<table>
<thead>
<tr>
<th><strong>Relevant Work Package</strong></th>
<th>WP3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author(s)</strong></td>
<td>Ann Mari Svensson, Kari Aamodt Espegren</td>
</tr>
<tr>
<td><strong>Author email</strong></td>
<td><a href="mailto:ann.m.svensson@sintef.no">ann.m.svensson@sintef.no</a></td>
</tr>
<tr>
<td><strong>Institution(s)</strong></td>
<td>SINTEF, IFE</td>
</tr>
<tr>
<td><strong>Unique Ref. number</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Date released</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Intended audience</strong></td>
<td>HyWays partners and Member State stakeholders in Norway, as well as NorWays partners with reference to Confidentiality Agreement between HyWays and NorWays</td>
</tr>
</tbody>
</table>
| **Purpose of document**   | Within HyWays Context  
The results will be used as an input for HyWays hydrogen pathway / chain selection by LBST as well as input to the energy models (e.g. potentials for biomass, wind, CCS etc.). The results will also be used for end vision building by the transition analysis team run by ECN.  
**Task Specific**  
Reports that aim to outline the main issues that are discussed by national stakeholders regarding the present potential, the identified potentials, and the future vision for hydrogen energy at the national level in a structured way that aids ongoing discussion and provides information which could be used for purposes of comparison and selection. |
Table of Contents

Aims and objectives .................................................................................................................. 3
Current Status of Energy System ............................................................................................ 4
Projected energy system evolution ....................................................................................... 19
Overview of Policies and Measures .................................................................................. 24
Hydrogen Pathway Components ......................................................................................... 27
Conclusions .......................................................................................................................... 33
References ............................................................................................................................ 34
**Aims and objectives**

This profiling report has been prepared to provide qualitative socio-economic input to the HyWays hydrogen pathway selection process, and ultimately, to the energy modeling work. The report will be used in the end vision building process conducted by the transition analysis team led by ECN, as shown in Figure 1.

Specifically, the report will outline the main issues regarding the present potential and future vision for hydrogen in Norway, thus providing a foundation for subsequent work.

![Diagram of HyWays process](image)

*Figure 1 Member State Profiling in the HyWays process*
Current Status of Energy System

Figure 2 provides a representative overview of Norway’s general energy situation. Norwegian energy production is more than ten times higher than the domestic energy consumption.

![Energy Production and Consumption](image)

**Figure 2.** The Norwegian energy production and consumption in 2003 in TWh. Data are adapted from Statistics Norway and the Ministry of Petroleum and Energy, illustration by [Energidata 2005].

This section is divided into two parts, Energy Supply and Energy Demand, respectively.

**Energy supply**

As can be seen from Figure 2, Norway has a substantial oil and gas production primarily subject to export. With respect to electricity, the hydropower production (including a minor contribution from wind) is roughly in balance with the domestic electricity demand.

**Oil and gas**

Oil and natural gas constitute the dominant sources for the Norwegian primary energy supply (see Figure 2) and are primarily exported. The total production has increased over the years, as shown in Figure 3. Oil production has levelled out over the last years whereas gas production is steadily increasing. Norway is presently the world’s third largest exporter of oil as well as natural gas [Facts 2005, OED] and a major non-OPEC source of oil. Norway is the second-largest natural gas exporter to Western Europe, after Russia. Producers on the Norwegian continental shelf have entered into sales agreements with buyers in Germany, France, the UK, Belgium, the
Netherlands, Italy, Spain, the Czech Republic, Austria, Poland, Denmark and Switzerland, the relative amounts exported are shown in Figure 4. When Snøhvit LNG commences operation in 2007, Norway will also supply gas to the USA. The Norwegian gas transport system is extensive, totalling more than 6 600 kilometres of pipelines, equivalent to the distance between Oslo and Chicago. An overview of sub-sea pipelines for gas export is given in Figure 5. Treaties have been developed to govern rights and obligations between Norway and the countries that have landing sites for gas. Achieving the highest possible value for Norwegian petroleum resources is a paramount goal.

Figure 3. Development in oil and gas production since 1971 [Facts 2006, OED].

Figure 4. Norwegian natural gas exports 2005 [Facts 2006, OED]
Most of the fields on the Norwegian continental shelf contain both oil and gas, so that attempts must be made to achieve the optimum balance between oil and gas production. At the same time, the gas management system must facilitate efficiency in all stages of the gas chain – exploration, development and transport. All licensees on the Norwegian continental shelf are responsible for selling their own gas.

Figure 5. Sub-sea pipelines for gas export [Facts 2006, OED]

Domestic utilization of oil and gas has up to now been very limited. A local pipeline network for distribution of natural gas exists in Rogaland (south-west coast), with a capacity of 1 M scm/year. There are, however, plans for a pipeline for NG from Kårstø (Rogaland) across the country to
eastern Norway and further to Sweden and Denmark. Such a pipeline will lead to an increased domestic utilization of NG. Decisions concerning investments will be made in 2009 with a possible start-up in 2012. NG is at present also distributed as LNG to a few locations along the coast (i.e. Grenland and Sunndalsøra).

