## Energy definitions, conversion factors and the theoretical energy content of various fuels

**Energy units**

Energy is defined as the ability to carry out work.
The basic unit of energy is the joule (J).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | MJ, | megajoule | = | $10^6$ | J | = | 1 million J |
| 1 | GJ, | gigajoule | = | $10^9$ | J | = | 1 billion J |
| 1 | TJ, | terajoule | = | $10^{12}$ | J | = | 1 000 billion J |
| 1 | PJ, | petajoule | = | $10^{15}$ | J | = | 1 million billion J |
| 1 | EJ, | exajoule | = | $10^{18}$ | J | = | 1 billion billion J |

**Sometimes, the following are also used for electrical energy:**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | kWh, | Kilowatt-hour | = | $10^3$ | Wh | = | 1 000 Wh |
| 1 | MWh, | Megawatt-hour | = | $10^3$ | kWh | = | 1 000 kWh |
| 1 | GWh, | Gigawatt-hour | = | $10^6$ | kWh | = | 1 million kWh |
| 1 | TWh, | Terawatt-hour | = | $10^9$ | kWh | = | 1 billion kWh |

PJ is obtained by multiplying TWh by 3.6.

1 MWh is about the amount of electrical energy needed to heat a detached house during one week in winter.

1 TWh is about the amount of electricity used in one year by a town with around 50 000 inhabitants.

**Power is energy per time unit.**

The basic unit for power is watt, and the following units are used:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | W, | watt | = | 1 | J/s | | |
| 1 | kW, | kilowatt | = | $10^3$ | W | = | 1 000 W |
| 1 | MW, | megawatt | = | $10^3$ | kW | = | 1 000 kW |

**Conversion factors and average theoretical energy content of various fuels:**

| | MJ | kWh | toe | Sm³ natural gas | barrel raw oil | cord of wood* |
|---|---|---|---|---|---|---|
| 1 MJ, megajoule | 1 | 0,278 | 0,0000236 | 0,025 | 0,000176 | 0,0000781 |
| 1 kWh, kilowatt-hour | 3,6 | 1 | 0,000085 | 0,09 | 0,000635 | 0,00028 |
| 1 toe, tonne oil equivalent | 42 300 | 11 750 | 1 | 1 190 | 7,49 | 3,31 |
| 1 Sm³ natural gas | 40 | 11,11 | 0,00084 | 1 | 0,00629 | 0,00279 |
| 1 barrel raw oil (159 litres) | 5 650 | 1 569 | 0,134 | 159 | 1 | 0,44 |
| 1 Cord of wood* (2,4 loose m³) | 12 800 | 3 556 | 0,302 | 359 | 2,25 | 1 |

* Depending on moisture content of fuel.

## Challenges linked to establishing a $CO_2$ value chain – overview of the Government's work

A great deal of international attention has been focused for many years on the development of technology for $CO_2$ capture and storage, especially from coal-fired power stations. In Norway, attention has been directed at capture of $CO_2$ from gas-fired power stations and at creating a chain for transport and injection of $CO_2$. A $CO_2$ chain covers capture of $CO_2$ from emissions, transport of $CO_2$ and use of $CO_2$ for increased oil production. Norwegian players are highly advanced in this area.

Power production and use of other fossil energy are the largest sources of greenhouse gases. Capture of $CO_2$ and storage in oil/gas reservoirs and geological formations stand out as a possible measure to reduce global emissions. Technology for capture and storage of $CO_2$ is still in the early stages of development. Available technology is very expensive and there is large uncertainty associated with costs and operation of a $CO_2$ chain.

Use of $CO_2$ for increased oil production could contribute to reducing costs of capture and storage, because the $CO_2$ that is captured gains added value. Use of $CO_2$ for increased oil production could render possible a profitable value chain for $CO_2$, but there are large challenges to be met if the $CO_2$ value chain is to become a reality.

The FN Climate panel has concluded in its special report, Special Report on Carbon Dioxide Capture and Storage (IPCC, 2005), that $CO_2$ storage could constitute up to half of the emissions reductions in this century, but that there are tremendous challenges to be solved before this potential can be realized. The IPCC report highlights that technology for $CO_2$ capture and storage is still largely immature and that there is not enough experience with $CO_2$ capture from major coal and gas-fired power stations.

