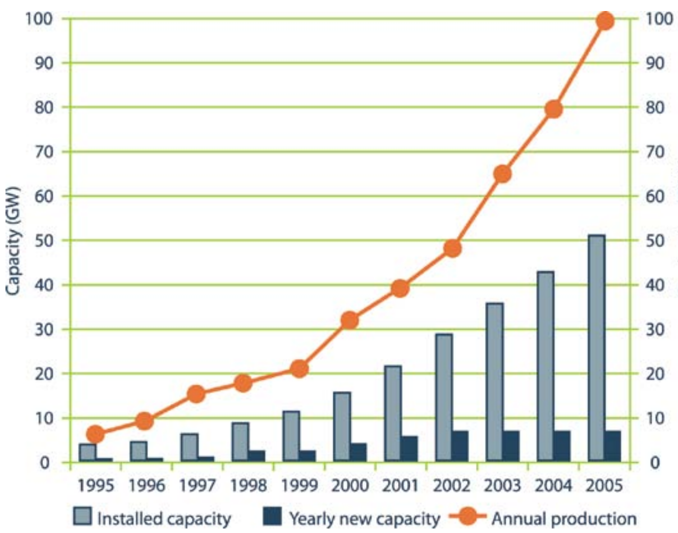


Figure 4-3: Installed capacity and annual production 1995-2005, for IEA member countries [IEA 2006].

Challenges for further wind power expansion

Economy

Wind power is a relatively mature technology. It competes with other energy sources in terms of price, environmental effects and usability. With the exception of hydro power, wind power is closer to commercial profitability than any of the other renewable sources, though improved project economy is a vital challenge for wind power. Wind power is in most cases dependent on public subsidies in order to be profitable.

The investment costs for a finished onshore project is at least 1000 – 1400 €/kW, by 2006 standards, including grid connection. The corresponding cost per kWh varies with the individual project, and is very dependent on wind conditions, operating time and grid costs. Typical energy cost varies between 3,5 and 8,5 c€/kWh, including capital and maintenance costs. Investment costs for offshore wind power is considerably higher. Floating wind mills cost typically 50 to 100 percent more than land based utilities.

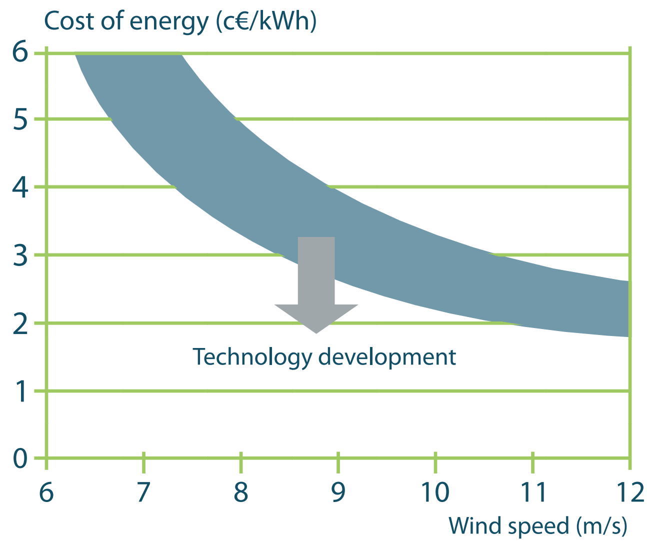


Figure 4-4 Cost of wind power related to annual mean wind speed. Source: SINTEF Centre for Energy Research.

The cost of turbine purchase is 60 to 80 percent of total development costs. Towards 2001, turbine costs decreased 9-17 percent annually, but because of increased demand, increased steel prices and insufficient supply in recent years, the price of turbines has increased considerably. Currently, supply lags demand, and there are long delivery times for turbines. In the case of future expanded supply capacity, prices may start declining again. With time, R&D efforts will also lead to lower prices.

Operation and maintenance costs for wind power vary significantly. For the first few years of operation, typical operation costs are 2-3 percent of investment costs, increasing slightly in subsequent years. Maintenance costs can be much higher if main components have to be exchanged due to wear and tear.

Environmental impacts

Operation of wind power has zero emissions of harmful substances. It does not add to global warming, the "fuel" is free, and is quite evenly distributed around the world. The energy needed to produce and install the turbine amounts to three months of turbine production. But, as with other sources of energy, wind power does have an environmental impact.

The visual effects of wind power are often deemed the most important environmental effect. The turbines are experienced as dominating in close range, but from a distance of 1,5-2 km, the visual impact is much less. In addition, wind mills throw moving shadows and produce noise.

The Norwegian wind industry has acquired extensive experience developing wind parks in Arctic territories. The picture above is taken from the world's northernmost wind park at Havøygavlen. Photo Atle Abelsen.

The affected area of a wind park is merely 1 to 3 percent of the total area, with roads taking most of the space. Therefore, environmental impact will be limited, and can be mitigated efficiently.

The impact of onshore and near-shore wind farms on wildlife - particularly migratory birds and bats - is hotly debated, and studies with contradictory conclusions have been published. The impact on wildlife is likely low compared to other forms of human and industrial activity. However, negative impacts on certain populations of sensitive species are possible, and efforts to mitigate these effects should be considered in the planning phase.

The whole fuel life cycle of wind power, from production, processing, transformation, construction and combustion, demonstrates that the economic costs of conventional energy sources far exceed those of wind power. The EU scientific programme ExternE has calculated that the external costs of wind power are less than 0,26 €/kWh, whilst for coal power they range from 2 to 15 €/kWh [EWEA 2004].

An important consideration is that constructing a wind park to large extent is a reversible impact. Most of the wind park can be removed with relative ease should it be the wish of future generations.

Transport of turbine elements to remote wind farms represents a considerable challenge. Often new roads and quay structures must be established. Photo: Vestas.

Grid limitations

The potential of wind power is largest at remote sites where the population density often is low, and with a distance to the electricity consumer as well as the existing grid. To realise the wind power potential, there is often a need for grid investments. This can be both costly and time consuming. Expensive grid connection is often one of the main reasons why wind sites are not developed. In addition power lines represent a considerable environmental impact.

The Utsira project

On the island of Utsira, outside Hagesund, Norway, Hydro has built a demonstration plant to show how wind power and hydrogen fuel cells can work together to secure renewable electricity supply for a remote community. The project utilises renewable sources only, and supplies 10 households year round.

The energy from the wind turbines must be stored in order to secure supply at times of insufficient wind. Hydrogen is used as chemical energy storage. When the turbines produce above demand, hydrogen is produced through electrolysis. The hydrogen is then stored in pressure tanks, and called upon for electricity generation when wind power production is insufficient. The project was awarded the prestigious Platts «Global Energy Award» in 2004. The technology employed is not commercially competitive as of today, but the demonstration provides experience with independent energy systems, which will be relevant also for other backup sources. Photo: Norsk Hydro.

System integration

Because the energy generation varies with the wind conditions, energy supply based on wind power is dependent on other complementary sources of energy. Hydro power is very suitable as a complementary energy source for wind power. Hydro dams can work as energy storage for the wind energy, and in this way work as a buffer for the stochastic nature of wind power. Through interaction with Norwegian hydro power, western Denmark has been able to establish a functioning electricity supply with a wind power share of 30 percent.

Radar interference

Military radar installations can be affected by rotating wind turbines. This has been a case especially in the north of Norway. The development of new radar technologies will diminish this problem considerably.

Areas of application

The output of wind power varies with wind conditions. As a result, wind power can only comprise a part of an energy supply. This can partly be offset by establishing a system of wind parks at different locales. As a rule, there will always be wind at some of the sites. Calculations show that 10 percent of the total installed capacity will be in operation at all times, employing a system of varied wind park locations.

There are also advantages to the ability to regulate wind power due to maintenance, for example. If a single turbine is disconnected, the effect will be comparably small. Disconnection of a single wind turbine of 2-3 MW is much easier to handle than the disconnection of a gas-fired or nuclear power plant of 1000 MW.

Wind power is a suitable candidate for off-grid power supply in remote places. To avoid blackouts when there is no wind energy storage is required. One possibility is the combination of wind power and hydrogen powered fuel cells.

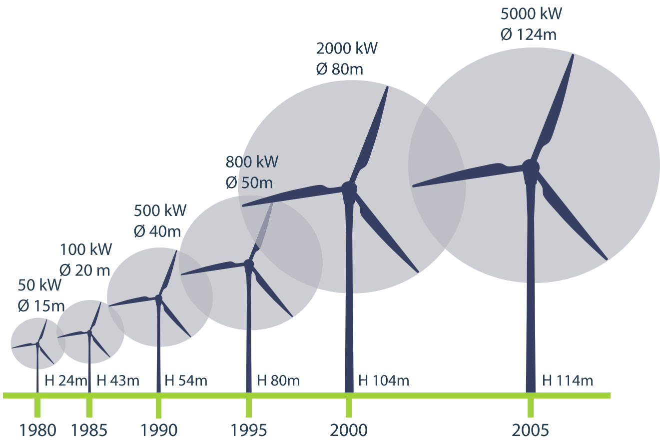


Figure 4-5 Increase in size of wind turbines in recent years . Source EWEA.

Wind turbine development

The most obvious technological development during the last five years is the increase in turbine size. In 1996 the normal size for commercial turbines was 600 kW. Today, 3 MW turbines is the norm, and 5 MW turbines are in mass production. There are several ongoing R&D efforts to further increase the size. The EU supported R&D project Upwind aims at exploring the possibility of turbines as large as 20 MW. See figure 4-5.

Installed output (kW)	Rotor diameter (metre)	Annual production at a capacity factor of 34 per cent (GWh)	Number of turbines per TWh
500	40	1,5	670
2 000	80	6,0	167
3 000	90	9,0	111
5 000	125	15	67

Table 4-1 Relationship between ouput, rotor diameter and production for wind turbines

Land based wind parks

Grid connected wind turbines are most often installed in clusters. There are numerous reasons for this. In densely populated areas property is expensive. An area with good wind conditions should therefore be utilised efficiently. The costs of infrastructure, such as road construction, grid connection, transport and installation, will be less per installed unit. Also, visual impact will be less per turbine when placed in parks as opposed to individual installations.

Offshore wind parks

Several countries are looking with increasing interest at the prospect of installing wind turbines offshore. This is due to the limited availability of land, but also due to more stable and generally stronger offshore winds. Both wind turbines installed with foundations on the sea floor as well as floating structures are being explored. Currently, only sea floor foundation turbines are installed, as companies conduct research to overcome the technical difficulties of floating structures.

Scanwind

Scanwind is the only Norwegian supplier of wind turbines. They deliver both direct drive units with permanent magnet generators and conventional systems with asynchronous generators. Scanwind's technology is particularly suited for the harsh Nordic climate.

Scanwind will deliver 15 wind turbines of 3,5 MW each to NTE's wind park at Hundhammerfjellet. Total installed effect for the park will be 50 MW. Photo: Scanwind.

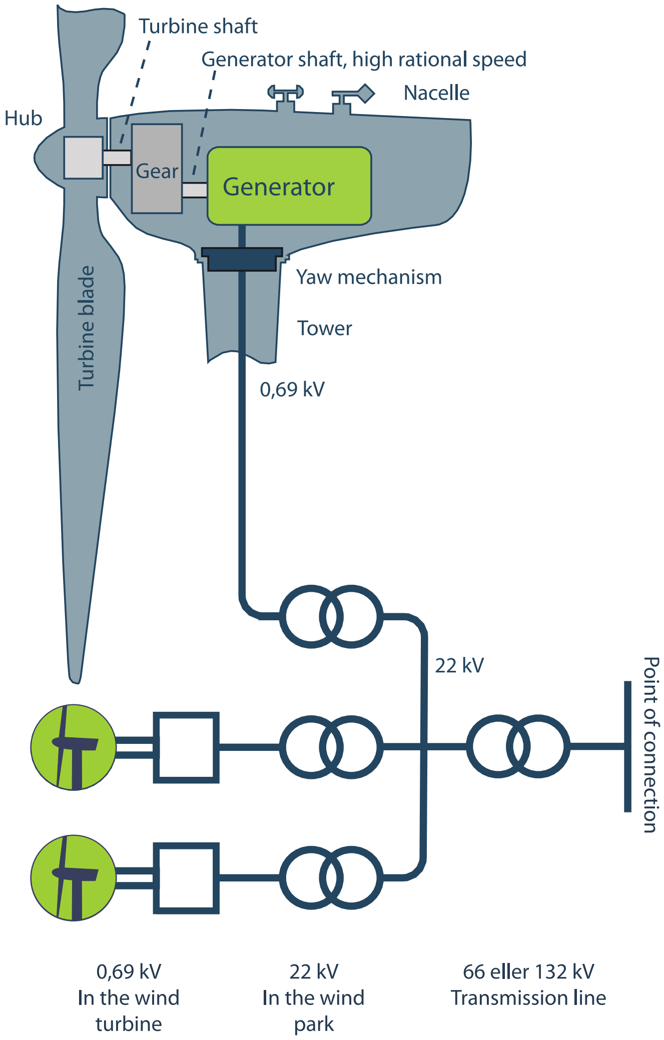


Figure 4-6 Wind turbine with grid connection. Illustration: Kim Brantenberg.

The current development is moving in the direction of larger turbines (3 MW +) with specialised designs for offshore conditions. Major challenges are associated with installation, foundation design and operation/maintenance. As of today, investment costs are 50-100 percent higher than for land based plants, but further R&D is expected to reduce the gap in the future.

In addition, technology for floating wind mills is currently being developed. Floating installation will make costly sea floor foundations unnecessary, but at the same time introduce new challenges, such as risk of increased wear and increased costs for anchoring and grid connection. As a start, floating turbines may be a good solution in areas of the world with a shortage of available land, good offshore wind conditions and a need for increased energy supply. This applies to USA, Japan and countries with existing offshore oil and gas instal-

Havgul

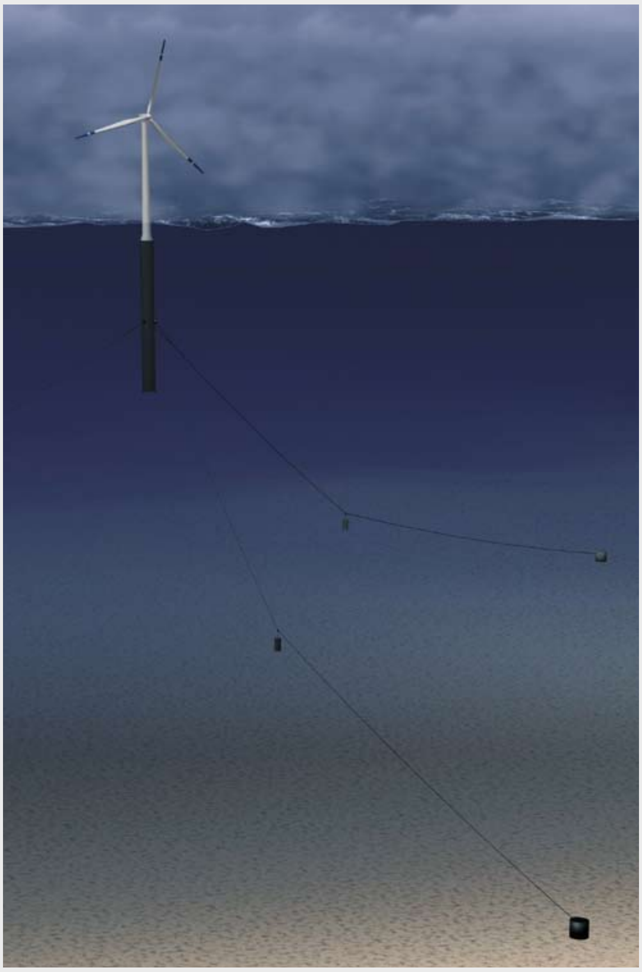
Norway has excellent wind resources, both at land and at sea. As of today, no offshore wind parks have been developed, but several are at the drawing board.

The company Havgul has applied for a permit to develop three wind parks off Ålesund, on the Norwegian west coast. The turbines will be of capacity between 3,5 and 8 MW, and will be installed at shallow water between 5 and 15 m sea depth. In total, the three parks will have an installed effect of 1500 MW, and a production of over 4 TWh. Photomontage: Havgul AS.

Norwegian floating offshore wind turbines

The Norwegian companies Sway and Norsk Hydro (Hywind) are currently exploring the possibilities of wind power at sea. The companies are utilising technology from the oil and gas activity in the North Sea to develop floating concrete or steel constructions as a foundation for offshore wind turbines. In this technology, the turbines can be installed at sea depths of several hundred metres. Wind conditions in the open ocean are excellent, making it possible for installations to reach capacity factors close to 60 per cent. Onshore, a capacity factor of 35 per cent is considered good. The projects are still at the drawing board, but both companies are planning to install full scale prototypes offshore within a few years.

The Hywind concept has a 5 MW turbine with a rotor diameter of 130 metres. Illustration: Norsk Hydro.



lations. Two Norwegian companies, Sway and Norsk Hydro (Hywind), are currently working on technology for floating wind turbines.

Market

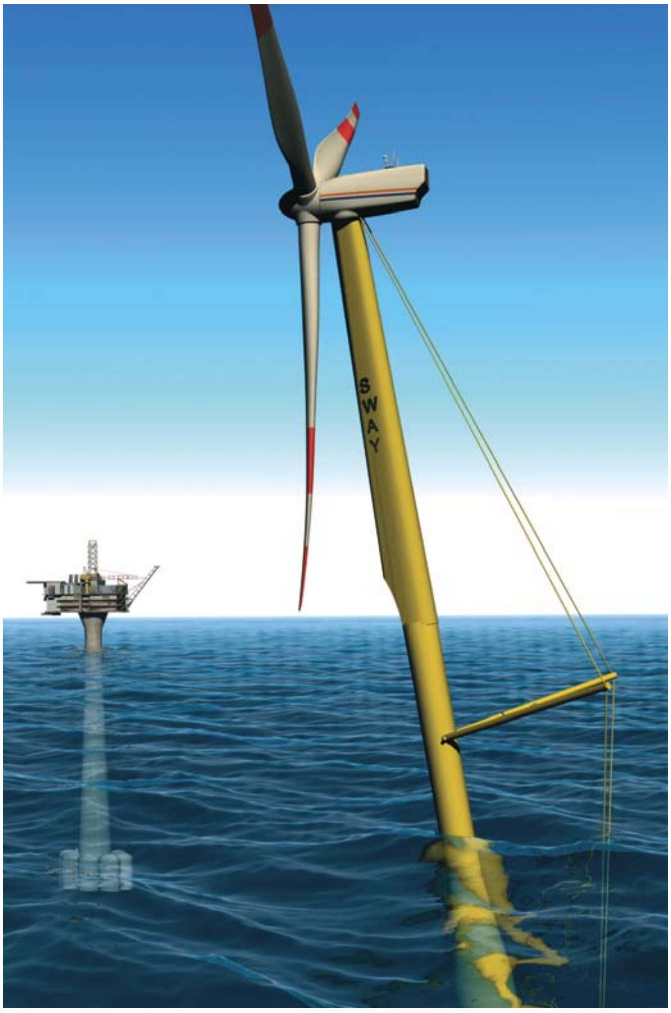
The wind power industry has changed considerably in recent years. The direction of development is towards larger wind turbines and larger wind parks. The development of ever-larger wind turbines is likely to continue, and the biggest turbines and parks will be erected offshore.

In 2005, the international wind industry had revenues of about 10 bn €, and employed about 150 000 people [GWEC 2006]. The wind market used to be dominated by national companies, but as the market has developed, large international conglomerates such as General Electric and Siemens have entered the market. Oil and gas giants such as Shell and BP are also developing their own wind projects. Nine out of ten of the world's largest wind turbine producers are European companies. The wind industry is especially large in Denmark, Germany and Spain. In addition, other countries such as Norway have a rapidly growing industry. Norwegian companies exported wind power technology for 50 million € in 2004, employing about 350 people.

Research and development

An important area of research and development for the next few years will be the development of large wind turbines suitable for harsh conditions both onshore and offshore (strong, turbulent wind and cold climate). Associated important areas are improved design and calculation tools, development of new techniques and tools for grid integration and improved wind forecasting techniques.

Increased use of power electronics, new generator technology, improved systems for regulation and control as well as development towards lighter modules is likely, and will contribute to reduced costs. Norwegian developers have collected valuable knowledge and experience in dealing with special challenges such as strong, turbulent winds and extreme climates through numerous projects. Norwegian companies are well positioned for utilising know-how from the oil & gas and shipping industry especially relevant for developing offshore wind power.