### $CO_2$ Capture

The costs of $CO_2$ capture and storage in connection with power production from fossil fuels is a crucial challenge, because this will significantly increase the costs of power production. The costs of $CO_2$ capture from a power station constitutes about 2/3 of the costs of the entire $CO_2$ chain, while transport and storage constitutes about 1/3. This distribution will apply roughly, regardless of the technology concept.

The technology for $CO_2$ capture from a gas-fired power station can be divided into three main categories: Post-combustion, pre-combustion and oxy-fuel. Post-combustion means that $CO_2$ is separated from the power station exhaust gases using chemical cleaning. Because $CO_2$ is separated from the exhaust gases, this technology can in principle be used in existing power stations without major modifications to the power station itself. Post-combustion is considered to be the most advanced technology, but there is nevertheless great uncertainty linked to its use.

Pre-combustion technology captures $CO_2$ before combustion. This takes place as the natural gas is converted to a hydrogen-rich gas mixture. The gas mixture is treated so that the $CO_2$ is captured, and the new fuel is thus decarbonised, giving an exhaust gas that contains very little $CO_2$. Pre-combustion presupposes modification of the gas turbine and is considered to be far more complex than post-combustion technology.

In the case of oxy-fuel, combustion

takes place in the gas turbine in an atmosphere of pure oxygen instead of air. This means that the exhaust only comprises water vapour and $CO_2$, and the $CO_2$ can be separated out by cooling the exhaust. Today's gas turbines give very low performance with oxygen combustion, and at the moment investment is low in development of new types of gas turbines that are better suited for oxygen combustion. In addition, oxygen production is highly energy-intensive, and the technology for energy production is highly expensive. Oxy-fuel is therefore considered to be a very immature technology.

$CO_2$ capture is energy-intensive. The IPCC report estimates that if 90 % of $CO_2$ from a power station is captured, fuel consumption will increase by 11-40 % depending on technology and fuel. $CO_2$ capture reduces the power station performance and results in an increase of other environmentally harmful emissions. The report estimates that the cost of power production will increase by 20-85% with $CO_2$ capture. If the current level of research and development is maintained, it will be possible to reduce the costs of $CO_2$ capture by 20-30 % over the next 10 years.

So far none of the mentioned technologies have been tested on a large scale in connection with a gas-fired power station. There is therefore large uncertainty around the use of current technology for $CO_2$ capture, particularly in relation to costs and performance.

**Transport of $CO_2$**

$CO_2$ must be transported from its source to the geological structure in which it is to be stored. $CO_2$ can be transported by pipe or ship. In general, transport of $CO_2$ is that element of the $CO_2$ chain that is least complicated both with respect to technology and to estimating realistic costs. Nevertheless, the transport stage is both energy-intensive and costly. Because $CO_2$ behaves quite differently depending on the pressure and temperature, it has to be transported in a controlled manner to avoid solidification and blockage of pipes or equipment.

Transport of $CO_2$ by ship is more complicated than by pipeline. To achieve maximum $CO_2$ load in a ship, the $CO_2$ is either pressurized or both pressurized and cooled to liquefy it. Good experiences with shipping $CO_2$ have been acquired through foodstuff production and industrial application of $CO_2$, but in a smaller volume. Storage of $CO_2$ in geological formations on the Norwegian continental shelf would require transport of large volumes of $CO_2$, and there is a need for skips with larger transport capacity. The largest challenges are assumed to lie in delivery regularity and cost effective loading of $CO_2$ from a ship to an installation at sea. An alternative could be shipped transport to an intermediate store on land, connected to a pipeline out to the field.

Transport of $CO_2$ in pipes is highly similar to transport of hydrocarbon gas. The technologies are known and there is long experience with building and operation of large pipelines for transport of gas from the Norwegian continental shelf to the mainland. There is however, no experience with transport of large quantities of $CO_2$ through longer pipelines on the seabed. Such experience will only be acquired after Snøhvit comes into operation from 2007.