SWAY is one of the Norwegian Companies developing technologies for floating wind turbines. Illustration: Sway.

Grid connection of large wind parks and efficient integration with the existing power supply are further themes demanding R&D efforts. In addition, further development is expected within off-grid wind power and energy systems integrating hydrogen and other types of energy storage.

Improved systems of wind forecasting will be able to increase the value of wind power by forecasting 6 to 48 hours in advance. There is also a potential for increasing the amount of energy produced from certain sites, because there is a large difference of output depending on whether the wind turbine placement is optimised or not. Simulation software for difficult terrain that simultaneously calculates the wind field and turbulence behind a turbine has been developed through a research program in Norway.

Improved tools for visualising the aesthetic impact of wind parks will grant a better decision-making base in the project development process. This will make it easier to identify suitable areas for development in terms of reduced conflict with neighbours and other stakeholders [IEA 2004].

Norwegian wind power stakeholders

The wind power industry is in steady growth. On the international arena, the competition is fierce. In some countries there are wind power companies with more than 25 years of experience with developing and producing wind power plants and modules. Still, Norway has several fields of technology and know-how that can be employed on the world market. Following are examples of areas where Norwegian companies can contribute with innovative solutions.

Wind turbine suppliers

The Norwegian company Scanwind produces large wind turbines. The company has developed a 3 MW and a 3,5 MW wind turbine. www.scanwind.no

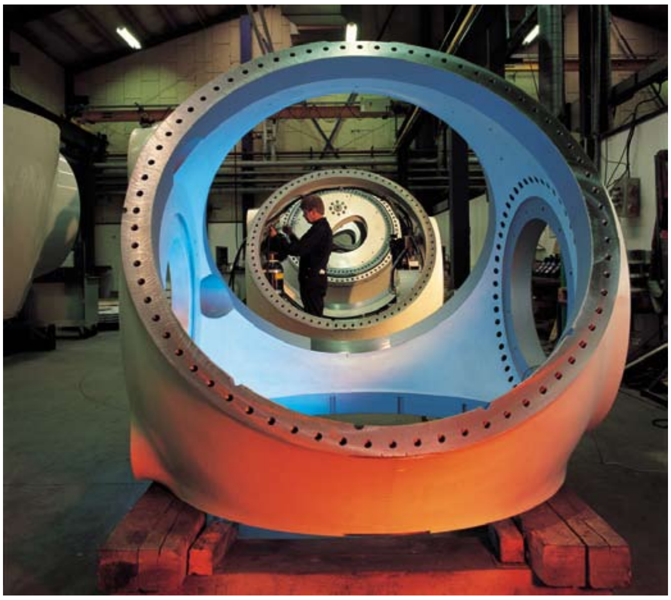
Blade production

Norwegian know-how on the areas of composite materials and aerodynamics can be utilised for the production of blades that comprise about 25 percent of the wind turbine costs. Umoe Rywing delivers blades for large wind turbines above 1,5 MW, and with lengths above 34 m. The company has a considerable export, and in 2004 delivered blades to projects in Germany, Czech Republic and Taiwan. www.umoe-blades.com

Devold AMT is a considerable supplier of glass- and carbon fibre mats for strengthening turbine blades. www.amt.no

Cast naves

Kristiansand Jernstøperi had an early entry into the market for large cast-steel modules for naves for the



Casting of hub for wind turbine at Vestas Castings Kristiansand. Photo: Vestas.

Danish wind turbine industry. It was later acquired by the Danish wind turbine producer Vestas, and as a result now bears the name Vestas Castings Kristiansand. The company has 200 employees, and exported for approx. 30 million € in 2004.

Another company worth mention is Ulstein Støperier (now Rolls-Royce Marine AS Foundry), which delivers cast naves and other modules for wind turbines. About 30 percent of the production is for these purposes.

Electronics and control systems

Statistics from wind power operation shows that more than half the repairs are connected to unloaded components such as electronics and control systems. Improvements on this area are especially important for offshore wind power for which repairs and maintenance are especially expensive.

Møre Trafo delivers transformers and grid stations for wind turbines. www.moretrafo.no

SmartMotor are developing a new type of permanent magnet generator for wind power. www.smartmotor.no

Offshore technology

Norway has a large oil and gas sector with very advanced offshore expertise. The Norwegian companies Sway and Norsk Hydro (Hywind) have developed projects for floating wind turbines. www.sway.no and www.hywind.no.

With a background from the offshore industry, OwecTower is designing foundations (tripods) for offshore wind power. www.owectower.no

Wind resources and simulation

Kjeller Vindteknikk AS delivers services including wind resource mapping and wind measurement.

Vector AS has developed the wind resource mapping software Windsim, which is used by wind power developers throughout Europe. They also provide consultant services and simulations of wind resources. www.windsim.com

Test stations

SINTEF Energy Research, Institute for Energy Technology (IFE) and the Norwegian University of Science and Technology (NTNU) are cooperating on wind power research and development, and has established The Centre for Renewable Energy (www.sffe.no). The organisations are also cooperating in the development of a wind power test station at Valsneset in Bjugn municipality – VIVA AS. The R&D activity at this station is being performed by SINTEF, IFE and NTNU, both for own purposes and for external clients. The test station is comprised of a research turbine of 225 kW, a measurement mast and a test house. The turbine is fully instrumented, and capable of measuring loadings and effects on the turbine. www.viva-test.no

Other stakeholders:

Developers. The most active developers in Norway have been the large conventional power companies, specifically hydro power. In addition, there is a number of development companies established by consortiums of lesser actors. On the website of the Norwegian Water Resources and Energy Directorate (NVE – www.nve.no), there is a list of all Norwegian wind power projects, the status of the projects, and information about the developer company.

Jotun AS delivers industrial paint and other solutions for corrosion protection, and for the inside and outside of turbine towers, nacelles and blades. www.jotun.com

Det Norske Veritas certifies wind parks and suppliers to the industry. www.dnv.com

Consultants.

Several Norwegian engineering and consultancy companies have extensive know-how and experience with all aspects of wind power projects.

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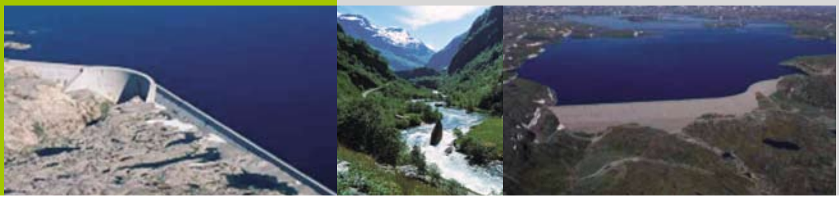


5. HYDROPOWER

The mechanical use of falling water is an age old technology. It was used by the Greeks to turn water wheels for grinding wheat into flour more than 2 000 years ago. It was not until 1870 that hydropower was exploited for the production of electricity.

During the first half of the 1900, hydropower became one of the world's most important electricity sources.

Today, hydropower is considered a mature technology and contributes a considerable share of the world's electricity production (approximately 16 per cent).

Norway is the world's sixth biggest producer of hydropower and the largest producer in Europe. Hydropower completely dominates electricity production in Norway with a share of approximately 99 per cent. Norwegian companies have a great deal of experience in the development and construction of hydropower projects. Norway also has a strong supplier industry that delivers goods and services to hydropower construction both on an international level and in Norway.

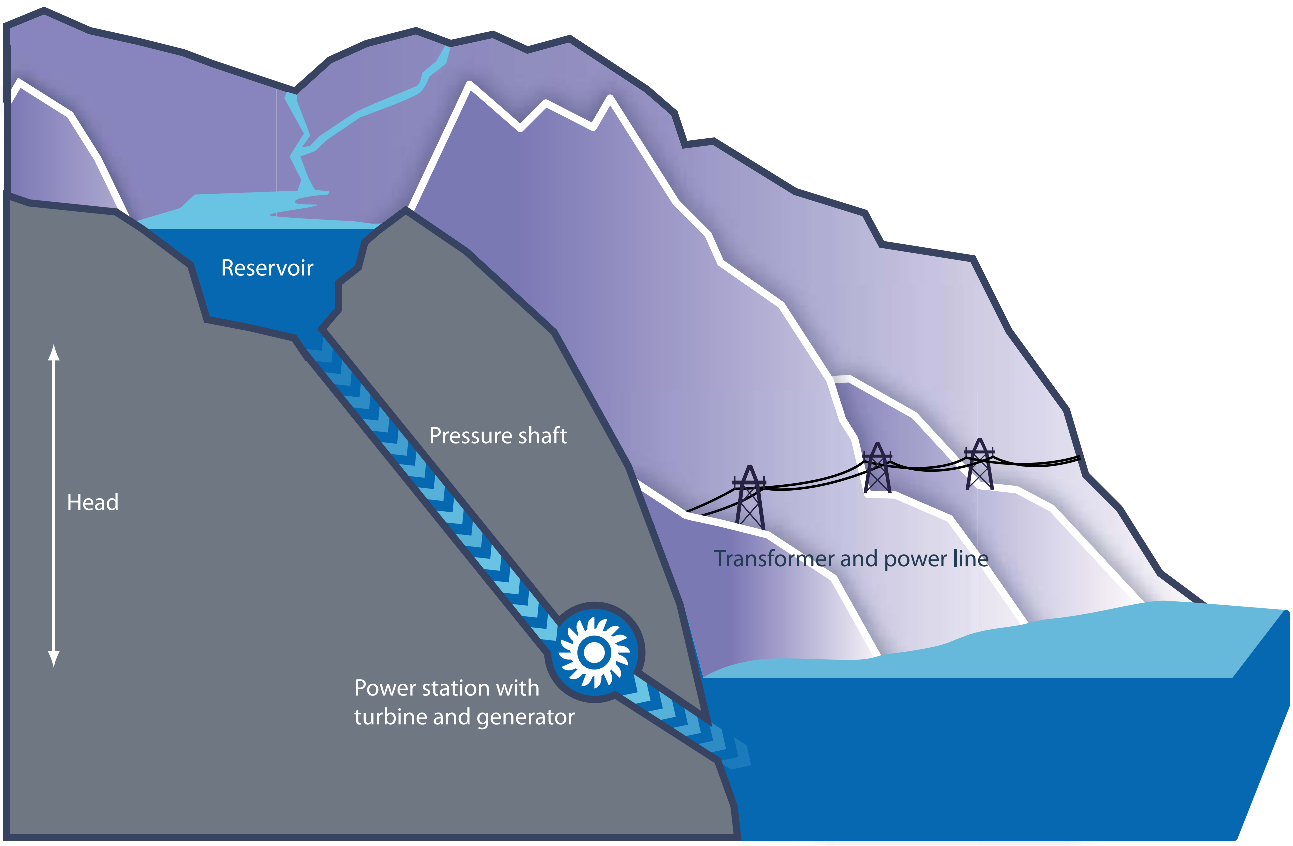


Figure 5-1 Working principle for hydropower. Illustration: Kim Brantenberg.

How does it work?

The natural water cycle is driven directly by solar energy. When the sun heats up water in the sea and surface water, vaporization takes place and the water rises in the form of water vapor. The water vapor rises. When the water vapor reaches higher layers of air and is cooled down, the water falls down in the form of rain, hail or snow. The water runs naturally towards the lowest level and is transported on the earth surface in streams and rivers, and finally reaches the sea where it again evaporates. By letting the water flow through turbines on its way to the sea, we can harness the kinetic energy of the moving water to produce electricity.

Volume and head of water determine the potential energy of a waterfall. The head of water is the height difference between reservoir intake and power station outlet. Water is directed into pressure shafts leading down to a power station, where it strikes the turbine runner at high pressure. The kinetic energy of the water is transmitted via the propeller shaft to a generator, which converts it into electrical energy.

Water power plants can be divided in two types based on the pressure height: low- and high-head power plants.

Low-head power stations often utilise a large water volume but have a low head, as in a run-of-river power station. Since regulating the flow of water is difficult, it is used when available. The amount of electricity generated therefore increases considerably when the river is carrying more water during the spring thaw or when precipitation is very high. The river is dammed up by the power plant to lead the water into one or more turbines. After having been exploited in the turbines, the water runs out in the river below the power station.

High-head power stations are generally constructed to utilise a high head but smaller volume of water than run-of-river installations. Many types of these power stations store water in reservoirs. The water is normally led from the water magazine in a pressure shaft. At the bottom of the pressure shaft, the water is distributed and led through pipes to the different turbines. Due to the large head of water the water is under high pressure. The water pressure drives the turbine around and the momentum from the turbine is transferred through a shaft to the generator. Modern high pressure power plants are normally built into the rock. The power station and regulation magazine are connected by tunnels through the rock or pipelines down the mountainside. Reservoirs allow a larger proportion of runoff to be used in power production. They usually have a larger installed capacity than run-of-river stations, but a shorter utilisation period.

Hydropower production is exploitation of potential energy in the water, not the speed of the river. The challenge is to exploit this energy without the water gaining unnecessary speed, because with an increased speed the head loss increases (first and foremost the friction loss in the pipe) and the exploitation is reduced.

The energy production (P) is measured in kWh and is calculated with the help of the formula

$P=(V \bullet Hn)/Kp$

Where

V=*total average inflow to the turbine(s) during a year* (m^3)

Hn=*average net head of water*[m]

$Kp=3600/(n \bullet 9{,}81 \bullet p)$ $[m^2 \bullet s^2/h \bullet kg]$

n=*average efficiency for turbine, generator and transformer during a year.*

p= *water density*

We see that the decisive factors are volume and head of water. The other factors are the efficiency of the turbine and generator and the water density.

Water storage reservoirs

A water storage reservoir is a natural or artificial pool for accumulation of water in periods with a high inflow and low consumption, and for tapping of water in periods with low inflow and high consumption. In other words, the water storage reservoir is used to regulate production and is therefore often called a regulation reservoir.

During storage, a larger share of the drain is used in power production. Depot power plants are also appropriate for fast up and down regulations of production (load control). In this way, the power plant can produce more during the day, when consumption is at its highest compared to during the night.

The storage reservoirs can be used to store water during seasons when water consumption is low and when the demand for power is highest. This is called seasonal regulation. Power producers can also hold water back in the storage reservoirs during periods of flood and let the water out during periods with drought. Therefore, regulation storage reservoirs can have a flood reducing effect.

Regulation storage reservoirs can be dimensioned to store water for several seasons. They are then called perennial storage reservoirs.

The power producers can achieve an economic profit by pumping low-lying water up to regulation storage reservoirs with higher height of fall because the water's potential energy increases in proportion with the head of water. When prices on power are low, it can be profitable for the producers to use energy to move the water to a higher storage reservoir, so that the water can be used for production in periods with high prices.

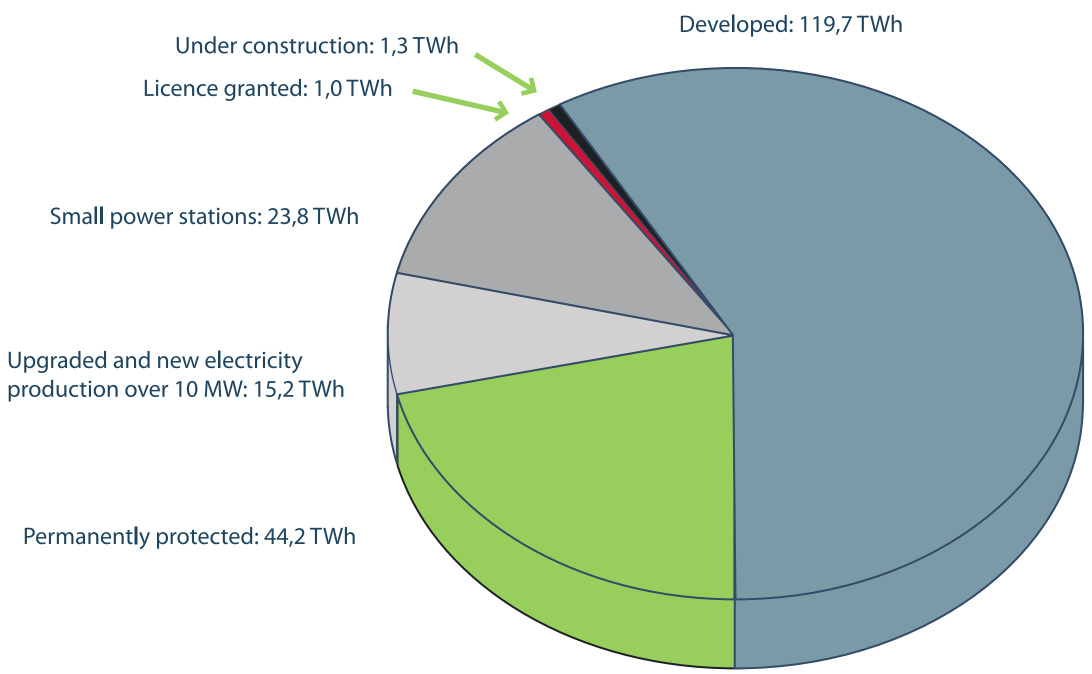


Figure 5-2 Norway's hydropower potential at 1 januar 2006, TWh/year. Source: Norwegian Water Resources and Energy Directorate.

Water inflow

Inflow is the amount of water that flows to a power plant from its entire catchment area. A catchment area is the land area with drainage to a certain outlet, for example, storage reservoirs or inlets to a power plant. Precipitation varies from place to place through the season. There is also often a large variation in the inflow from year to year.

RESOURCE BASIS

On a global scale, is has been calculated that the total hydropower potential that is technically feasible to exploit is approximately 14 000 TW/year. Of this, 8 000 TWh/year is considered economically exploitable. [IHA/IEA, 2006].

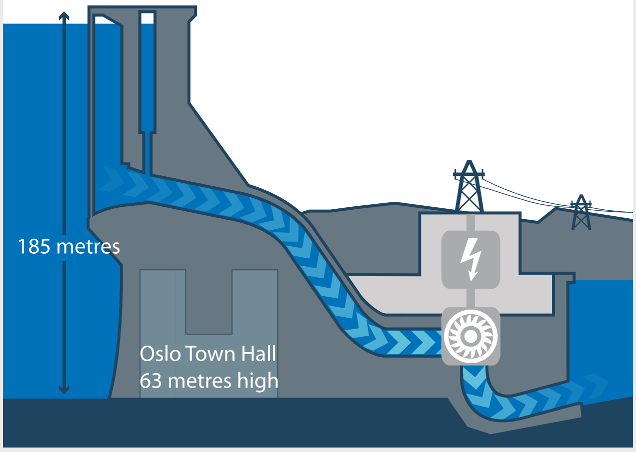
Today, 2 645 TWh/year of electricity is produced from hydropower, something which covers approximately 2.2 per cent of the world's energy production and 16 per cent of the world's electricity production. This makes hydropower the largest renewable energy source by far with a 90 per cent share of renewable electricity production, and 16.2 per cent of renewable energy production [IEA, 2005a].

Most of the installed effect is found in Europe and South- and North America, but Africa, Asia and South America has the largest potential for further expansion. Asia has en economic potential of 3 600 TWh/year, and an expansion of approximately 153 000 MW of new hydropower is being planned. South America has an economic potential of 1 600 TWh/year and Africa's potential is 1 000 TWh/year. It has been calculated that hydropower production will increase by 1.8 per cent annually until 2030, but the share of energy production will remain unchanged at approximately 2 per cent [IEA, 2005b].

In many countries, the driving force behind river system regulation is as much to mitigate the harmful effects of flooding, as well as to support irrigation and water supply protection, as it is to produce electricity.

Challenges to further development of hydropower

Hydropower is a mature technology. No big technological breakthroughs are needed in order to develop it further. The impact on nature and environment is a big challenge for hydropower. Changes in the flow of water can affect animal life and flora, and water reservoirs can occupy large areas of land. More information is found in the section regarding environmental consequences of hydropower.



The world's largest hydropower plant and construction project is Three Gorges in China. The Chang river has been dammed up with a 2.3 km long and 185 metres high dam. When all the turbines are in place in 2009, 26 Francis turbines of 18 700MW in total, will produce as much as 84.7 TWh/year. To give room to the water reservoirs, 13 smaller cities have been moved. In addition to power production, the plant will also prevent the annual flooding along the Chang river which claims the lives thousands of humans each year. The construction started in 1993 and the power plant will be completed in 2009. Illustration: Kim Brantenberg.

The economic risk in hydropower projects can be large, because they are very capital intensive. There is uncertainty with regard to power prices in the future, and the costs of building and producing hydropower vary strongly from power plant to power plant with one of the main variables being the size of the plant. A small generator requires approximately as many people to operate and maintain as a large one. Larger hydropower plants normally have a lower cost per kilowatt. Compared to other sources of electricity, production costs in relation to hydropower are around one third of costs related to fossil power (gas, coal or oil) or nuclear power plants. The main factor for the difference in production cost is the fuel cost for other power production. Plant costs including capital costs for a hydropower plant is similar to nuclear power plants, but somewhat higher than for fossil fuelled plants. But since the "fuel" for hydropower plants is free, the total costs per kilowatt-hour are in most cases lower than for nuclear or fossil fuelled power plants.

Another big challenge is dependency on rainfall and therefore on rain forecasts. A hydropower-dominated power system is vulnerable to large variations in rainfall. The system is therefore very dependent on power transmission integrated with other energy systems.

Most new hydropower plants in the world will be built in developing countries. In developing countries, the big investments and the long repayment period of hydropower could be an even greater challenge than elsewhere. The lack of competence on a local level is often a problem, both when it comes to hydrologic data, project management and especially operation and maintenance.

In densely populated countries people often live in the areas that are dammed. Naturally, it is a big challenge for a hydro project if people have to relocate.

Application areas

Hydropower has several advantages compared to many other sources of electrical energy. Hydropower is a renewable energy source that only to a small degree contributes to air pollution, acid precipitation or greenhouse gas emissions. Hydropower contributes to reduced use of fossil energy sources such as oil, gas or coal. Average CO_2 emissions from the production of the 21 largest power producers in EU-15 were 358 kg CO_2/MWh in 2003 [PWC, 2003]. In comparison, emissions from the production at a typical Norwegian hydropower plant are approximately 0.15 kg CO_2/MWh and 0.7 kg CO_2/MWh in total, including the construction of the power plant [Statkraft, 2002].

Hydropower with storage reservoirs has a high level of reliability. It is simple to control production, and the ability to adjust to load changes. It is a trusted technology with a long working life, high efficiency, and low operation and maintenance costs. Regulation of the river system gives an increased flood control and a possibility to limit the extent of flood damage when the flow of water is high. Regulation can also give other positive effects such as safeguarding flow of water during dry periods.

It is difficult to store large amounts of electrical energy. It has to be produced at the same time as it is used. This physical fact is a challenge for the power supply system. As opposed to most other energy sources, hydropower production with regulation storage reservoirs is very easy to adjust. It makes the hydropower suitable to combine with other energy sources.

This flexibility makes hydropower suitable to be combined with other renewable energy, for example wind power. When there is little wind and the wind power plants are not producing enough, adjustable hydropower production can easily be phased into the supply system.

When there is a lot of wind, water can be held back and the hydropower production is reduced.

TECHNOLOGIES FOR STORAGE RESERVOIRS, DAMS AND WATERWAYS

Water storage reservoirs and dams

In Norway more than 330 large dams have been built at heights of over 15 metres. Norwegian companies have considerable experience and competence in construction, government regulations, reassessment and maintenance of dams.

Water storage reservoirs are established by damming up the natural water level of the sea or water flows with the help of dams. Different technologies are used to achieve such damming up. The most common types of dams are embankment dams and concrete dams.

Embankment dams

An **embankment dam** is built up of earth or stone mass in different zones. The zones consist of different masses and fractions depending on the function they will have in the building. Most common are dams with a tightening core of moraine, concrete or asphalt surrounded by a filter zone of gravel, then a transition zone of fine-blown stone. This is followed by rough-blown stone as support filling, and furthest out there is a circle of stone blocks. Today one emphasizes that the dams should fit in the landscape and become part of the surrounding nature. Dams can vary from small units that can hardly be seen in the terrain to large constructions that dominate the landscape.

Concrete dams

There are a number of different concrete dams. The choice of dam type depends on the topography on the premises. The most common types are gravity dams, plate dams and arch dams.

A **gravity dam**, also called a solid dam, is a concrete dam where stability is secured by the dam's own weight. **Arch dams** are placed in narrow valleys, so that the pressure from the upstream face is transferred through the vault to the rock towards the sides. Plate dams transfer structural weight through pillars.

Storglomvassdammen is the highest filling dam in Norway. Photo: Statkraft.

In Norway there has been built more than 330 large dams (higher than 15 metres). Here the Førresvass dam which is a combined gravity and arch dam. Photo: Statkraft.

Waterways

Waterways lead water from water reservoirs via the inlet to a power station with as little head loss as possible and in the most economically sound way. The waterways can consist of tunnels, canals, or pipes that lead the water between the storage reservoirs to the inlet water reservoirs, followed by a pressure shaft or pipe trench that leads the water to the turbine in the power station, and finally to an outlet. It must be possible to close the waterway with a valve or hatch in the inlet.

Technologies for water turbines

Norwegian companies have much experience in the construction and adjustment of hydropower turbines. Optimization of existing turbine types is ongoing, along with the development of new turbines.

The choice of turbine depends on two factors: Height of fall (head) and the amount of water. The three most common types of turbines are Pelton-, Francis- and Kaplan turbines, but several other variations exist.

The **Pelton turbine** is a tangential flow impulse turbine, where water flows along the tangent to the path of the runner. Nozzles direct forceful streams of water against a series of spoon-shaped buckets mounted around the edge of a wheel. Each bucket reverses the flow of water, leaving it with diminished energy. The resulting impulse spins the turbine. The Pelton turbine is normally used in high-pressure plants with relatively small amounts of water. Pelton turbines are used at heads between 500 and 2 000 metres and a good turbine has an efficiency of 91-93 per cent.

The **Francis turbine** has vanes like the Pelton turbine. Guide vanes direct the water tangentially to the runner. This radial flow acts on the runner vanes, causing the runner to spin. The guide vanes may be adjustable to allow efficient turbine operation for a range of water flow conditions. As the water moves through the runner its spinning radius decreases, further acting on the runner. Francis turbines are the most common water turbine in use today. They operate in a head range of 30-600 metres and a good turbine can have an efficiency of 90-96 per cent.

The Kaplan turbine is a propeller-type water turbine that has adjustable blades that are moved by the flow of water. Kaplan turbines are often used at heads of up to 50 metres and when there are large amounts of water, as in river power plants.

For small power plants, the challenge often lies in finding turbines that have high efficiency at different flows of water, instead of very high top-flow efficiency. This has led to the development of new turbines such

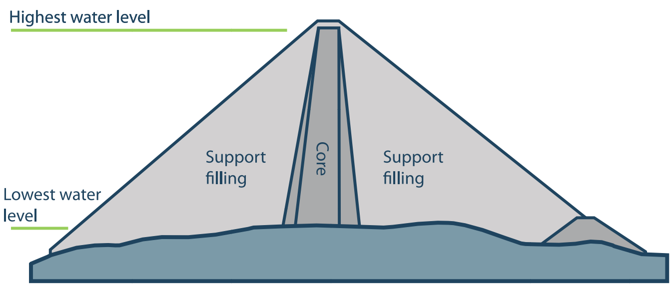


Figure 5-3 Working principle for embankment dam. Illustration: Kim Brantenberg.

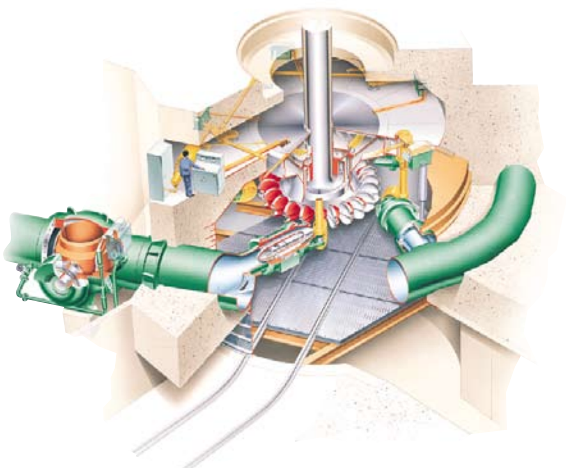


Figure 5-4 Working principle for Pelton turbine. Illustration GE Energy.

as the **Crossflow turbine**. A Crossflow turbine partially overlaps the application area of Kaplan, Francis and the Pelton turbines, but has lower efficiency. It manages great variation in the amount of water and heads of 2 to 100 metres. Crossflow turbines are used in non-regulated, small power plants.

A **plate turbine** has been developed for power plants under 4 MW. This type covers heads between 50 and 240 metres. The plate turbine is a simplified Francis turbine that has been developed in the university and research environment in Trondheim in Norway.

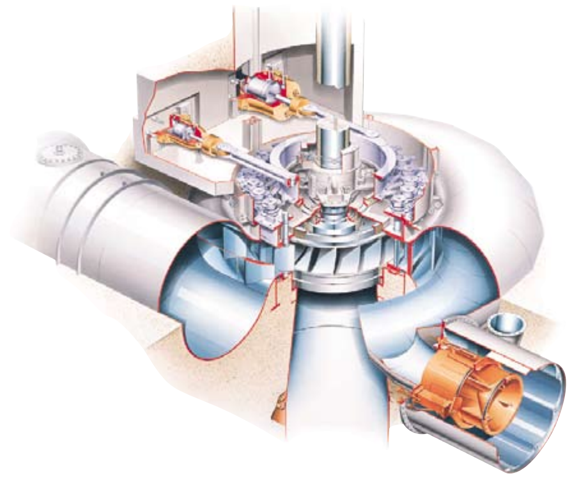


Figure 5-5 Working principle for Francis turbine. Illustration GE Energy.

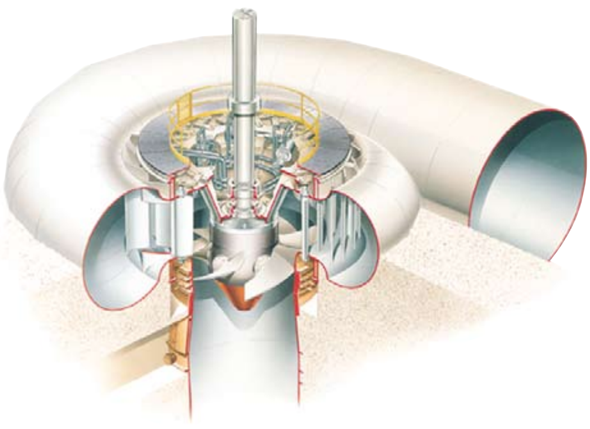


Figure 5-6 Working principle for Kaplan turbine. Illustration GE Energy.

Technologies for the generation of electric power

The turbine's mechanical energy is transferred through a drive shaft to the generator. In the generator, the rotation energy from the turbine is transformed into electrical power. Up to 98.5 per cent of the energy turns into electrical energy.

There are two main types of generators: synchronous generators and asynchronous generators. The most important difference between these is that the synchronous generator is self-magnetizing and can supply an isolated network, while an asynchronous generator (a motor) pulls the necessary reactive effect from the

Plate turbine
The company Small Turbine Partner comes from the university and research environment in Trondheim and delivers its own self-developed turbines for small power plants. The company developed a Francis plate turbine in the power area 500 kW and 4 MW and heads of 50 to 230 metres. Photo: Small Turbine Partner .

grid to be able to produce active energy. Asynchronous machines can not be used in isolated grids, because they depend on receiving magnetizing current from the grid. Asynchronous generators are used in micro- and mini power plants (i.e. up to approximately 1 000 kW) that are connected to the power grid.

In the power plant there is also a transformer. It transforms the voltage up to the level of the grid. In larger power plants there is also switch gear with switches and measuring equipment. Here, the power is distributed on the high-voltage lines out from the power station.

Environmental impact of hydropower

Hydropower is an energy source that makes it possible to produce electricity without using fossil fuels, and is subsequently not part of the emissions caused by electricity production in coal, oil, or gas fired power plants. The environmental consequences of hydropower are related to encroachments upon nature due to damming or lowering of the water level, changed water flow and building of roads and power lines.

Damming of large areas reduces public access to certain areas, and thereby affects outdoor recreation opportunities. Damming areas with rich, biodiverse flora also risks a negative effect on the climate because of large amounts of carbon that are tied to trees and other plants are released when the water reservoirs are filled with water for the first time and these crops rot without the help of oxygen. This leads to the creation of methane. Damming can also affect wildlife nourishment areas and travel routes.

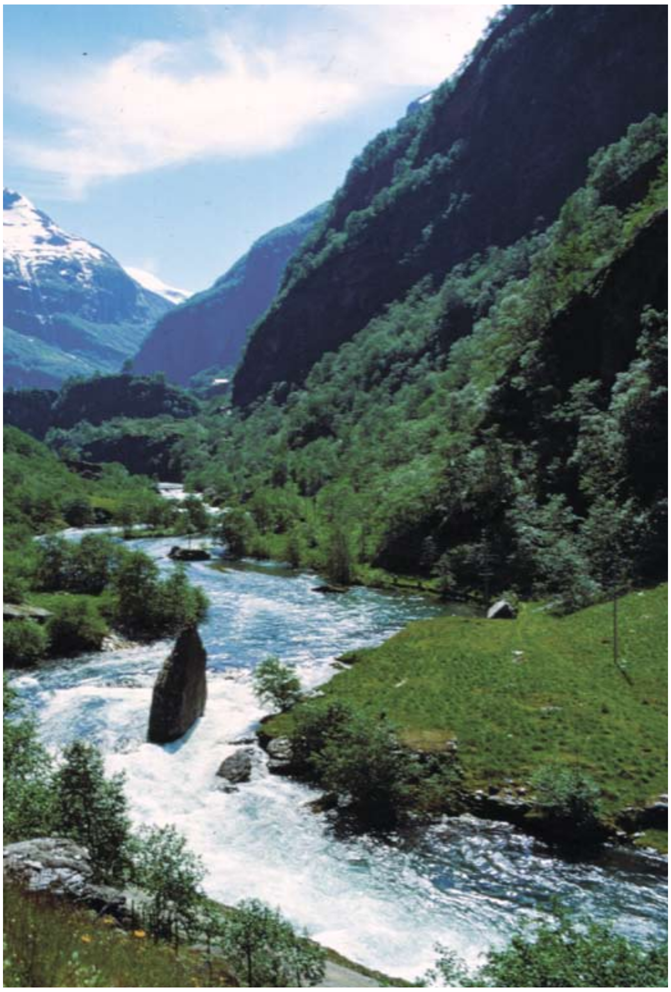
Hydropower often entails changes to the natural variations in the water in a watercourse. River power plants without water storage reservoirs cause relatively small changes to the level and flow of water, and therefore have little effect on biodiversity. In high-pressure power plants with regulation water reservoirs, the impact on biodiversity depends on the regulation height. Changes to the water level throughout the year can lead to scouring of fine substances and nourishment and cause erosion in the regulation zone.

When the power plants are built, there will necessarily be some physical encroachment close to the construction roads, such as the establishment of industrial structures in natural settings. These encroachments can be offset by obliging the constructor to replant the landscape, so that the encroachments will be as gentle and minimally intrusive as possible in the future.

Power lines are alien substances in nature and can ruin natural landscapes. Power lines can affect the bird population, either through collision or by short circuit due to contact. Conversely, when power transmissions are installed as underground cables, digging and blasting of ditches affects hydrology and vegetation.

Hydropower projects affects the water flow in river systems. But it is still possible to have a healthy fish stock in a regulated river system. Many of Norway's best fishing rivers are regulated. Photo :P. Storm-Mathisen.

The affect of regulation on fish and fishing is a complicated interaction between a number of physical and biological factors. The natural habitat of fish is formed by physical circumstances such as water level, water speed and hiding possibilities, and also access to food. Draining would be completely devastating to the fish. The amount of water will also affect the fish in different ways, depending on the age of the fish and the fish species. A number of regulated river systems are still very good fishing rivers.



Modern hydropower projects normally take environmental concerns making the river regulation as gentle as possible on nature. Aurlandsdalen is one of the river systems in Norway with the largest power production. Still thousands of tourists each year walk the Aurlandsdalen trail and enjoy the beautiful scenery of the valley. Photo: E-CO Vannkraft..

Technology development

The first hydropower plants were built in the end of the 19th century, while the large construction era started early in the 20th century. Many of these plants are still fully operational, although most of them are upgraded. Even though hydropower is a mature and reliable technology, it is still subject to development.

Better computer tools have led to a better and more standardized system for monitoring, control and operational simulation. This development is likely to continue. Today, most power plants can be controlled by remote control, something that has led to a dramatic reduction in operating costs. This has been important especially for small power plants, where those responsible for the operation often lack hydropower competence.

The efficiency of the turbines has gone through a development the last years. By using more powerful computer tools for simulation, calculation and three-dimensional hydraulic stream models the efficiency of the Pelton and Francis turbines are improved. Top efficiency can be as high as 97 per cent.

There has also been a considerable improvement in drilling technology. Where previously blasting was used, today it is possible to drill completely straight tunnels, several hundred metres in length, in rock. This has made this type of work more economically sound and possible to put tunnels in places where it was not possible to drill or blast previously. The newer, less-intrusive designs of outside structures are also an environmental advantage.

In the last few years, the possibility of using the hydropower potential in waterworks has been investigated. This can be exploited by replacing pressure reducing valves with mini or micro power plants, using the existing dam and pipe trench to attach to power stations, or by building power plants in combination with new waterworks plants.

Important areas of commitment for further development are:

- To modernize by continuously upgrading aging equipment
- Developing better methods to handle the consequences of disconnection and reducing disconnection periods by shifting ruined equipment more effectively
- Developing better methods for risk assessment and prioritization of investments
- Improving technical changes in new markets related to operation
- Integrating hydropower with other renewable and distributed energy technologies such as wind power and hydrogen [IEA, 2004].

Norwegian hydropower actors

The Norwegian hydropower industry has a long tradition and is still one of the world's largest producers of hydropower. Norway has developed competence that covers all aspects of a hydropower project; from planning and projecting to delivery and installation of hydropower technical equipment. In addition, authorities have developed expertise in regulating and administering hydropower resources through a hundred years of experience.

Norway has utilized approximately 60 per cent of its accessible hydropower potential. Installed capacity in Norwegian hydropower plants is around 28 300 MW, and approximately 620 power plants have an installed capacity over 1 MW. At the end of 2005 the average annual production capacity was about 120 TWh. Most power plants were built before 1990. As a result of shrinking demand in Norway, the Norwegian supplier industry is increasingly looking abroad. In addition to turbines and electromechanical products, the deliverables to other countries include consultant services within planning, projecting and other engineering tasks. There is also an increasing demand for Norwegian competence in system operation and preparation for a power market [OED, 2006].

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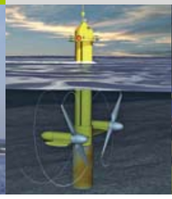



6. OCEAN ENERGY

The ocean is an enormous energy storage that is supplied with energy from sunlight, geothermal sources, the earth's rotation and gravity, in concert with mechanical and hydrothermal processes. There have been many ideas to try to extract some of the energy potential from the ocean through the years. The oldest ones are several hundred years old, and on a global basis there are more than 1 000 patents on different constructions to harness this potential. Only a small number of these have been built and tested. Much research and development remains before wave force and tidal power are competitive with commercial energy sources. Oceanic current, ocean thermal energy and salt power have an even longer way to go.

The ocean contains many times more energy than what one can extract from the oil and gas resources underneath the sea bed. Illustration: Solberg production/Nork Hydro.

Meteorological phenomena in the atmosphere create wind which creates waves on the ocean surface. Wave power has a high energy density, typically 30-40 kW/m along the Norwegian coast. Out in the open sea, energy density can be up to 100 kW/m. Wave power may have the technology closest to a commercial breakthrough of ocean based energy sources.

Tidal power is energy we can extract when the sun and moon's gravity draws and pulls the enormous volumes of water in the sea, causing high tide and falling tide along the coasts all over the world. In particularly favourable places like straits and inlets, large volumes of water can reach high speed and provide energy density in the area of 500 -1 000 W/m^2. A small number of large-scale plants have been built but they are far away from being commercially viable. Tidal power can expect to have a breakthrough during the next decade, possibly around 2010-2015.

Salt power is the exploitation of the salinity difference between sea water and fresh water. Energy density can be 1 MW/m^3 of fresh water. The potential for osmotic energy exists where ever a stream or river enters the ocean. The technology needed to utilize this energy source commercially is still 5 – 15 years away at the earliest [Statkraft].

Ocean thermal energy can be extracted in tropical waters by utilizing the difference in temperature between the warm surface water that typically holds 25 °C and cold oceanic current at a depth of 1 000 metres that holds 5 °C. In the long term, this can give an energy output of 0.04 W/m [Energy, 1992], but a commercial technology will probably not be accessible before 2020.