The most suitable method of transport will depend on need and circumstances in each case, including the number of emission sources, the volume of emission from each source, the distance from source to storage site and the volumes of $CO_2$ to be transported. With today's technology, pipe transport is considered to be the easiest and most cost effective, and from 2007 experience with transport of $CO_2$ in pipes will be acquired from the LNG plant on Snøhvit.

### Storage of $CO_2$

Norway has long experience with $CO_2$ storage in geological structures. Since 1996, 1 million tonnes $CO_2$ have been separated out during gas production at Sleipner Vest in the North Sea and stored at Utsira in a geological formation 1000 metres below the seabed. 2007 will see the start of production of natural gas, NGL, and condensate from the Snøhvit field in the Barents Sea. Treatment of the well-flow at Melkøya will result in the separation and storage of 700 000 tonnes $CO_2$ in a reservoir 2 600 metres below the seabed.

There is vast technical potential for storing $CO_2$ in geological formations around the world. Current and old oil and gas fields, and other formations are suitable for such storage. Storage in abandoned reservoirs are a geologically sound solution because the structures are most probably impervious seeing that they have already held oil and gas for millions of years. Other formations may also be deemed safe for storage of $CO_2$. The international SACS project has documented that that there has been no leak of $CO_2$ from the Sleipner field that was pumped down into the enormous Utsira formation.

The probability of a leak from geological storage is deemed to be very small. The IPCC report concludes that if storage is effectuated in a proper manner, it is highly probable (90-99 % probability) that more than 99 % of the stored $CO_2$ will still be present 100 years later. After 1000 years, it is probable (66-90 % probability) that more than 90% will still be present.

### Use of $CO_2$ for increased oil production

As the oil fields mature, the pressure in the reservoirs sinks and there is a need for additional pressure to maintain production. In some parts of the Norwegian continental shelf, water or natural gas is used to provide the extra pressure needed to maintain production. Injection of $CO_2$ can be an alternative or supplement to water or natural gas as the pressure provider. Under certain conditions, $CO_2$ can be mixed in the reservoir oil, which causes swelling of the oil and reduces its viscosity. $CO_2$ can thus contribute to increased oil production over and above that achieved with water or gas injection.

There are major challenges associated with using $CO_2$ to increase oil production from the fields of the Norwegian continental shelf. In particular, there are major costs associated with modification of existing installations and equipment for injection and post-treatment of recovered $CO_2$. Several of the possible candidates for $CO_2$ injection contain large amounts of gas, and recovered $CO_2$ must be separated from the gas in accordance with gas retail specifications. These processes require a lot of space and in many instances it will be necessary to build a new installation to accommodate the necessary equipment.

There is not necessarily concordance between access to $CO_2$ from a gas power station and the need for $CO_2$ at an oilfield. The expected lifetime of a gas power station is considerably longer than the need for $CO_2$ at an oilfield. Furthermore, the need for supplementary $CO_2$ will decrease as more and more $CO_2$ is produced in the process flow. This $CO_2$ must be separated from the process flow and be re-injected into the field. After a while, the amount of $CO_2$ produced by the process flow and reinjected will be sufficient for the oilfield, and there will be no further need for additional $CO_2$ from an external source. As the need for $CO_2$ for increased oil production is reduced, an infrastructure will become necessary for transport of $CO_2$ to storage.

An oilfield requires a constant supply of $CO_2$, if it is to be used to increase oil production. A commitment to supply $CO_2$ to an oilfield could therefore affect the operational strategy of a gas-fired power station. In order to ensure the agreed volume of $CO_2$ to the oil field the gas power manufacturer must ensure sufficient uptime of the gas-fired power station. In these circumstances, the operating strategy could be different to that where the station's primary production is linked to the relationship between power price and gas price.

Huge volumes of $CO_2$ are necessary if it is used to increase oil production. $CO_2$ from just one source (for example Kårstø) will probably not be sufficient for optimal injection in the oilfield. It could therefore be necessary to procure $CO_2$ from other sources in Norway or abroad.

### Projects to ensure progress in the work to establish a $CO_2$ chain

The government has initiated three projects to ensure the progress of the work in establishing a $CO_2$ chain and the involvement of relevant players.