Oceanic current power has many similarities with tidal power. Here the earth's rotation in interaction with the sun and moon's gravitation and hydrothermal phenomena in certain ocean areas provide access to energy. For example, the Gulf Stream holds a speed of five knots in certain places. This technology can probably not be commercialized until 2020 at the earliest.

Ocean energy resources

According to the International Energy Agency, the potential for total global resources from ocean related energy sources lie at up to 100 000 TWh/year. In comparison, the earth's total energy consumption lies at over 13 000 TWh/year (see chapter 1). However, factors like immature technology, large technological challenges and high costs mean that no commercial ocean based power plant can compete with conventional power production without strong support. Other important shortcomings are value chain functions, infrastructure, legislation and standardization.

Challenges to using ocean energy resources

Considerable R&D efforts and special measures for market introduction are needed in order to establish energy from the sea as a commercial alternative to conventional power production. Such measures can be in the form of special incentives for demonstration projects. Large means may not be needed to achieve this and it could be possible to limit incentives over time. These type of support systems (for example feed-in) have been introduced to re-establish even competition between fossil and renewable energy.

In certain areas ocean energy can be introduced already today. One example is isolated power systems in island communities where the alternatives are small, expensive and not very environmentally friendly, and are based on fossil fuel. Tidal power has in some places been established as pump-fed power stations on a large scale. However, these plants are based on damming up entire river mouths, and the environmental impact is so large that such solutions will not be widespread.

Ocean based energy systems must handle operating in extremely harsh marine environment. The saline ocean water makes the environment very corrosive. At the same time, energy content of as well the waves as tidal current and oceanic current are so high that the mechanical strains would be considerable.

Another challenge is bringing the power to shore. This mainly concerns power from wave powered generators offshore, as well as those near the coast using generators that harness oceanic currents and ocean thermal energy. The greatest challenge is the dynamic part of the high-voltage cables that connect the transformer stations to the shore. The cable must tolerate both the movements in sway and net weight when depth can get up to more than a thousand metres. It is therefore necessary to develop new types of cable solutions.

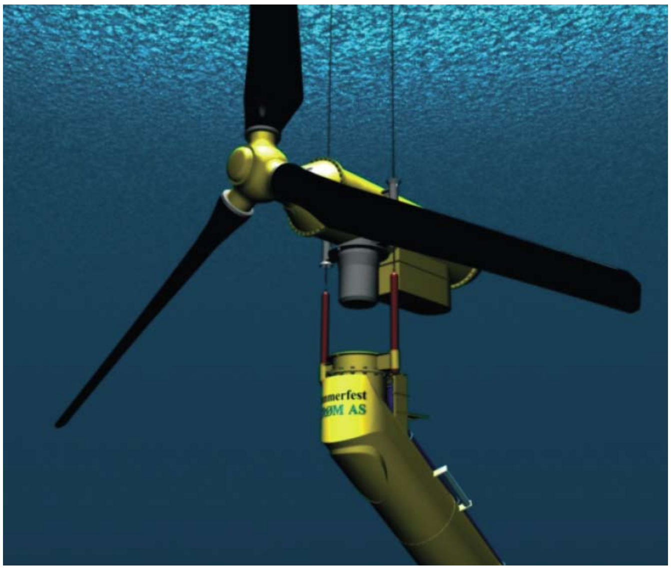


Figure 6-1 Tidal turbine operated by Hammerfest Strøm. Illustration: Hammerfest Strøm AS.

Wave power

The largest wave energy potential is in the Atlantic Ocean and in the Pacific Ocean between 400 and 650 latitude. Here there is approximately 50 to 100 kW per meter breadth of the wave summit (wave front). Close to land, energy density diminishes because the waves are hindered by islands and mainland. In addition to this, energy is lost through friction against the bottom in ground waters. Energy in waves is equally distributed between potential energy (due to water lifted up from the through of the wave up to the wave summit) and kinetic energy (due to the water's changing speed). A number of players have established test- and pilot projects. Some of these have been running for many years without having gone further than the pilot phase.

Areas of application

Ocean waves are a clean and renewable energy source, formed by the reshaping of wind energy when wind blows over the ocean surface. Wind energy in its turn comes from solar energy, because solar heat creates high pressure and low pressure. Energy transport is condensed through both of these energy conversions. Directly under the surface, average wave energy transport is typically five times denser than wind energy transport 20 meters above water and 10-30 times denser than the intensity of sun radiation.

The average values of wave energy transport vary to a certain degree from one year to another. Values vary more strongly between seasons. The level of wave energy (and wind energy) is higher in winter than in summer.

Since there can be waves (swells) even when the wind is calm, wave energy is more stable than wind energy. Most often, wave power must be exploited outside the established infrastructure. Wave power plants can be located offshore, close to shore, or on land.

Offshore plants have by far the largest energy potential and are the least controversial among environmentalists. However, plants require large investments in cables and plants for connecting to the grid ashore. System enlarge-

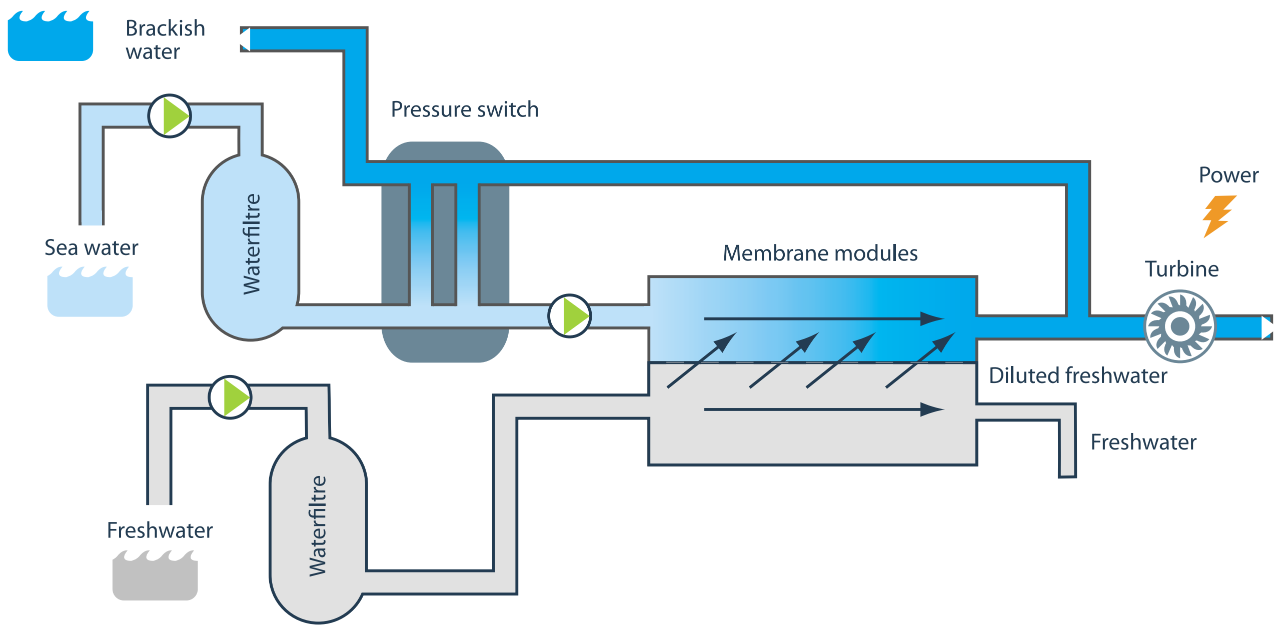


Figure 6-2 Working principle for salt power. Illustration: Endre Barstad.

ments can reduce costs related to grid connection down to an acceptable level.

Plants that are close to the coast can be visible from land, and coastal traffic limits area utilization. Energy density in the waves near the coast is lower compared to further out to sea. However, investment costs in plants that are close to shore are lower than for offshore plants, and access for control and maintenance are simpler.

Wave energy must be transferred to energy in a swinging system that reacts with the waves. The swinging system can be an oscillating water column in a liquid or a stationary chamber. The energy must also be converted to useful mechanical energy with the help of turbines or other hydraulic or pneumatic engines. Finally the energy is converted to electricity through a generator.

A simple and popular concept for exploitation of wave energy is the Oscillating Water Column (OWC). This technology is often used at plants on land. Through continuous changes in the level of liquid, the waves create alternating air pressure inside a chamber that again runs the air turbine. When water rises in the chamber, excess pressure is created. When water sinks again, a vacuum is created. These differentials in pressure drive air currents in and out of the chamber. Wells turbines are suited to utilize this air current, because the turbine turns in the same direction regardless of the direction of the air current.

Another concept with increasing popularity is the point absorber. Here the unit floats in or under the surface, moored to the bottom. A pump is fastened to the mooring line, and the movements of the waves run the pump.

A hybrid plant can pump sea water to a high pressure tank or an elevated reservoir on shore. An aggregate (turbine and generator) can produce electricity by leading water back to sea.

Technology status

Exploitation of wave energy is still in an early stage. Wave energy is competitive in some niches, for example in the operation of navigation buoys, desalinization of sea water and power supply to isolated island communities where they only have expensive electricity from diesel aggregates.

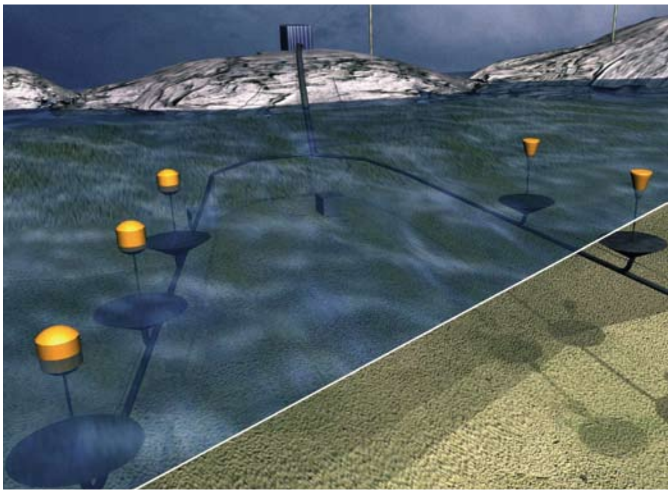
	Resource	Technologies	Estimated global resource	Cost estimate
Wave power	Onshore, Along the coast, offshore	Coastal tidal reservoir, straits	8 000–80 000 TWh/year	99–137 USD/MWh
Tidal power	Coastal tidal reservoir, straits	Propeller, turbines	200 TWh/year	
Ocean currents	Offshore	Turbines, reciprocating wing	800+ TWh/year	56–168 USD/MWh
Salt power	By river mounths in the ocean	Semipermeabel osmotic membrane	2 000 TWh/year	
Ocean thermal power	Offshore deep sea	Thermodynamic Rankine-cyclus	10 000 TWh/year	

Table 6-1 Resources, technologies and cost estimates for Ocean Power technologies. Source: Renewable Energy: R&D Priorities IEA 2006.

Wave power plants are in such an immature phase that it is impossible to give any general cost estimates. These are parameters that must be calculated for each single project. They depend on wave resources, technology lifetime and grid connection. Among the relevant players is Norwegian Fred Olsen (Fobox) who has expressed a goal to bring down the price to 2.7 c€/kWh. However, they have expressed that there is a long way to go before they reach this. Australian Energtech believes that power from the first plants will cost approximately 7 c€/kWh, and in the long term, their goal is to bring the price down to 2.9 c€/kWh.

A number of plants with basis in Norwegian technology and Norwegian companies are being planned and constructed:

Norwegian Pelagic Power bases their technology on a variant of the wave pump technology. Several pumps will be moored to the seabed, and floaters will run the pumps. The units will pump the sea water to a central turbine and generator that produces electric power. The plant will be built in a simple way and with economical materials, and the company will concentrate on low production costs rather than high efficiency. Pelagic Power will install a 1:3 pilot installation in 2007, and plans a full-scale installation in 2009.



The Norwegian company Pelagic Power concentrate on low production costs rather than high efficiency. Illustration: Pelagic Power.

FO^3 is the Norwegian wave power project that has come the furthest. The ship owner and investor Fred Olsen, who is behind the company Fobox AS, financed the project. They have an installation outside Jomfruland, in the outer parts of the Oslo fjord, which is the laboratory platform "Buldra", built in the scale of 1:3. The wave-powered generator here is integrated in a floating platform construction, which is built in composite. Under the platform there are a series of plastic bridging boats that move with the waves. The bridging boats run a hydraulic system that again generates electric energy. The full-scale platforms will be 36 metres wide and 18 metres high. They will be placed together with common monitoring and control systems and common connection to the distribution grid on shore through a deep-sea cable. Installed output from the plant is planned to be 1,5 MW per platform. The platforms will be unmanned and have an expected service life of minimum 15 years.

Wave Energy AS is another Norwegian company that has developed a wave power concept with background in the oil industry. The wave-powered generator is built

The "Buldra" platform is one of the Norwegian wave power projects that have come the furthest. Photo: Fobox AS.

over an incline with several floors where the principle is to let water from three different basins run a number of impellers on the same shaft. In this way, waves on all levels are exploited. Technology will prevent start and stop sequences for the turbine, even though water is only added to the impeller on one level. This increases supply stability of electricity and the generator's service life. Tests carried out at the University of Aalborg show that a wave power plant can exploit 50 per cent of the wave's energy. Wave Energy AS has bought the patent "Seawave Slot-cone Generator" (SSG) which has the advantage that the water energy is held in a number of reservoirs, one above the other. This increases the hydraulic effect.

The company has also developed the technology "Multi-stage turbine" (MST), which uses different heights of waterfalls on the same turbine wheel. The concept can be used in the area close to the sea as well as in floating devices. Wave energy is planning a full-scale prototype generator at Kvitsøy in Rogaland, and the project has received financial support from the EU.

In 2007 Ocean Power Delivery Ltd. (OPD) will establish the commercial wave-powered generator Pelamis off the coast of Northern Portugal. The project has had prototype testing and try-out at the Orkney Islands. The full-scale project will have a total installed output of 2.25 MW. If the project is successful, OPD plans to add 30 more production units, with a total output of approximately 20 MW. Pelamis WEC (Wave Energy Converter) consists of two cylindrical steel sections that are hinged together. This gives it a "worm-like" structure that floats semi-submersed in the sea. When Pelamis is exposed to waves, the sections move in relation to one another. These movements run hydraulic pistons on the vertical as well as the horizontal level. The pistons pump liquid with high pressure through accumulators through hydraulic motors, which again run generators. The Pelamis-units are moored in a way that they can be adjusted to all types of waves. The depth during construction is 50-60 metres, and the distance to shore is 5-10 kilometres. This makes it possible to exploit the energy in the swells, unaffected by the seabed. The electric power is transferred to shore in cables through the seabed. Pelamis can utilize a large spectrum of wave heights and frequencies. At the same time, the plant will adjust to very large waves by reducing production. The construction will be 120 metres long and 3.5 metres in diameter. The company is partly owned by Norsk Hydro.

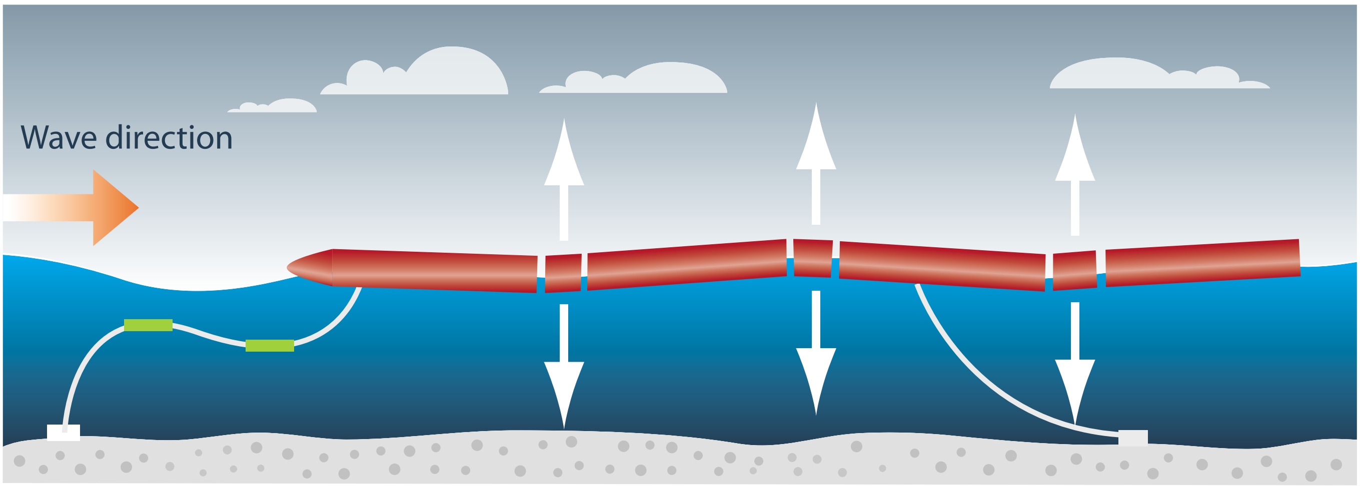


Figure 6-3 The worm-like structure called Pelamis WEC (Wave Energy Converter) consists of cylindrical steel sections that are hinged together. Illustration: Endre Barstad.

Tidal power

Tidal differences are due to gravitational forces from the sun and the moon. During a tidal difference, the sea level will rise or fall depending on what part of the earth is facing the moon. By this phenomenon waves are created. Due to earth's rotation, these waves move west with a wave height of less than 1 metre and a period of 12 hours and 25 minutes, which is the time between high and low tide. The sun and the moon phases result in 14 day periods with maximum and minimum in tidal differences. Topographic conditions make tidal differences larger or smaller than the wave height of 1 metre. In addition, variations of high pressure and low pressure together with an influence of wind direction can lead to considerable deviations to the tidal difference.

The global potential is estimated by IEA to 200 TWh/year, while the Norwegian company Hammerfest Strøm believes there is a global potential of 450 TWh/year. However, Canadian experts believe that as much as 3 000 TWh/year can be extracted along the world's coastlines.

Areas of application

Despite the fact that tidal water is rarely used as an energy resource, several significant plants have been established. The largest and most important one is the pump power plant at the mouth piece of the Rance River in Northern France. It was completed in 1966 and consists of a 330 metre long rock-fill dam where 24 turbines, each at 10 MW, have been installed in the dam itself. The Rance power plant is in reality a pumped-storage power plant that can hold water back at high and low tide and produce power when prices are best during low tide period. However, this power plant has a large environmental impact, since it encloses large amounts of water, sediment, and other material that naturally would float with the river flow out into the sea. As a result of this effect very few of these "barrier-power plants" will be built in the future.

The Norwegian company Hammerfest Strøm is one of the companies that have come the furthest in the development of tidal technology. In 2002 they installed a 300 kW turbine (propeller) at the bottom of Kvalsundet outside Hammerfest. The nacelle (the turbine shell) of

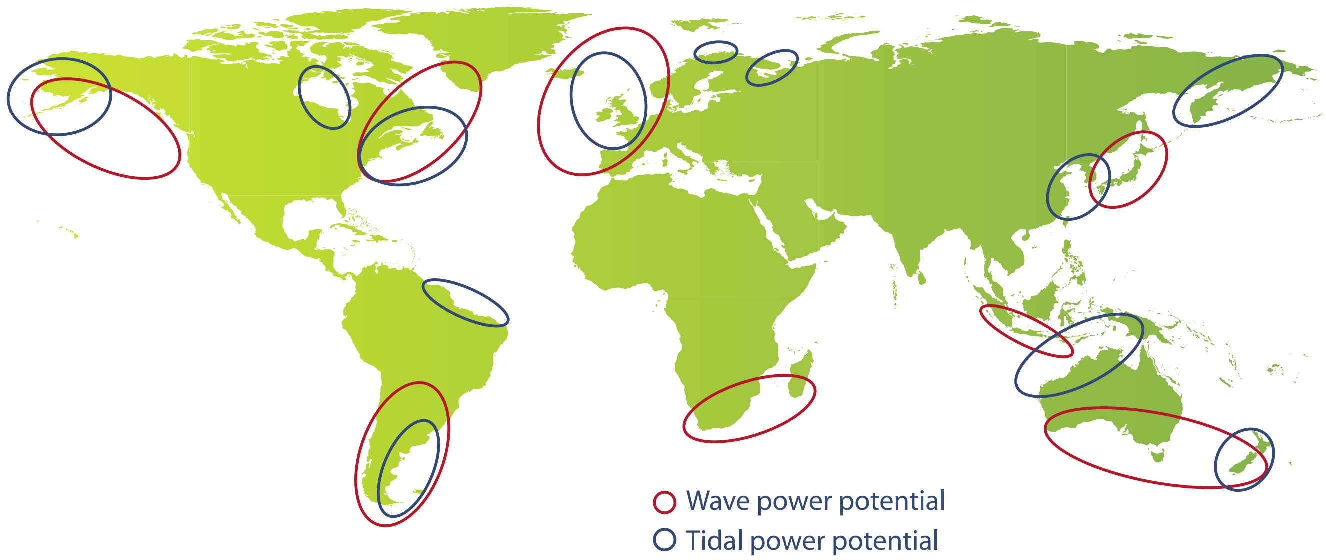
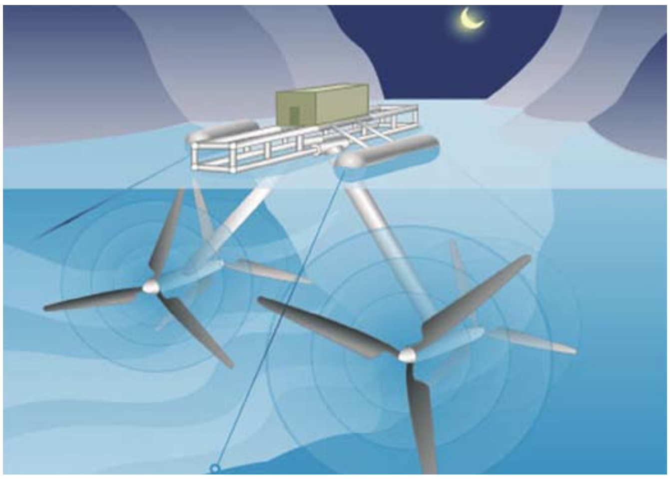


Figure 6-4 Tides and waves can provide us with enormous amounts of renewable energy worldwide. Source: Renewable Energy: R&D Priorities IEA 2006/red. Illustration: Endre Barstad.

this turbine is 50 metres under water, and the propeller diameter is 22 metres. The pilot project ended in 2006, and the company reported that the project period proceeded without stops or problems of serious nature. The aim is to have a production cost of about 3.5 c€/kWh. During winter of 2007, management will work to find financial partners that can support commercialization of their technology.



Statkraft is planning to install a tidal power plant outside Tromsø in the Northern part of Norway. Illustration: Statkraft.

Hammersfest Strøm's technology is based on a horizontal axle propeller, similar to a wind turbine. Since tidal water has a fixed, predictable behaviour, the turbine does not need to be as flexible as a wind turbine. Most tidal technologies that are being projected and tested out are in the same category. Hammerfest Strøm chose not to use a one-legged tower on an early stage, and instead chose a three-legged structure.

Both the physical and output related size of a tidal turbine have other limitations than a wind turbine. Oceanic currents have swirls that can lead to large mills being destroyed because different power is used on each wing. Due to the strong force in the onrush of water, the rotors of the tidal turbines must tolerate greater weight than wind turbines. The output of a tidal turbine depends not only on the power in the flood tide, depth of the inlet also plays a role. The rotor wings must be located deeply enough not to come into conflict with surface traffic. Rotor speed can come up to 20 rpm, i.e. approximately three seconds per turn. This gives a speed of around 80 km/h on the tip of the rotor blade. This is a danger not only to surface traffic, marine life, like fish

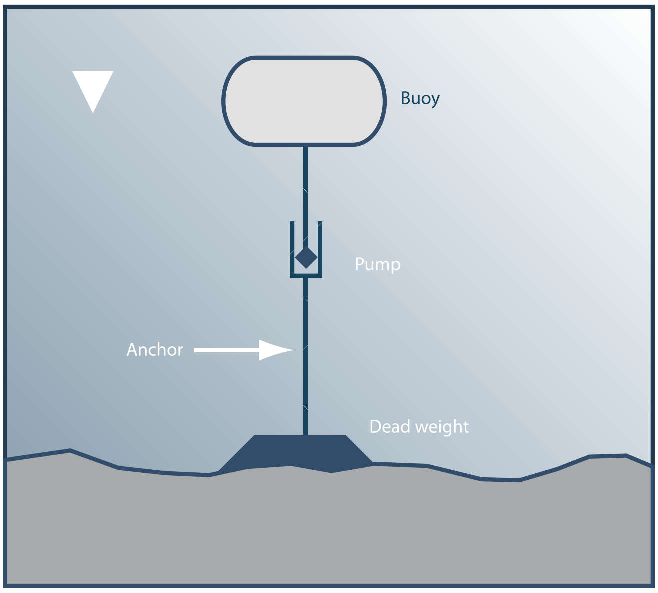


Figure 6-5 Wave pump. Illustration: Endre Barstad.

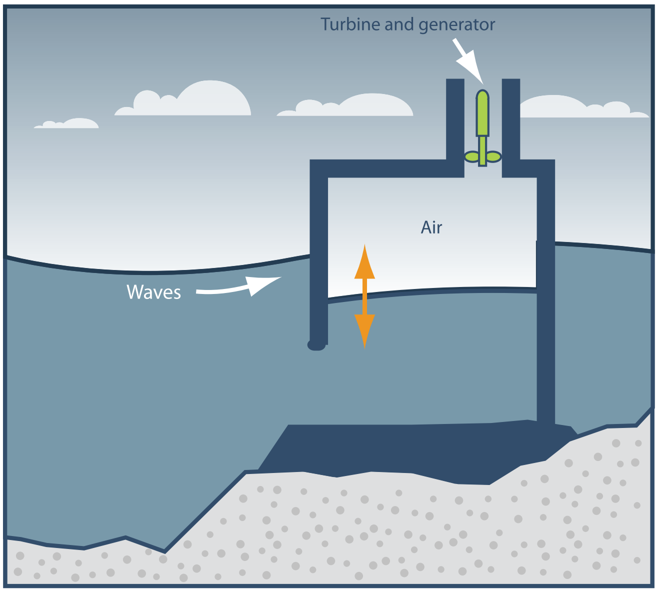


Figure 6-6 Swinging water column. Illustration: Endre Barstad.

and molluscs, are also vulnerable. However, no negative effects on marine life have been reported after several years of experimental operation in Kvalsundet. [NINA, 2006].

The pilot turbine in Kvalsundet produced power virtually continuously for several years. The only interruptions to production were to clean the rotor wings.

Also the Norwegian company Statkraft has plans to develop a tidal project outside Tromsø through the company Hydra Tidal Energy Technology (HTET). Their concept is based on a floating, moored steel structure and produces electric power by flood tide running several large turbines. Turbines and generators will be below the water surface, but can easily be brought up to the surface for maintenance. Since the tidal power plant floats on the water, there are no large permanent encroachments upon the seabed, and the project will then have limited environmental impact. The entire plant with the corresponding anchor can easily be moved or removed. The prototype's turbines are counter-rotating propellers with three blades, with a propeller diameter of 22 metre. Nominal output per floating unit will be approximately 1 MW. They will be able to produce approximately 3.6 GWh/year.

Salt power

Salt power is based on the chemical phenomenon that saline solutions attract fresh water from their surroundings. This is called osmotic power. Even though the phenomenon has been known for hundreds of years and the potential in river mouths around the world is large in the ocean is large, little has been done to develop technologies for this energy source. The power potential is proportional to the difference in salt concentration between salt water and fresh water. Theoretically, each cubic metre of fresh water that flows out into the ocean can generate 0.7 kWh of electricity.

A number of technologies to exploit salt gradients exist. Pressure retarded osmosis is in 2006 the most promising one, but in international environments vapour compression and reversible dialysis are being examined. Pressure related osmosis is based on establishing a fresh water reservoir and a salt water reservoir at river mouths, where a semi-permeable membrane divides the two reservoirs. The membrane prevents salt water from mixing with fresh water, but lets the fresh water through to the salt water reservoir. The salinity gradient will make the elevation head in the salt water reservoir increase. This elevation head can be exploited by letting out water through a turbine, as a regular hydro power plant.

In 2006, no one has developed a semi-permeable membrane with sufficient efficiency, strength and durability to be able to carry out a pilot test. But several players have carried out model tests that confirm that the theory works in practice.

The salt power plants are flexible with regard to location and shaping. Process plants are of limited size, can be adjusted to local surroundings and be built in rock or beneath the ground. The investment costs can be limited by combining process plants with existing power stations and other infrastructure.

The Norwegian company Statkraft is behind the project that has come the furthest on an international level. Working with SINTEF they have carried out an extensive research project, where they among other things have installed small-scale salt power plants in the seashore at Sunndalsøra and in SINTEF's laboratories in Trondheim. Statkraft has expressed that they hope to achieve membranes with sufficient performance by around 2010-2015.

Ocean thermal energy

The sun heats up the ocean. This energy creates a temperature difference between water on different depths. In tropical and subtropical waters, temperature near the surface can be 20-25 °C higher than at 1 000 metres depth. This temperature difference can be used to produce electric power. The international term is Ocean Thermal Energy Conversion (OTEC). To achieve an acceptable efficiency, temperature differences of 20°C or more are needed on a yearly basis. These conditions are found in tropical and subtropical regions.

The high heating capacity of the water and the enormous volumes of water provide ocean thermal energy with theoretically very large potential. However, the temperature differences are so small that efficiency from power production is low.

Exploitation of ocean thermal energy is far from a commercial breakthrough, and it will probably be a long time before we can see profitable projects.

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7. GEOTHERMAL ENERGY

Geothermal energy is heat energy from the earth's interior. This is a substantial energy resource. It originates from heat energy stored in the earth's core and mantle, coming from a continuous supply of heat energy from the splitting of radioactive elements in the earth's crust. The temperature difference leads to a continuous heat flow from the earth's interior to the surface.

Temperature increases approximately 25-30 °C per kilometre from the earth's surface towards the centre, but in areas with favourable geological conditions this increase (gradient) can be up to ten times higher. The area of application and soil conditions will determine how deep it is necessary to go to extract heat energy.

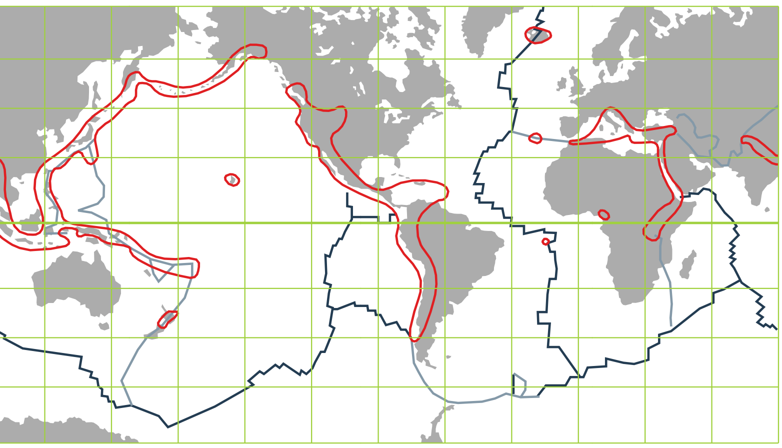

Figure 7-1 The most important geothermal zones and borders between the shelves that earth's crust is made of. Illustration: Kim Brantenberg.

Geothermal sources that have well flow temperatures over 175 °C, can be exploited directly in a turbine in order to produce electric power. Binary technology, where the well flow is heat exchanged with a medium with a lower boiling point, makes power production possible for well flows down to approximately 100 °C. Energy wells with temperatures over 40°C can be exploited directly for heating purposes.

The exploitation of low-temperature thermal energy from the ground is called background heating. In this case, the energy comes from the earth's interior as well as from the sun through the earth's surface. If the energy source holds a lower temperature than needed, it is possible to use a heat pump to increase the temperature in order to utilize the energy, for example for heating purposes or process heating. It is also possible to use such installations for cooling. Profitability for such installations increases with balanced heating and cooling demands. For background heating, energy wells in mountains especially with depths down to 200 metres have increasing importance to economy and energy.

The utilization of waste heat uses the same technical solutions as geothermal energy in principle, but the energy originates from a waste heat source instead of coming from energy wells. For example, this can be cooling water from process industry, exhaust air or sewage Waste heat potential is therefore briefly discussed in this chapter.

Resource basis

Geothermal energy is heat that originates from earth's interior. This heat mainly have two sources:

- The original heat from the time when the earth was created
- The energy that is released from the ongoing radioactive decomposition in the earth's crust

Researchers are continuously working with measurements, models and experiments that improve the estimates for the geothermal energy resource. An article in the journal Nature indicates that 31 TW is a likely amount of the total heating effect emitted by earth [Araki et al, 2005]. Approximately one third of this heat flow comes from the original heat in the earth's core and mantle. Two thirds originate from radioactivity in the earth's crest.

A geothermal resource is characterized by the reservoir's temperature, pressure, chemical compound and capacity. Well flow temperature is particularly relevant to the application of the resource with regard to the value. High temperatures have most application areas and are considered the most high-grade.

There are large discrepancies in the estimates for the potential exploitation of the earth's geothermal resources. IGA (International Geothermal Association) uses the term "useful accessible resource base", which is the part of the resource that can be utilized legally and economically within a period of 100 years. In their Internet portal for geothermal energy (www.iea-gia.org), IEA makes reference to an estimate for the world's total geothermal resource potential accessible for future development of 42 PWh (150 EJ) of electric power production per year and 350 EJ of heat production per year. The estimate is uncertain, and the actual development depends on an array of technical, economical and political factors.

Challenges to using the resource

Investment costs associated with utilizing geothermal energy and background heating are relatively high while operating costs are fairly low for an efficient plant. If a

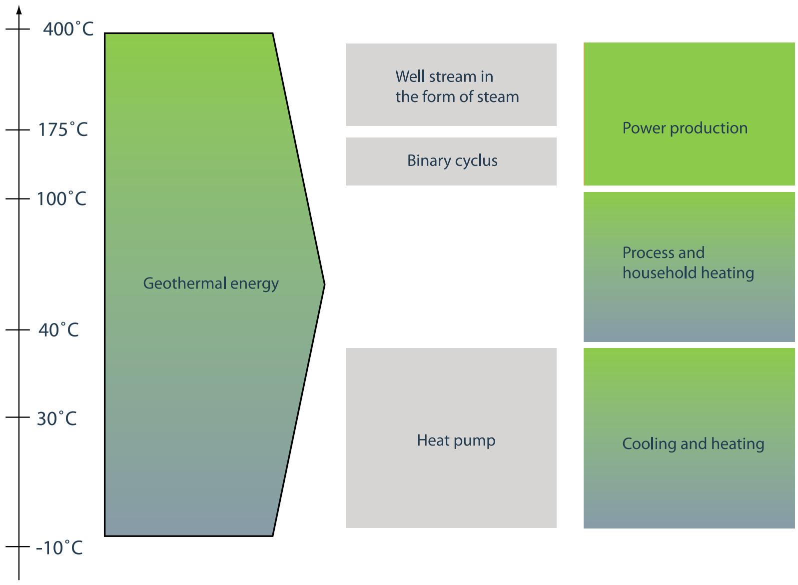

Figure 7-2 Different temperature areas for geothermal energy and the most relevant areas of application. Illustration: Endre Barstad.

building will use geothermal energy for heating purposes it must also have a water borne heat infrastructure.

Projects for the utilization of high-temperature geothermal energy for electricity production involve a high level of economic risk. Costly and time consuming research and experimental drilling must be carried out to know if the geothermal resource is profitable.

Though background heating projects require a high level of knowledge about ground conditions, they are much less complex. Through the access to increasingly better information and improved methods for research, they represent a considerably lower risk.

Under otherwise equal conditions, the energy resource cost will increase with the temperature that is to be delivered. Correspondingly, an energy resource with lower temperatures will lead to higher equipment and operating costs.

AREAS OF APPLICATION, VALUE CHAINS, TECHNOLOGIES AND MARKET

The most obvious application of geothermal energy and background heating with heat pumps is for heating and cooling purposes. On a global scale, the total installed output is 27 825 MW thermal output and the total production in 2005 was 261 400 TJ (or 73 TWh) [Lund et al, 2005]. Geothermal energy sources with temperatures over 90-100 °C can be utilized for power production. In 2005, the total installed electric output on a global basis was 8 902 MW [IEA, 2006].

Heat pumps based on background heat can be used all over the world, and this is the geothermal energy utilization that has grown the most on a global scale.

High-temperature geothermal energy

Since it is impractical to transport heat over long distances, the resource must be exploited where it is. As an alternative, it can be used for producing electric power that can be transported over long distances. The development of geothermal fields requires extensive feasibility studies in order to evaluate field profitability. Experimental drilling well tests represent a considerable share of the total project cost, and this cost accumulates before it is certain if the project can be carried out. Field development including well drilling represents the highest cost and therefore can limit progress. According to IEA, a 50 MW plant for electric power production can cost up to 150 million US dollars and take ten years to build. The advancement of existing fields entails considerably less risk and is much less expensive.

The extent to which geothermal power production is developed is determined to be high in regions with particularly good conditions which generally have a short distance to high temperature reservoirs. Countries with commercial power production from geothermal energy are the U.S. (2 020 MW), the Philippines (1 931 MW), Mexico (953 MW), Indonesia (807 MW),

Figure 7-3 Some places hot water comes up to the surface of the earth, for instance on Iceland. Photo: Unknown.

Italy (790 MW), Japan (560 MW), New Zealand (421 MW) and Iceland (202 MW).

The most high-grade geothermal resources are wells that produce dry steam. Steam in these wells can run a standard steam turbine with a generator. Other pressure and temperature conditions in the well require the treatment of the well flow before it can run a turbine.

Lower temperature sources (approximately 100 °C) can be utilized with the help of a binary cycle. The heat from the well is transferred to a liquid with a boiling point so low that is will go over to a gas phase and run the turbine. A binary cycle is a more complex solution, but it is expected that it will be used in most future projects since the majority of the geothermal fields have temperatures below 175 °C. In addition, the well flow is run in a closed circuit without emissions to air.

Electric connection to existing grid is normally made part of the initial cost. However, in developing countries there are examples of smaller geothermal power stations being built as a more economic alternative to building new power lines.

Geothermal power production has a constant production pattern. Since it has a low electric efficiency, power production is most effective if the residual heat can be used for heating purposes. This gives a fluctuating increase of thermal efficiency.

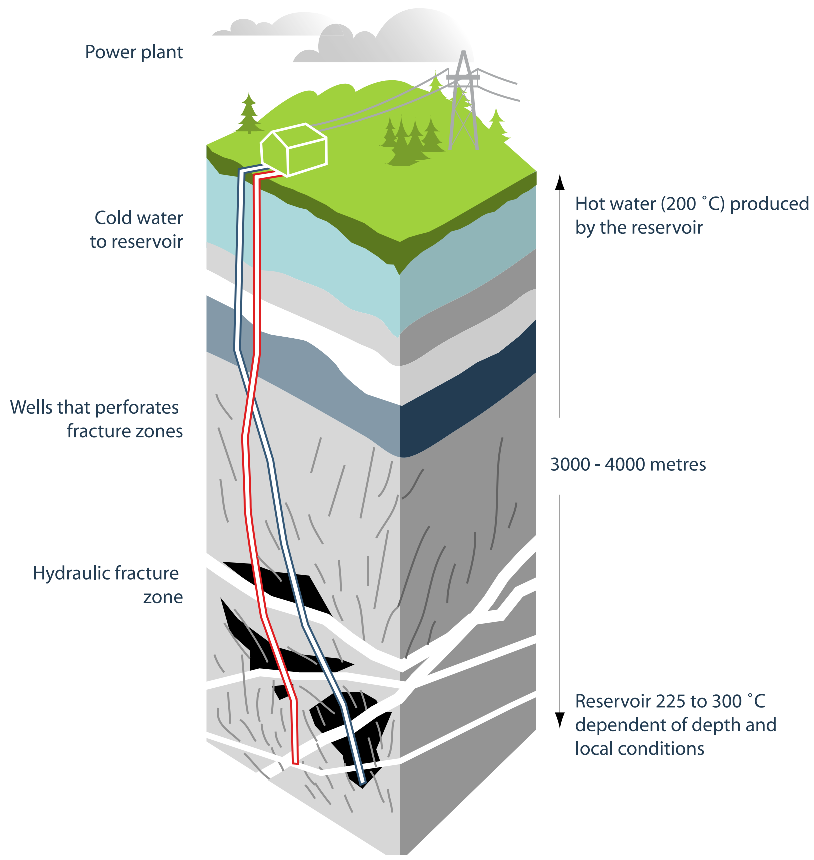

Figure 7-4 Working principle for Hot Dry Rock concept. Illustration: Endre Barstad.