Sub-project 1 covers the entire $CO_2$ chain with capture, transport and injection of $CO_2$ for increased oil production or storage. The earnings and costs for all stages of the $CO_2$ chain shall be quality assured in preliminary negotiations between the gas-fired power stations and other major point sources of $CO_2$ and the oil companies. Mapping of the players' actual willingness to pay will provide an overview of possible income in the chain, and thus also of the framework for state involvement.

Sub-project 2 will delineate the time perspective and costs of establishing a cleansing plant at Kårstø. The goal is to have established a cleansing plant at Kårstø by 2009. The work will demand close collaboration with suppliers of $CO_2$ cleansing technology. A judicial unit will also be established that will assume responsibility for tenders and procurements, construction, operation and ownership.

In sub-project 3, the Ministry of Petroleum and Energy will clarify various aspects of the organisation and the judicial framework for the national involvement in the $CO_2$ chain in cooperation with relevant Ministries.

### Cooperation between the authorities and industry

If $CO_2$ capture and storage is to be an important measure in the battle to reduce global greenhouse gas emissions, technological solutions must be found that make capture and storage of $CO_2$ a competitive alternative to other energy solutions in a global context.

Norwegian authorities are participating in international research and technology joint-ventures. At government level, the Carbon Sequestration Leadership Forum, cooperations under the jurisdiction of the International Energy Agency, and various research programs in the EU, in addition to bilateral cooperations are important arenas for collaboration and coordination.

Several prominent Norwegian research institutes and companies are participating in international collaboration projects, in which energy and supply operators cooperate with the authorities of several countries. These projects ensure that both the necessary technology developers (supply companies) and technology procurers (energy companies) participate in the technology development.

Capture and storage of $CO_2$ is an important topic in the energy dialogue with the EU Commission. The Government will cooperate with the EU commission about $CO_2$ capture and storage and its application to achieve increased oil production.

In 2005, The Norwegian Minister for Petroleum and Energy signed a joint declaration with the British Minister for Energy about geological storage of $CO_2$ in the North Sea, and appointed a Working Group for the North Sea basin. The goal is to define common principles as a foundation for the regulation of $CO_2$ storage in the North Sea.

### Gassnova SF

Gassnova is the national centre for eco-friendly gas technology and was established in 2005. The purpose of Gassnova is to promote the development of future, environmentally-friendly and cost effective gas-fired power technology. Gassnova supports projects that are at the stage between research and commercial units, such as pilot or demonstration units. In collaboration with the Norwegian Research Council, Gassnova manages the national program Climit, which supports development and demonstration of solutions for gas power stations with $CO_2$ management.