The use of high temperature sources for heating and process heating is the oldest application of geothermal energy. The total installed output on a global basis is 12 103 MW thermal power, and the total production in 2005 was 174 744 TJ (49 TWh) [Lund et al., 2005]. The largest application areas were bathing facilities followed by space and district heating, greenhouse, aquaculture and industry.

Since it is expensive to build infrastructure for heat transport, thermal energy consumption per surface unit is a deciding factor for the economy of a project.

Geothermal energy sources can be used for heat production when they are located near energy intensive industries or relatively densely populated areas. In Iceland, 87 per cent of the buildings are heated using geothermal energy as district heating. In addition to heating, it is possible to use high-temperature geothermal energy to run absorption heat pumps for cooling.

Technology status, costs, markets and trends
Technologies for the utilization of geothermal energy have become established and mature. Costs related to the utilization of high-temperature geothermal energy are to a large degree determined by the qualities of the local reservoir, and it is difficult to make general predictions regarding cost development. Continuous improvements, standardization of smaller plants and taking advantage of business incentives for larger plants are expected to give future cost reductions.

Large plants are principally built in areas with the possibility of establishing infrastructure for the distribution of energy, and small standardized plants are usually built in more isolated areas.

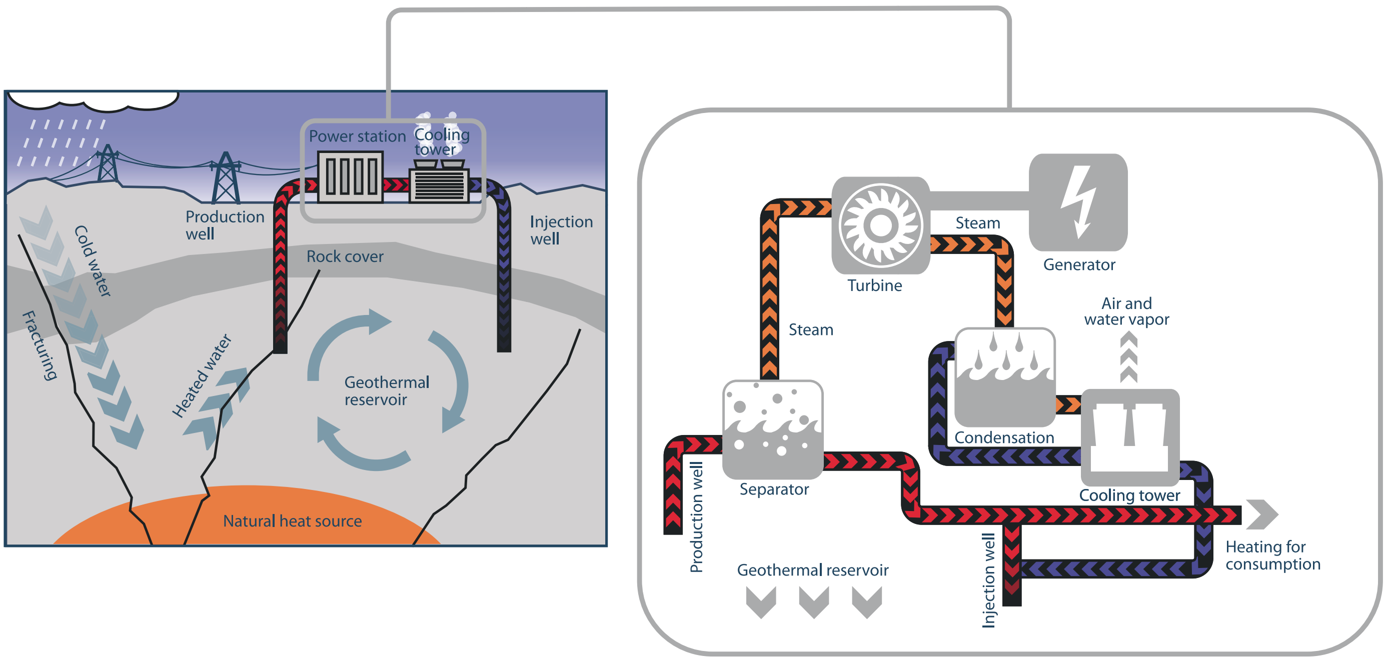

Figure 7-5 Working principle for a geothermal power plant. Illustration: Kim Brantenberg.

Low-temperature geothermal energy and waste heat

Background heat is the utilization of low temperature energy in the ground, found in higher earth strata, in ground water or in bore holes in the rock. Energy is extracted at low temperatures and is upgraded to higher temperatures with the help of heat pumps. This can be carried out through pumping of ground water in open systems or closed systems, where an antifreeze solution circulates in a closed circuit between the heat source and the heat pump's evaporator. The plants can also be built to supply cooling demands. Energy is then led back into the ground which is used as energy storage for heating at a later stage or in another place.

The size of these plants can range from a simple single energy well for space heating of a house, and can become as elaborate as having combined heating and cooling plants with hundreds of energy wells. The largest plants can cover the heating and cooling needs for industrial parks or hospital complexes; alternatively it can provide the end-users through a district heating and cooling network.

Many forms of waste heat are suitable sources for heat pumps, since they often hold an even and relatively high temperature. New heat pump technology allows gradual temperature increase of up to 100 °C, which is sufficient for a number of industrial processes.

Heat pumps based on background heat is the geothermal application that has experienced the strongest growth on a global basis with an increase from 5 275 MW of total installed thermal power in 2000 to 15 723 MW in 2005.

Background heating can be utilized all over the world, as opposed to high temperature geothermal energy that with today's technology is only practically accessible in the fringe ranges between the nine shelves that earth's

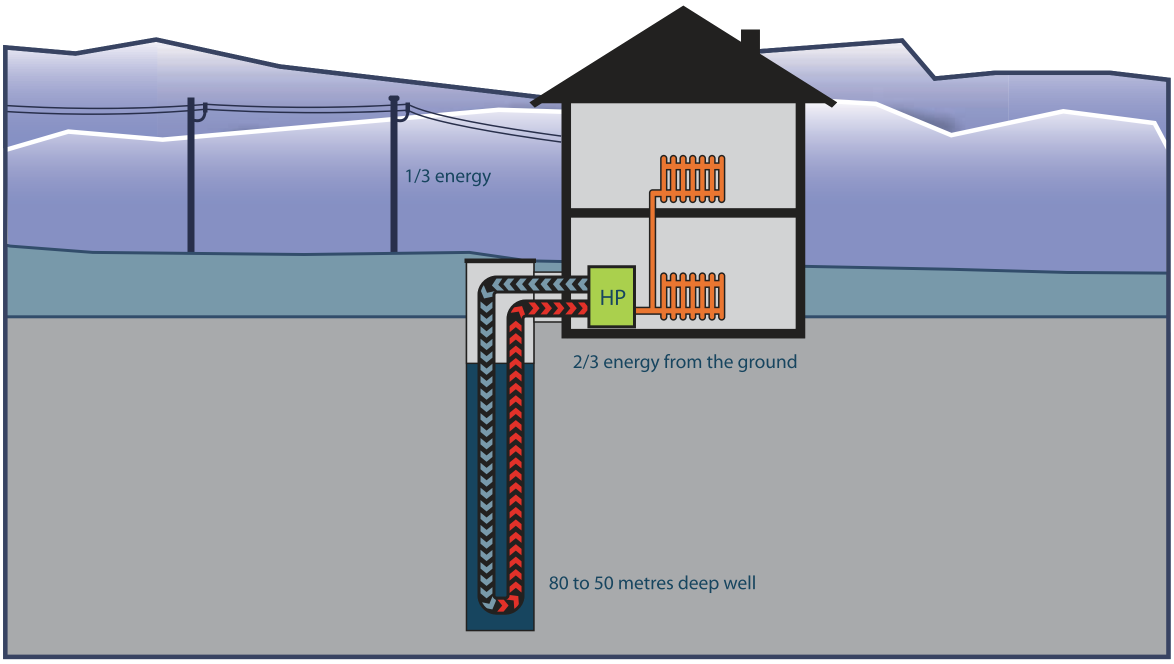

Figure 7-6 Ordinary heat pump arrangement for domestic use (closed circuit). Illustration: Kim Brantenberg.

crest is made of. Background heating technology can be considered as mature in the sense that accessible products as well as knowledge and services are sufficient for large-scale commercial use. Research, development and increasing practical experience contribute to continuous improvements.

Energy wells are used as energy storages if there is also a cooling demand. In this case, heat is led back to the well through cooling.

A background heating plant will in many cases cover entire cooling demand or parts of it in buildings with free cooling. Free cooling implies that the low energy in the energy well or ground water is heat exchanged with the cooling plant in the building without having to use the heat pump as a cooling machine, and the need for added electric energy is therefore minimal.

Energy wells represent approximately 20-40 per cent of the total investment. The specific initial cost for the energy wells is almost independent of capacity, while a larger heat pump gives a higher output capacity per invested amount of money. Larger plants have shown good profitability without public investment aid.

Environmental impact

Geothermal energy, background heating and waste heat are ecologically sound energy sources. Utilization of background heating and waste heat in most countries is a non-emission alternative to use of fossil fuels.

Some examples of environmental impact:

- The heat pump's working medium. Traditionally, chlorofluorocarbons have been used. These have a disruptive effect on the ozone layer and strong greenhouse effect. The hydrofluorocarbons that are currently used do not harm the ozone layer, but still contribute to the greenhouse effect. This has created an increasing interest for the use of natural gases such as ammonia, CO_2 and hydrocarbons.
- The working medium of the common collector circuit. Due to a certain risk of leakage to ground water, glycol has been replaced with denaturized alcohol and biologically decomposable potassium salts. Pilot installations with CO_2 in Germany have been a success.
- Thermal pollution. Temperature increase through the return of cooling water can affect flora and fauna.
- Emptying of ground water reservoirs through pumping of ground water without re-injection.
- Hydrothermal liquid/steam from geothermal reservoirs can have a chemical content that pollutes through direct emissions to the ground or air.

Products and services in the value chain

The life cycle of geothermal projects can be determined through a pre-study with a survey of energy needs and consumer profile, choice of solutions, localization and dimensioning of wells, dimensioning of the energy central, installation and start-up, operation and maintenance.

Unproblematic operations and profitable economy depend on good products and professional services. Design and optimization of larger plants require high competence. This particularly concerns plants where the rock is used as thermal energy storage – that is, where the rock is a heat source during winter and heat outlet (cooling) during spring, summer and autumn.

Technology for different uses of geothermal energy and waste heat is well established. There are no serious obstacles to further expansion. Commercial installations are numerous, and they are increasing in number.

Norway's SINTEF Energy Research is one of the participants in IEA's heat pump program that works on reducing technical and market-related barriers for increased application of heat pumps for background heating. Emphasis is given to the importance of interdisciplinary cooperation and the need to optimize quality throughout the system's lifetime to achieve good profitability.

Norwegian players

An increased interest for energy recycling and heat production from background heating, stimulated by public subsidy schemes and not least an array of successful projects, constantly attracts new players to this market. This secures access to professional services and products.

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8. TECHNOLOGIES FOR RENEWABLE ENERGY

Integration of renewable energy sources in the energy system is a challenge. In many cases this integration requires additional technologies for the system to work acceptably. This chapter discusses some technologies that can be important in order to achieve a successful integration of renewable energy sources. Some of the technologies that are discussed have received much attention in later years. These have been given broader attention in this chapter. This particularly applies to hydrogen, fuel cells and heat pumps.

Renewable energy sources can be difficult to control. They are based on weather related phenomena, such as wind, sun and rain. To adjust energy production to consumption, it can therefore be necessary to store energy for short or long periods of time.
General summation points:

- Pumped hydro storage is the most effective and most used technology to store energy.
- Compressed air can store large amounts of energy.
- Flywheels, batteries and super capacitors have considerably lower capacity than pumped hydro storage power stations and compressed air.
- Heat pumps can be used to store thermal energy in the ground.
- Heated water or melted salt are other good thermal energy storages.

Hydrogen is an energy carrier that can be produced from all types of energy sources with the help of water electrolysis, or through gasification or chemical reforming of hydrocarbons. Hydrogen is a clean energy carrier if it is produced from renewable energy. Therefore, making hydrogen is an alternative to storing and consuming energy from a renewable energy source, but production and storage of hydrogen is very expensive and technically immature. The efficiency for this energy chain is also relatively low. When hydrogen is used to produce electricity in fuel cells the only emission is water. Security of supply is another important factor which favors extended use of hydrogen.

Fuel cells can produce electricity more efficient than gas turbines, petrol engines and other heat engines. A fuel cell is built according to the same principles as a battery. There are several types of fuel cells suitable for different areas of application and fuel types. Some are suitable in mobile phones and cars, while others are better suited for stationary power production.

Heat pumps work as "reverse refrigerators". They are employed to increase the temperature of a heat source, for example outdoor air or sea water. Heat pumps contribute to effective utilization compared to direct electric heating, but heat pumps can also be used for combined heating and cooling in the food production industry.

Two-way communication between energy seller and energy consumer (Automatic Meter Management – AMM) can improve the utilization of the energy resources. At present, AMM is mostly used for measuring energy consumption.

Energy storage

Energy demand varies on many time scales; from hour to hour, day to day and season to season. Most renewable energy sources have production that is difficult to adjust to consumption. When there is much wind, there is not always a need for all the energy from the wind turbines, and when the wind calms there may be too little energy to meet demand. In the same way, many buildings have a need for cooling in the summer while during the winter there is a need for heating. Thus, it is often wise to implement energy storage in systems with a large share of renewable energy.

In some places, limitations to transmission capacity in the grid demonstrate a need for local storage solutions to optimize grid capacity. This way, the grid owner avoids a costly upgrading of the transmission lines. A storage solution can encourage local production. In this case transmission of electricity to the main grid is possible, and at the same time grid expansion is avoided. In island communities this is a relevant topic for discussion, and a good example of one such case is the island Utsira in Norway. In a demonstration project at Utsira, electricity from wind is produced, and electricity is stored as hydrogen when the production is higher than the consumption. In the case of too little wind, hydrogen is used for electricity production, so that the consumers can have their demand covered independently of the wind intensity.

Pumped hydro storage

Pumped hydro storage is the method capable of storing the largest amount of energy and is the method with the largest production capacity. A pumped hydro power station mainly consists of two vertically separated water

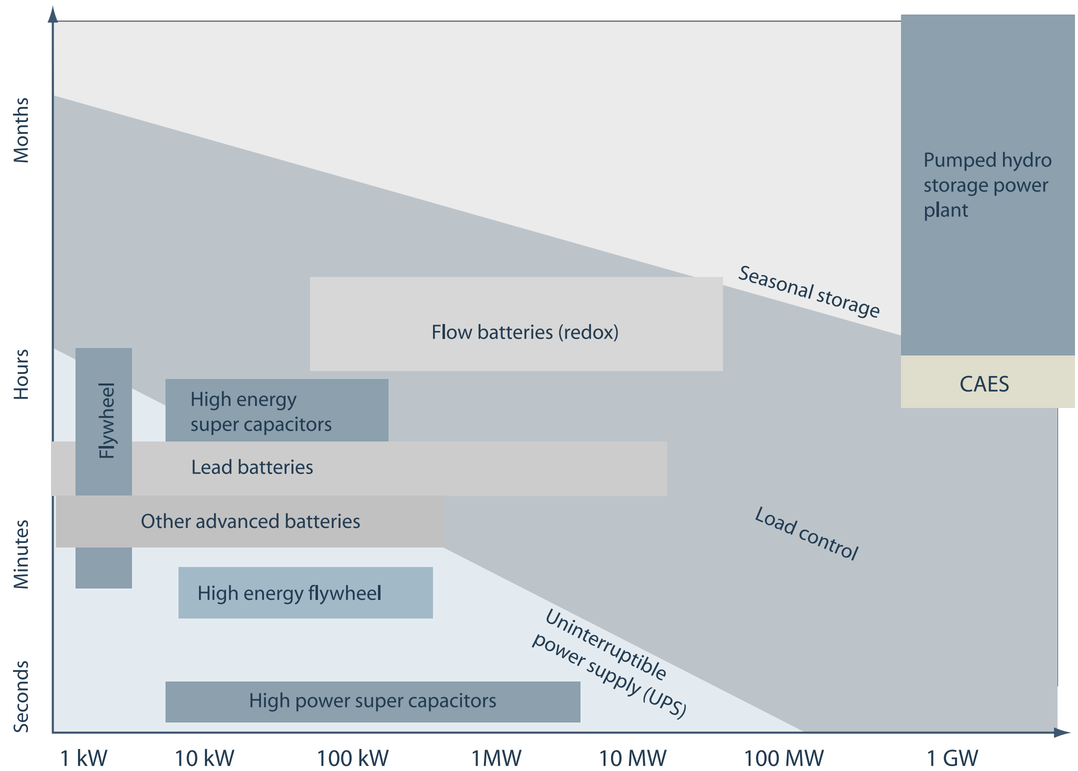


Figure 8-1 Various technologies for energy storage with corresponding areas of application.

reservoirs. At the bottom reservoir, a turbine is placed that can be run both ways, or it could be a pump and turbine mounted on the same generator. The generator works as an engine during pumping. When energy is stored, water is pumped up to the highest reservoir. The energy is harnessed by letting the water flow back through the turbine. The amount of energy that can be stored depends on the vertical distance between the reservoirs and the useful volume of the reservoirs. The power capacity depends on the size of the turbine. A more detailed description of hydropower is given in chapter 5.

Pumped hydro power stations are a mature technology with high efficiency. It is possible to recover more than 80 per cent of the energy that is put into the system.

Compressed Air Energy Storage

Compressed Air Energy Storage (CAES) is a storage technology based on turbines in the same way as pumped hydro power stations, but instead uses gas turbines instead of water turbines.
A gas turbine consists of a compressor, a combustion chamber, a turbine and a generator. The compressor and the turbine are often mounted on the same shaft. The purpose of the combustion chamber is heating the compressed air. The turbine runs the compressor and the generator. Gas turbines that are used in energy storages with compressed air are different from normal gas turbines in that the compressor and turbine are set on different shafts, so that they can be run independently of each other. Finally, a storage tank for the compressed air is needed.

Energy storage occurs by letting an electric engine run the compressor feeding the reservoir. When energy is released, the air is fed through the combustion chamber and turbine. The turbine runs a generator. Compared to a normal gas turbine, this system uses 40 per cent less gas, since the compressor is run by electric energy.

Depending on the efficiency of compressor, turbine and reservoir, this type of energy storage will make it possible to recover 70-80 per cent of the stored energy.

Compressed air as energy storage is a relatively expensive technology. In order to ensure profitability of operation, the time between storage and production should be short. The few existing plants are often run for peak shaving.

Batteries

A battery can convert chemical energy directly into electrical energy via an electrochemical reduction-oxidation (redox) reaction. This type of reactions implies the transmission of electrons from one material to another, and in the battery the electron flow goes through an outer circuit in order to use it. The driving force in this process is the noble quality of the substance encapsulated in the battery. Lithium is an example of a less noble substance that will react electrochemically with a more noble substance such as silver. Some substances are capable of reacting electrochemically with oxygen in the air, and batteries of this kind are often called battery hybrids. One example of such a hybrid is the zinc-air battery where zinc reacts with oxygen into zinc oxide. The Norwegian company Revolt Technology is developing a rechargeable version of this type of batteries.

Most people use batteries for small electronics such as mobile phones, flashlights and stereos. Many of these batteries have very good storage capacity, as for example lithium-ion and nickel-metal hydride batteries. However, currently most types are too expensive to be used for large-scale storage of electricity.

Other known battery types are the sulphuric acid battery, which is cheap but has a short working life, and flow batteries, where a large share of the stored energy can be restored.

Super capacitors

In capacitors, energy is stored in the form of an electric field, as opposed to batteries where the storage occurs via electrochemical reactions. The electric field is created by two electrically conductive surfaces, separated by a thin isolating material being supplied with direct current. On one surface there will be an excess of electrons, while the other will have a corresponding deficit. Since there are no phase transitions or chemical reactions in this process, capacitors have very high efficiency. They can also tolerate a larger number of charge cycles than batteries (up to a million cycles, compared to some thousands of cycles for batteries). Capacitors are characterized by relatively low storage capacity (measured in kWh) and they can be charged and discharged very quickly.

Super capacitors are also often called Electric Double-Layer Capacitor, EDLC. A super capacitor can have storage capacity up to 3 kWh/kg with an output of 30 kW/kg.

Due to high costs, super capacitors are seldom used for large scale energy storage. They have been used mainly for emergency power supply and in electric cars. However, extensive research is currently carried out on product improvement and cost reduction in order for the super capacitors to become accessible for more applications in the future.

Flywheels

A flywheel stores energy in the form of a rotating cylinder. The speed, mass and radius of the cylinder determines how much energy can be stored. The rotating cylinder is attached to an electric motor that also works as a generator. Energy is supplied by increasing rotation speed with the motor, while energy is extracted by using the motor as a generator, decreasing rotation speed. Charge and discharge of flywheels is very rapid. This is why flywheels often have the same application area as the super capacitors.

The principle for energy storage with flywheels has been known and used since the beginning of mechanical engineering. A new type of flywheel has been developed consisting of composites that tolerate very high rotation speed. The flywheel uses magnetic bearings and is placed in a vacuum tank to reduce aerodynamic loss. Thus, a modern flywheel has very low losses. It is possible to restore approximately 90 per cent of the stored energy. The lifetime of a flywheel is about 20 years and it can sustain tens of thousands of charge cycles. The technology is relatively mature and there are several commercial products on the market.

Flywheels are often used in emergency power supply to deliver power in the period between power loss and start-up of the emergency power generators, as emergency power generators often have a longer start-up time. Flywheels are also used in base stations for mobile phones.

Superconductors

Superconductors can be used to create a strong magnetic field that can be converted to electricity at a later stage. This storage method is at an exploratory level, as are superconductors themselves. Most known superconductors require very low temperatures. They need cooling units that require energy and thus overall efficiency is reduced. Magnetic fields from superconductors can be charged and discharged quickly and with high power output.

Storage of thermal energy

Thermal energy, or heat, can be stored in almost all types of material. For commercial use, materials with high heat capacity in proportion to weight, volume and costs are the most suitable ones. The thickness of the insulation surrounding the storage medium decides how long the energy can be stored.

Water is a well-suited storage medium for thermal energy. It is often used for heating of buildings. In central heating systems, a water tank is often used as a heat storage to decouple heat production and demand. In systems with solar collectors (see chapter 2) the water tank is a central element in order to store heat between night and day. There are solar collector systems where very large heat storages are used to save solar energy from summer to winter. Storages such as these are expensive and so far little used.

Solar-thermal electricity production use concentrated sunrays to heat the storage medium to more than 100°C. In this way, oils or melted salt become more suitable as energy storage. The purpose is to achieve a more even electricity production, both through the day and when clouds block the light from the incoming radiation.

For buildings that require both cooling and heating, it can be a good idea to store energy between the different seasons. The most economic storage medium for this purpose is normally the ground itself. Using the ground as energy storage is relatively uncomplicated. However, it can be inefficient, since the heat storage in the ground will spread to surrounding areas. These plants often consist of a heat pump in combination with energy wells. The heat pump can run in both directions, so that excess heat is pumped down into the ground during summer and taken up during winter. For buildings that do not have a cooling demand, the losses are normally too great to justify thermal ground storage.

Hydrogen

Hydrogen (H_2) is the most common element in the universe. On earth, the largest incidence is in the form of water (H_2O), but hydrogen is also part of a number of organic and inorganic compounds. If hydrogen is allowed to react with oxygen, large amounts of energy are released (look for "heating value" in table 8-1). The product from this reaction is water. This is why hydrogen is considered a pure energy carrier. Hydrogen can be compared with electricity since the main function of

Hydrogen	
Symbol	H
Atomic number	1
Appearance	Colorless
Phase at room temperature (25 °C)	Gas
Atomic mass	1,008 g/mol
Density (25 °C, 1 atm/ 1.013 bar)	0,07(1) g/cm^3
Melting point	-259 °C / 14 K
Boiling point	-253 °C / 20 K
Ignition temperature in air	530 °C
Ignition limit in air	4,1 – 72,5 Volum per cent
Higher heating value (HHV)	285,830 kJ/mol (39,41 kWh/kg)
Lower heating value (LHV)	241,820 kJ/mol (33,33 kWh/kg)

Table 8-1 Hydrogen. Source: [Gordon, 1994] and [Moran, 1998].

both hydrogen and electricity is to transport energy from source to consumer.

Production and distribution

Hydrogen is an important raw material in several well- established industrial processes, for instance in oil refining and production of fertilizers. On a global scale, currently more than 500 million normal cubic metres (Nm^3) are produced annually. Electrolysis and natural gas reforming dominate industrial hydrogen production. Hydrogen from fossil sources represents approximately 95 per cent of the world production, of which natural gas make up the largest share. Steam reforming is the most used method for extraction of hydrogen from fossil sources. Energy in the form of heat must be added to the process. Carbon dioxide (CO_2) is also produced. If hydrogen produced from natural gas is to be considered neutral with regard to the greenhouse effect, the CO_2 generated in the production process has to be collected and stored in a safe place so that it is not released into the atmosphere. To remove CO_2, one can either use a membrane that separates hydrogen and carbon dioxide or a solid or liquid substance that binds the carbon dioxide. Statoil removes carbon dioxide from natural gas on a large scale at the Sleipner field in the North Sea. In this process, amines (liquid chemical) bind the CO_2 in a reactor and release it in another reactor. The carbon dioxide is then stored in an aquifer called the Utsira formation which is 800 metres below the seabed. Regardless of which method is chosen for the removal and storage of carbon dioxide, energy is required to drive it. The produced hydrogen will contain less energy than the amount that was extracted from the well in the form of natural gas.

From	To ->			
	Nm^3	kg	kWh	MJ
Nm^3	1	0,0899	4,7	16,92
kg	11,21	1	52,3	188
kWh	0,21	0,019	1	3,6
MJ	0,059	0,0053	0,278	1

Table 8-2 Converting table for hydrogen. The energy values are based on the amount of electricity that is need to produce hydrogen by electrolysis. Source: Knut Harg, Hydro.

When hydrogen is produced from electricity, the water molecule is decomposed into hydrogen and oxygen in an electrolyser. An electrolyser works like a fuel cell that runs backwards, i.e. that electricity is used to split up water into hydrogen and oxygen. Electrolysis is a well-known principle that is used on a large scale for production of aluminium and silver plating of jewellery in addition to hydrogen production. A more detailed description of the fuel cell principle is given later in this chapter.

Electrolysis is also connected with loss, so the hydrogen that is produced contains less energy than the amount of electricity used in the production. Table 8-2 shows that 52.3 kWh are needed to produce 1 kg of hydrogen, while in the box for hydrogen we can see that the energy content of hydrogen is only 39.41 kWh/kg [HHV].

Hydrogen can also be produced from processes other than natural gas reforming and electrolysis.

Figure 8-2 Pressure tank battery for hydrogen from Raufoss Fuel Systems. Photo: Raufoss Fuel Systems.

If hydrogen is produced centrally in a large factory, the hydrogen must be transported to the customer through a pipeline or on tanker trucks. The choice of transport method will depend on amount and distance. To avoid truck transport, decentralized hydrogen production can also be used. In combination with electrolysis, the energy can be transported in the form of electricity to a local electrolyser. These are relatively simple to scale so that they can be built in a size appropriate for local consumption.

Storage of hydrogen

Storage is the largest technical challenge for hydrogen to be used for transport applications. Hydrogen has very low density and it is difficult to design storage tanks with storage capacity that corresponds to petrol and diesel. Moreover, hydrogen can cause brittleness and breakage in certain metals, so the choice of containment material is limited. Another challenge is that the molecule is so small that leakages can occur even through the smallest breaches.

Hydrogen can be stored as gas, liquid or in solid shape. In stationary applications, it is most common to store the hydrogen as compressed gas. The amounts of energy that are utilized in the storage processes must be as low as possible. Research is being conducted on an array of different methods for storage. Car producers have chosen different strategies for how they store hydrogen. Today, most demonstration vehicles have been equipped with storage tanks for compressed or liquid (-253°C) hydrogen.

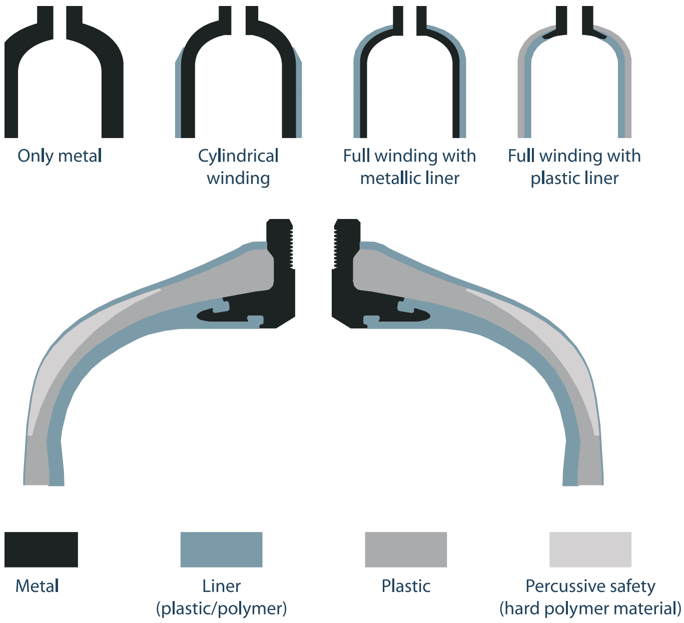


Figure 8-3 Top: Various pressure tank systems for hydrogen storage. The technological development has moved from left to right in the figure. A more detailed model of the last generation high pressure storage tank from Raufoss Fuel Systems is explained in the lower figure. Source: Raufoss Fuel Systems.

Technology	Volume (litre)	Weight (kg)	Density (Weight per cent H_2)
Compressed 350 bar	145	45	6,7
Compressed 700 bar	100	50	6,0
Liquid (-253 °C)	90	40	7,5
Low temperature metal-hydrid	55	215	1,4

Table 8-3 Best availiable technology for various methods of hydrogen storage. Hydrogen compressed to 800 bar will have the same volume as in liquid phase, 90 litres. Source: [IEA-HIA, 2006].

Compressed hydrogen

Most high pressure storage tanks for transport are made of composites. In figure 8-3 there is a sketch of one such tank produced by Norwegian Raufoss Fuel Systems. The technology has come a long way in this field, and the majority of the producers already offer safety approved tanks for pressure up to 700 bar. Compressed hydrogen can also be stored in micro glass balls. This technology is less mature than pure pressure tanks.

HyNor

In Norway a joint industry initiative called HyNor has been established to demonstrate real life implementation of hydrogen energy infrastructure. The project will connect various activities and cities in a common network along one of the major national transport corridors. The route will be 580 kilometres and go from Oslo to Stavanger beginning in 2005 and completion is scheduled for 2008.

The project comprises all steps required to develop a hydrogen infrastructure and includes various hydrogen production technologies and uses of hydrogen, with adaptations to local conditions. The project seeks to demonstrate the commercial viability of hydrogen energy production and use in the transport sector. www.hynor.no

HyNor has established a partnership with partners in Denmark and Sweden called "Scandinavian Hydrogen Highway Partnership" (SHHP). The purpose is to connect the Norwegian hydrogen highway with the corresponding projects in Denmark and Sweden. www.scandinavianhydrogen.org.

Liquid hydrogen

Hydrogen can be stored in liquid form if the temperature is lower than -253°C. This type of storage gives higher storage density than compressed solutions, but the cooling is very energy demanding. As a rule of thumb, 30 per cent of the energy content (LHV) in the tank would have been used for cooling. Therefore, one of this storage technology's challenges is to develop less energy-consuming cooling methods. Another challenge is that part of the hydrogen evaporates over time.

It is also possible to store hydrogen as a constituent in a liquid, such as $NaBH_4$ solutions, rechargeable organic liquids or anhydrous ammonia NH_3

Storage in solids

Some solids have qualities that facilitate more efficient hydrogen storage than gaseous hydrogen storage. In order to achieve an efficient storage in such materials, it is important that the storage medium has a large surface. In practice this means that the material is used as powder.

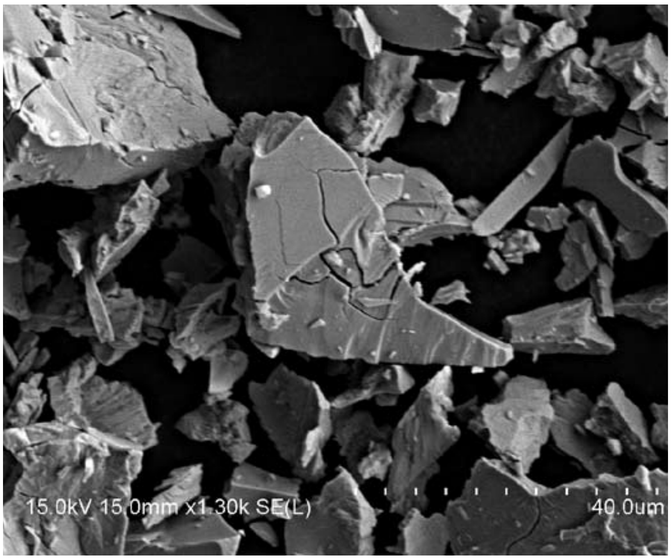


Figure 8-4 Close up of the nickel based powder type AB5 (LaNi5). Norwegian researchers at IFE study the storage properties of AB5-type materials. Source: IFE.

There are mainly four series of materials that are suitable for solid-state storage of hydrogen:

1. Carbon and other materials with a large surface areas
2. H_2O-reactive chemical hydrides
3. Thermo-chemical hydrides
4. Rechargeable hydrides

Researchers at the Institute for Energy Technology (Institutt for energiteknikk, IFE) at Kjeller in Norway study metal hydrides in group four, in particular aluminium hydride and magnesium hydride. As part of the development, they have also built storage tanks for demonstration in cooperation with Raufoss Fuel Systems. Figure 8-4 shows a picture of the type of powder that is studied.

Hydrogen in future energy systems

It is not likely that hydrogen will have a central role in our energy system in the near future. In the first phase, it is likely that hydrogen will be used for small electronics as for example mobile phones, flashlights etc. There is also a trend towards more demonstration projects for use of hydrogen in the transport sector. However, for the time being the road to a commercial breakthrough is long. In the more distant future hydrogen can play a more important role in the energy economy. This will likely employ hydrogen mainly as an energy carrier that connects stationary energy production to consumption for transport purposes.

Today it is possible to buy cars that run on hydrogen. The majority of the car producers believe in a market

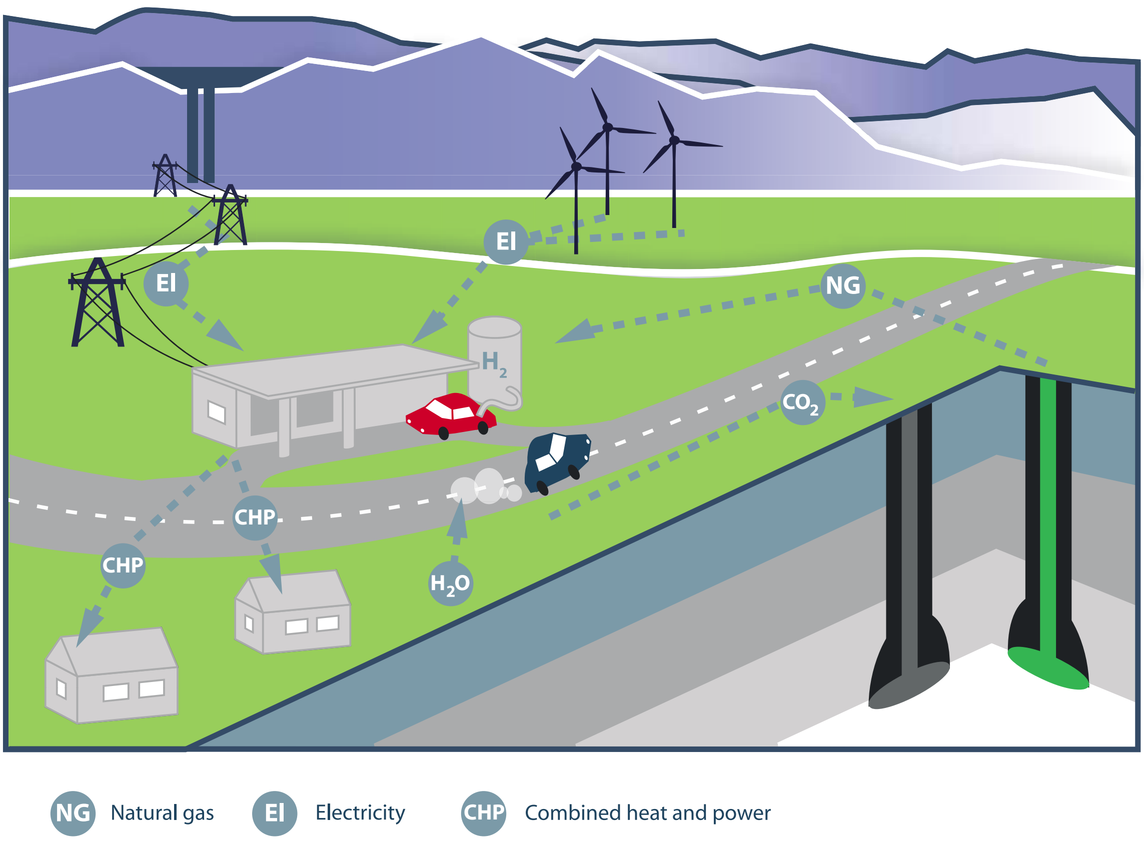


Figure 8-5 Hydrogen as energy carrier in the energy system of the future. Source: Statkraft. Illustration. Kim Brantenberg.

introduction of hydrogen cars in the time span 2015-2020, but many technical challenges must be solved by then.

Hydrogen research in Norway today is to a large degree motivated by a rich access to natural gas, export of electrolysers and electric power. This is why Norwegian technology environments are good at systems for hydrogen production, storage and logistics, and Norwegian environments are acknowledged on an international level in this field. An example of how Statkraft envisages the future's energy system is shown in figure 8-5.

Fuel cells

Fuel cells are not a new technology. The first fuel cell was built by William Robert Grove in 1839, but it was not until the 1960s that the first fuel cells came into use with the space program Apollo (NASA). The fuel cells

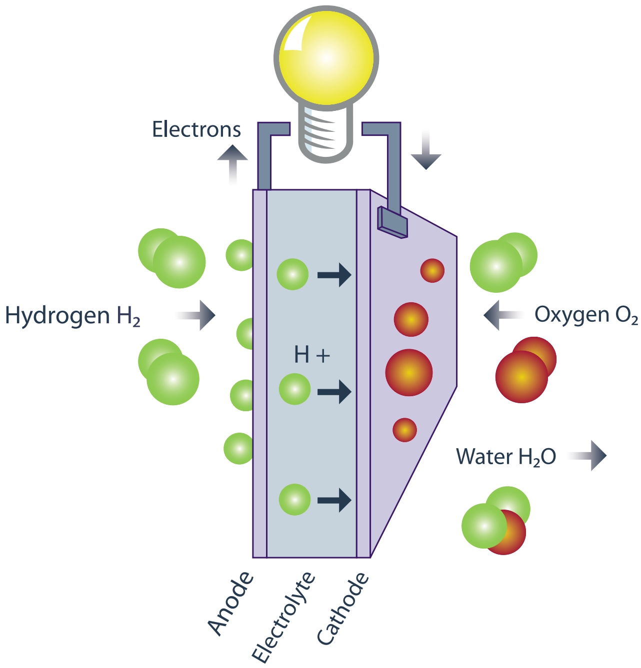


Figure 8-6 Hydrogen fuel cell. Illustration: Endre Barstad.

were particularly well suited for this application area since the "waste" from power production was water that the astronauts could drink. The result was saved space and weight.

Large resources have recently been allocated to research and development of fuel cells. The driving force in this development has always been the fuel cell's especially effective conversion of chemical energy to electric energy. Fuel cells are easy to scale, so that they can be used in mobile phones, cars and power production. In addition to this, if hydrogen is used as fuel, the only emission would be water. Fuel cells are often mentioned as an environmentally friendly and emission free technology.

What is a fuel cell?

A fuel cell consists of two chambers that are separated by a membrane (wall). One chamber contains fuel (for example hydrogen), while the other chamber contains air. One of the purposes of the membrane is to separate air and fuel, because if these two substances are mixed at a sufficiently high temperature, they will react with each other and create water (burn up). In a fuel cell we wish this reaction to happen but we would like to control the process so that it occurs through the membrane. Figure 8-6 shows an example of the working principle of a hydrogen-fuel cell.

Compared to traditional electricity production with heat engines (as gas turbine power plants and coal power plants) fuel cells are more effective, since power is produced directly from the chemical energy. In heat engines, the chemical energy is first converted to heat, which thereafter is used to run a machine which again runs a generator.