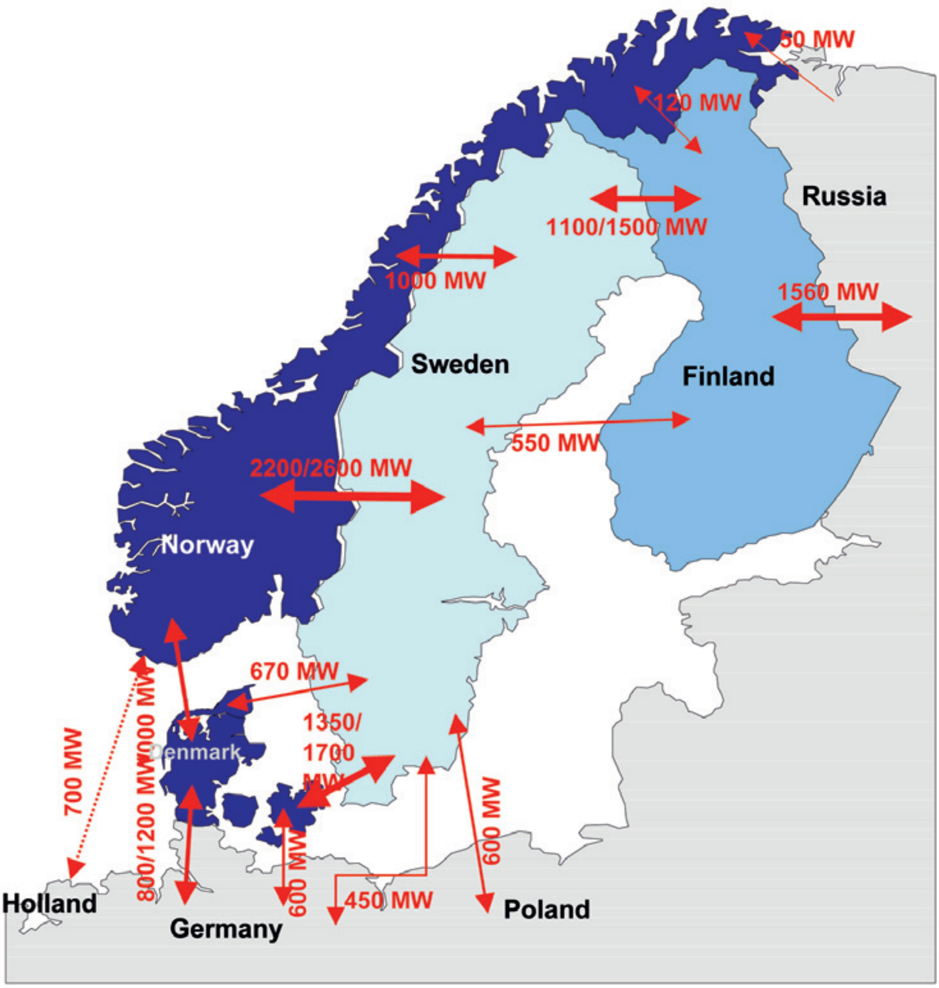
## Key figures for the energy sector for 2005, in TWh

| | Total | Change from 2004 |
|---|---|---|
| Average years' production capacity for | | |
| Norwegian hydro power (inflow series 1970-1999) | 119.8 | +0.8 |
| Production | 137.6 | +26.0 |
| Hydropower | 136.1 | +26.6 |
| Thermal power | 1.0 | +0.1 |
| Wind power | 0.5 | +0.2 |
| International trade | | |
| Import | 3.7 | -11.6 |
| Export | 15.7 | +11.9 |
| Net import | -12.0 | 23.5 |
| Net consumption | | |
| Energy intensive industry | 35.9 | +0.2 |
| Pulp and paper | 6.4 | 0 |
| Mining and other industry | 8.7 | +0.3 |
| Households, service providers, etc. | 60.6 | +0.8 |

## Net domestic end-consumption of energy, in TWh

| | Total | Coal, coke | Bio-energy | Petroleum products | Gas | Electricity | District heating |
|---|---|---|---|---|---|---|---|
| Aggregated | 225,0 | 12,1 | 12,4 | 79,2 | 6,7 | 112,2 | 2,4 |
| Industry | 81,1 | 12,1 | 4,4 | 7,2 | 6,0 | 51,0 | 0,4 |
| Energy intensive industry | 51,9 | 8,6 | 0,1 | 1,9 | 5,3 | 35,9 | 0,1 |
| Pulp and paper | 11,4 | 0,0 | 3,2 | 1,7 | 0,1 | 6,4 | 0,1 |
| Mining and other industry | 17,8 | 3,7 | 1,1 | 3,6 | 0,6 | 8,7 | 0,2 |
| Households, service providers, etc. | 84,6 | 0,0 | 8,0 | 13,6 | 0,5 | 60,6 | 2,1 |
| Transport | 59,5 | 0,0 | 0,0 | 58,7 | 0,1 | 0,6 | 0,0 |

**Transmission capacity in the Nordic region (MW))**



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| | |
|---|---|
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| St.prp. nr. 24 (2005-2006) | Om endringar av løyvingar på statsbudsjettet for 2005 m.m. under Olje- og energidepartementet |
| St.prp. nr. 49 (2004-2005) | Om løyve til overføring av vatn gjennom bygging av ein tunnel mellom Breidalsvatnet og Raudalsvatnet |

### Other

| | |
|---|---|
| Fakta 2005 | Energi- og vassdragsvirksomheten i Norge |

## Useful internet addresses:

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**Other players**

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