In principle, the functioning of fuel cells and batteries are identical, but a battery can only produce energy corresponding to the amount of fuel encapsulated in the battery. In the fuel cell on the other hand, both the air- and combustion chamber are open so it can produce current as long as it is supplied with fresh air and fresh fuel. Thus, the fuel cell depends on being surrounded by an auxiliary system that ensures the supply of air and fuel. Current and voltage will vary with the fuel cell's operational status, so a converter is necessary to achieve a current quality adjusted to the network's requirements.

A single fuel cell can produce electricity at 0.5-0.7 V. To get a higher voltage, several fuel cells are often joined in a series in a fuel cell stack. The amount of current that is produced is proportionate with the membrane's surface area and fuel supply. Therefore, fuel cells are easy to scale; more fuel cells give higher power output. Similar to rechargeable batteries it is also possible to design fuel cells that can run both ways. These are called "regenerative fuel cells" that either operate in "fuel cell mode" or "electrolysis mode".

The core of fuel cell technology is the membrane that separates air and fuel. The requirements for this component are strict and until now they have been difficult to fulfill. In particular it has proved difficult to achieve sufficient durability. The materials are expensive to produce, and the special atmosphere inside the fuel cell often requires expensive materials in surrounding components. As a consequence, fuel cells today are too expensive to compete on the market. Further research strongly focuses on identification of new and cheaper materials with long durability and more efficient production methods.

Fuel cell technologies

There are several types of fuel cells, since there are several types of materials that are suitable as a membrane. The different membrane materials have different operation temperatures. They are then divided into

	Fuel cell type	Operating temperature (^{0}C)	Fuel	Mobile ion	Area of application	Power efficiency (per cent)
Low temperature	PEMFC	60 - 90	Hydrogen	H^+	1 W - 250 kW	35 - 45
	DMFC	60 - 120	Methanol	H^+	1 mW - 100 W	10 - 20
	AFC	50 - 200	Hydrogen	OH^-	50 - 100 kW	50 - 65
Medium temperature	PAFC	~200	Hydrogen	H^+	50 - 200 kW	35 - 45
High temperature	MCFC	~650	Reformed hydrocarbons	CO_3^{2-}	100 kW - 500 kW	45 (~53)
	SOFC	650 - 950	Hydrogen/ reformed hydrocarbons	O^{2-}	1 kW - 500 kW	45 (~53)

Table 8-4 Overview of the most important types of fuel cells and some of their properties.

the main groups of low temperature fuel cells, middle temperature fuel cells and high temperature fuel cells. Some important details on the different types are listed in table 8-4. The different fuel cells have qualities that make them suitable for different areas of application. Different fuel cell technologies also require different fuel qualities.

Table 8-4 shows that the efficiency for most fuel cells is relatively high. This can be further increased by operating the fuel cells under high pressure. All fuel cells in the table are accessible on the market, but in 2006 most types are very difficult to obtain. The costs are also very high and it can be difficult to find producers that are willing to give guarantees with regard to safety in operation and availability.

Prototech, located in Bergen, Norway, develop fuel cells. Prototech has worked with fuel cells since the 1990's and was involved in the construction of the first SOFC-stack in Norway (Mjøllner). In 2006, Prototech is still working on this technology, both in cooperation with NTNU in Trondheim, the University of Bergen and IFE at Kjeller.

Fuel cells in the energy system

The fuel cell's task in the energy system is an effective conversion of chemical energy to electricity. Already today we see indications that it will be difficult to provide enough energy in the future. Therefore it is important to achieve higher efficiency on all types of energy production and energy consumption. In this perspective, the fuel cell has promising qualities, but whether we have a breakthrough for fuel cell technology will also depend on what competing technologies can deliver.

For power production, the fuel cell has been viewed as part of the system for distributed power production. First of all, the fuel cell's efficiency is almost independent of size, so even the smallest plant can obtain a high efficiency. If electricity production occurs on a local level, it is easier to utilize waste heat, for example for heating tap water.

Another important motivation is security of supply. A power system based on few, but larger production units, is vulnerable. Shut-down of one unit would entail a large loss of production. Many small units will on the other hand not be as vulnerable.

Much attention is given to use of hydrogen in the transport sector, since here the efficient hydrogen systems will be competing with motor concepts with much poorer efficiency (petrol- and diesel engines).

Economic conditions

Cost reduction is the most important condition for fuel cells to have a large scale commercial breakthrough. This means that the cost must be in proportion to the service life. The fuel cell's scalability enables it to compete on several levels. It is likely that the first fuel cell uses will come in small applications like mobile phones, PDAs, and mp3-players. Willingness to pay in relation to power (€/kW) is high in this market segment. A breakthrough on this market will lead to mass production, which again will lead to reduced costs. Scalability of fuel cells will assume reasonable breakthroughs for small units that will lead to lower costs also for larger units.

Heat pumps

Technology

With the help of a heat pump it is possible to move thermal energy from a source with low temperature to a receiver with high temperature. Since this is the opposite direction of normal thermodynamic transition, high quality energy (for example electricity) must be added in the process, but that energy consumption is much less than the amount of thermal energy that is moved. A schematic diagram for the heat pump is given in figure 8-7. The heat pump is an important contributor to energy saving.

Most heat pumps consist of two heat exchangers, a compressor, an expansion valve and a working medium. The working medium is a liquid or gas with boiling and condensation temperatures adjusted to the temperatures of source and user. There are also heat pumps that are based on high-quality energy in the form of heat. For these heat pumps, compressors are not necessary. On the other hand, heat from a source with a high temperature is needed as driving energy. This is called an absorption heat pump. A heat pump and a refrigerator rely on the same type of machine, only the application is different.

Heat pumps are based on the relation between pressure and temperature for gases and liquids. A gas that is compressed will increase its temperature, and a pressure decrease will correspondingly give a lower temperature.

In the cold heat exchanger (evaporator) the work medium is in liquid form and the temperature is lower than the surrounding temperature. While the work medium is led through the evaporator it is supplied with thermal energy and it evaporates. Then the gas is compressed in order to give it higher pressure and temperature before it is led into the warm heat exchanger (condenser). Heat is given off through condensation inside the condenser. The work medium then passes through the expansion valve so that pressure and temperature are reduced before it reaches the evaporator again.

Heat pumps can be used for almost all heating purposes with moderate temperature levels. It can be space heating, heating of tap water or ventilation and for industrial purposes such as drying or process heat in chemical processes. In order for a heat pump to work optimally, it has to be tailor made for a specific purpose. Specifically, it is the shape of the heat exchangers, the work medium and the compression ratio that must be adjusted to the purpose.

The coefficient of performance (COP) indicates how much energy is exploited in relation to the energy consumption. COP varies with the difference between the temperature levels, and a larger difference in temperature gives poorer (lower) COPs. The coefficient of performance applies for certain conditions, but in many cases the heat pump gets heat from an energy source with varying temperature. To take this into account, the Seasonal Performance Factor (SPF) is used. The SPF is a measurement of the heat pump's efficiency over a broad operational area and thus it represents an "average COP" measured over an entire year.

Air/air heat pumps are the most common type of heat pumps for households. Most heat pumps of this type are

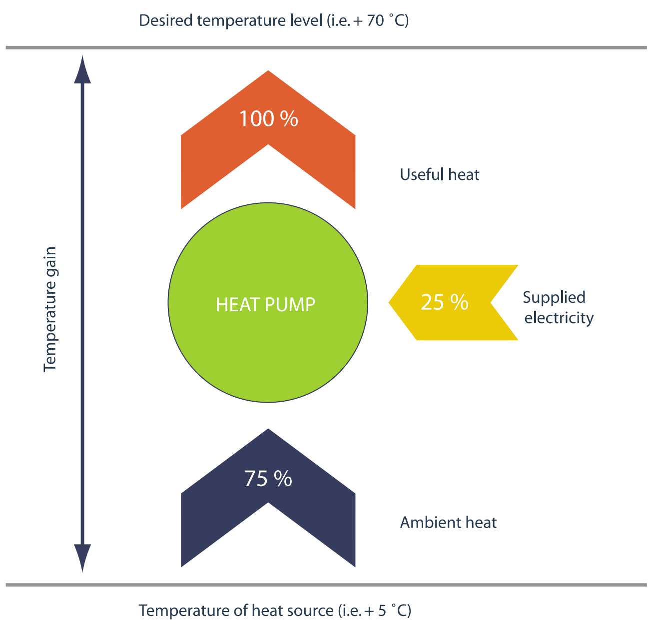


Figure 8-7 Working principle for a heat pump. By supplying energy in the form of electricity, energy (heat) is moved from a low temperature reservoir to a recipient with high temperature. Source: NRK/Schrödingers katt. Illustration: Endre Barstad.

of 4 to 7 kW and cost between 1 200 to 3 000 €, and they can deliver up to 50 kW of heating effect. Air/air heat pumps are relatively easy to install and represent an economic investment for existing buildings.

Air/water heat pumps are used for heating of warm water by getting energy from outdoor air. This type of heat pump can be used both for room heating in combination with water borne heat, or only for heating tap water. SPF for air/water heat pumps is somewhat better than the same air/air heat pumps and slightly worse than water/water heat pumps. The same applies for investment costs since an air/water heat pump needs lower investment costs on the cold side than a similar water/water heat pump.

Water/water heat pumps receive thermal energy from the ground, subterranean water, sea water or fresh water. These sources often have a more stable temperature throughout the year than outdoor air. It is particularly higher during the heating season. This is why water/water heat pumps have a much better SPF than similar air/air heat pumps. Water/water heat pumps require higher investment costs, but provide a higher level of energy saving. Water/water heat pumps are suitable for sizes from a few kW and up to several MW. The smallest heat pumps are normally used for space heating of villas in combination with water borne heat, while the largest types are used in district heating networks or for industrial processes. Water/water heat pumps are especially well suited for buildings that have both cooling and heating demand.

For ground source heat pumps, the ground can work as a seasonal storage for energy. In summer, the house is cooled down by heat being pumped down into the

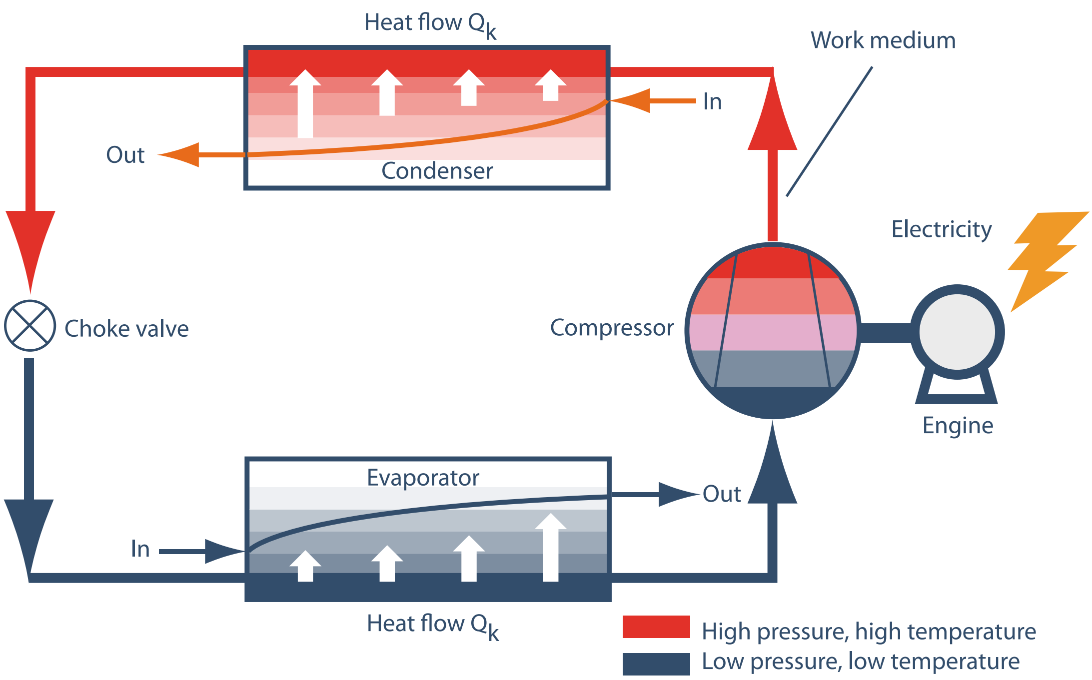


Figure 8-8: The heat pump is put together of the main components condenser, choke valve, evaporator and pump. The work medium circulates and thus providing heat transportation. Source: Sintef Energy Research AS.

ground. During autumn when there is need, this energy is used for heating the building. In springtime and in summer when the demand for cooling has increased, the ground turns cold again, so the cooling can take place more effectively.

If there is access to a heat source with high temperature in addition to a heat source with low temperature it could be attractive to use an **absorption heat pump**. It needs considerably less electric energy than a mechanical heat pump, since the working medium is not compressed. Instead the work medium is absorbed into a liquid before being pressurised. A heat source with a high temperature is needed to separate the work medium from the liquid again. Today absorption heat pumps are used to a small extent since they are often connected with high investment costs, but in cases where there is access to economically free high temperature heat, such a heat pump can be profitable.

Research and development of heat pumps

Heat pumps have been on the market for many years and can be considered a mature technology. Unfortunately, many of the most well known refrigerants contribute to breaking down the ozone layer in the atmosphere, global warming or both. The most often used refrigerants that are free from chlorine (HFC) are 1 300 to 2 200 times stronger greenhouse gases than CO_2. As a consequence, much of today's research focuses on finding alternative and environmentally friendly refrigerants with adequate performance.

Two important contributions to this research have come from Norway. One of the contributions is a heat pump based on CO_2 as refrigerant which has been developed at SINTEF/NTNU. This heat pump is especially well suited for heating warm tap water (air/water heat pump). It is also able to reduce power consumption compared to an electric hot water tank by a factor of four (SPF= four). In addition, the use of CO_2 involves nearly no burden on the environment if leakages were to occur from the installation. This technology has been commercialized through the company **Shecco Technology**, Hydro Aluminium AS, that is owned by Hydro ASA.

The other contribution comes from the IFE in Kjeller. They have developed a heat pump that is a combination

Heat source	Operational reliability	Installation cost	Operating cost	Maintenance	Life cycle cost
Sea water	Good	Moderate	Low	Moderate	Low
Ambient air	Moderate	Moderate	Moderate	Moderate	Moderate
Exhaust air	Good	Moderate/ high	Low	Low	Low
Ground heat	Excellent	High	Low	Low	Low
Waste heat	Good	Low	Very low	Low	Low

Table 8-5 Comparison of heat sources for heat pumps: Operational reliability - costs - maintenance. Source: COWI.

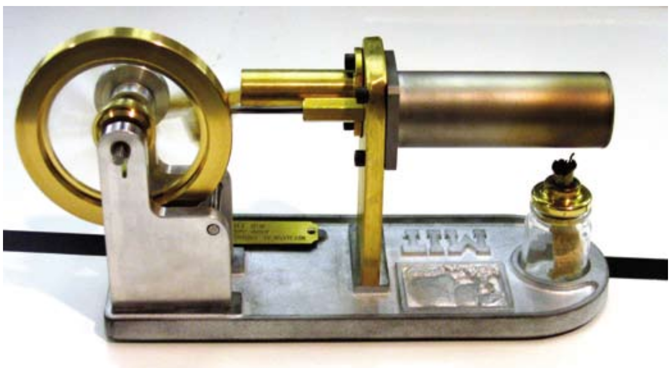
of a compression heat pump and an absorption heat pump referred to as a hybrid. The hybrid heat pump uses a refrigerant that consists of natural substances such as ammonia and water, and is especially suitable for the exploitation of waste heat from industrial processes. A typical working range for this heat pump is 20-60 °C (cold side) and 75-100 °C (warm side). A good example of such a process can be hot water production in dairy processes. TINE has installed a 300 kW demonstration at their dairy plant at Nærbø in Rogaland. This plant has a heat factor of 2.5 - 3 and the payoff time was two years. The plant was supplied by **Hybrid Energy AS**.

Heat engine concepts

A heat engine is an engine that can convert thermal energy to mechanical energy. Heat engines are often divided into groups based on the applied thermodynamic principle. The most well known are:

- Otto (the petrol engine)
- Diesel (the diesel engine)
- Rankine (steam turbine)
- Brayton (gas turbine)
- Stirling
- Elsbett
- Steam engine

Otto, diesel, rankine, and brayton engines are often used to produce electric energy. In some cases, excess heat is delivered to a district heating network. All engines can



Stirling engine. Photo: MIT.

use renewable fuels such as biofuel or hydrogen, but not entirely without modifications. Hydrogen is a more reactive combustible than petrol. It has a much lower ignition limit and the flame speed is higher. Therefore, the relation between air and fuel must be adjusted, so that an otto engine running on hydrogen has a larger air excess ratio than a similar engine that runs on gasoline. High excess of air, or "lean combustion", reduces the formation of NOx, and this is one of the reasons why the hydrogen engine has very low emissions.

The stirling engine is a piston engine that converts thermal energy to mechanical energy. Combustion takes place inside the cylinders in the otto and diesel engines whereas in the stirling engine combustion occurs in an external chamber. The stirling engine can therefore in principle use any hot or cold source. Consequently, the stirling engine can be used to produce electricity from solar heat, waste heat and geothermal heat in addition to conventional fuels from fossil or biological sources. Another important difference is that the pistons in the stirling engine are run by a work medium in a closed circuit. The stirling engine also has high efficiency.

The stirling engine is most suitable for stable operation and is mostly used for stationary applications. The electric efficiency can come up to approximately 20 per cent, which means that there will be some waste heat. Therefore it is advantageous if there is both electricity and heating demand. A stirling engine of a few kilowatt can be placed in a normal house for both electricity and heat production. Consequently it is also suited for distributed electricity production.

The stirling engine has not yet achieved a significant commercial breakthrough. The construction principle is simple, but it is technically complicated to avoid work medium leakage and to achieve good service life for the heat exchangers, particularly on the warm side. The technical challenges are not impossible to overcome, and it is possible to buy stirling engines. In Norway there is strong stirling development from the company Adigo AS that aims to develop a stirling engine designed for domestic use.

The elsbett engine is a version of the diesel engine that can be run on unrefined vegetable oils. When the German Ludwig Elsbett invented it in the mid 1900, it was considerably more efficient than normal diesel engines. It does not need water cooling, and instead uses a small cooling system based on oil. The elsbett engine has good durability and high efficiency, but compared to today's engines with direct priming and turbochargers it is not competitive. Furthermore it is heavier than its competitors and works best during continuous operation. Resulting from its suitability for running on refined vegetable oils, this type of engine has had a small renaissance. It is possible to buy a conversion kit for conversion of diesel engines.

Control and monitoring systems

The energy market is growing strongly. The requirements for monitoring and control of the energy system and markets increase as more and more units are added to the system. More energy producers means increased flexibility in coordination of production, but it also means a rise in the system's complexity. Spot price agreements on electricity imply that energy consumption should be managed concurrently with varying prices, preferably by the hour. Today large customers may enter agreements where they abstain from planned consumption without compensation in situations where power demand is high. In order to be able to handle these challenges, there is a need for more frequent and faster information exchange between energy producer and energy consumer.
Technical solutions for this type of communication are often described as two-way communication or AMM (Automatic Meter Management).

For AMM there are three levels with varying degree of maturity:

- Remote reading of energy meters – Automatic Meter Reading (AMR)
- Remote disconnection of single consumers or parts of the consumer's components – Remote Load Control (RLC)
- Remote control of local power production.

Automatic Meter Reading is a well known technology. In Norway, most consumers with a consumption exceeding 100 000 kWh/year have this type of metering system. Remote Load Control of single consumers or parts of customers' consumption requires a slightly more complicated technology.

We distinguish between two varieties of remote control of local power production. One is a system where a mini-power plant is controlled centrally by a larger power company. This is quite common. The other variety is a solution for control of the system that is local to the customer.

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THE WORK IS FINANCED BY:

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Responsible for the elaboration of the information booklet:
SWECO Grøner, P.O. Box 400, 1327 LYSAKER, Norway.
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Illustrations: Endre Barstad / Kim Brantenberg

Print: Thoresen Grafisk AS
www.tgas.no

ISBN 978-82-410-0637-1

Renewable energy

The Norwegian Water Resources and Energy Directorate (NVE), Enova, The Norwegian Research Council and Innovation Norway have collaborated in preparing this information booklet. The purpose of this information booklet is to present a concise overview of the progress of technology, economy and market in relation to the special field of renewable energy. The booklet will also present examples of Norwegian companies that deliver technology within renewable energy sources.

The booklet has chapters about:

- Solar energy
- Bioenergy
- Windpower
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