There are currently several plans for building gas-fired power plants, and the following projects have been licensed. Construction of one power plant started spring 2007 by Statoil. The other plants are not yet realized:

<table>
<thead>
<tr>
<th>Location</th>
<th>Region</th>
<th>Company</th>
<th>MW</th>
<th>TWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mongstad</td>
<td>Hordaland</td>
<td>Statoil ASA</td>
<td>280/350</td>
<td>2.2</td>
</tr>
<tr>
<td>Tjeldbergodden</td>
<td>Møre og Romsdal</td>
<td>Statoil ASA</td>
<td>920</td>
<td>7</td>
</tr>
<tr>
<td>Kollsnes</td>
<td>Hordaland</td>
<td>Naturkraft</td>
<td>390</td>
<td>3.1</td>
</tr>
<tr>
<td>Kårstø</td>
<td>Rogaland</td>
<td>Naturkraft</td>
<td>430</td>
<td>3</td>
</tr>
<tr>
<td>Skogn</td>
<td>Nord-Tr.lag</td>
<td>Industrikraft Midtnorge</td>
<td>800</td>
<td>6.4</td>
</tr>
<tr>
<td>Grenland</td>
<td>Telemark</td>
<td>Skagerak Kraft AS</td>
<td>1000</td>
<td>8.0</td>
</tr>
<tr>
<td>Melkøya</td>
<td>Finnmark</td>
<td>Statoil</td>
<td>215</td>
<td>1.5-2</td>
</tr>
</tbody>
</table>

In accordance with the new Climate Quota Act, compulsory quotas apply to gas fired power stations. The gas fired power stations planned at Kollsnes, Kårstø and Skogn will be allocated a quota if they are built before 2008. A CO₂ tax will be levied on the Snøhvit energy plant for the period under the previous Norwegian quota system.

An economic/technical evaluation of the possibilities for injection of CO₂ in the oil fields of the southern parts of the North Sea, the Troll/Oseberg area, the Tampen area and the Norwegian Sea has been performed [CO₂ report]. In all of these areas there are fields suitable for CO₂ injection (with the purpose of enhanced oil recovery). Gas fields have generally not been evaluated. The transport of CO₂ will have to occur by ship or by pipeline.

**Coal**

Norway is currently a net exporter of coal, with a minor production of around 3 million tons and a net domestic consumption of 1.6 million tons. Norway's coal production occurs on Spitsbergen of
the Svalbard Islands, north-west off the country’s northern coast, and it is operated by state-owned coal monopoly Store Norske Spitsbergen Kulkompani. The company’s main production is in Svea Nord mine, which has expected commercial reserves of 32 million tons. This island also has Norway's only coal-fired power plant, the Longyearbyen Energiverk. This information is based on [Store Norske], [Statistics Norway Energiregnskap] and [SSB Svalbard].

**Nuclear energy**

Norway has no energy-related nuclear capacity, only two small nuclear reactors for R&D purposes.

**Hydropower**

The country’s topography and hydrological status result in concentrated rainfall in the western areas leading in turn to high run-off through waterfalls and river systems. Norway is the sixth largest producer of hydropower in the world [NVE 2004], currently encompassing 620 hydroelectric plants (larger than 1 MW), with a total installed capacity of 28 300 MW [Facts OED, Energy and Water, 2006]. The Norwegian hydropower sector has been designed to accommodate variation in the natural supply of water to the power stations and to match production to seasonal changes in demand.

Around 99 % of Norway’s electricity consumption is covered by hydropower. However, in years with normal climatic conditions (precipitation and temperature) the hydropower generation potential is somewhat lower than the consumption, and import is needed. Figure 6 shows the variation in production and consumption, with respect to the average production capacity for the period 1980 to 2005. The total mean, annual, electricity generation capacity from hydropower is now estimated to be about 120 TWh. In 2003 the import was 7.9 TWh and the production 107.3 TWh (corresponding to 7% import) [NVE 2004], whereas in the years 2000 and 2005, the net production (around 140 TWh) was higher than the consumption.
Other renewables
The renewable energy resources utilised in Norway, aside from hydroelectricity, have been biomass (wood), wind and solar. Export of solar-grade silicon and solar cells has experienced a tremendous growth during the last 5 years, and the Norwegian company REC is now the world’s largest producer of silicon wafers with a market share of 30%. Domestic utilization of solar energy, however, is very limited (primarily used for lighting at cottages in remote areas without electricity grid), and will not be described further here. Due to the long coast line, several research and development projects are carried out within various ocean energy technologies (wave energy, tidal energy as well as osmotic power generation). These technologies are still at an early stage of development, and are not expected to contribute significantly to the energy production in a short to medium time frame.

Norway possesses tremendous wind resources, and the annual peak power period for a wind turbine in Norway is expected to exceed 3000 hrs at a large number of sites (4000 hrs can be expected at exposed locations). By 2006, 280 MW of wind power was installed in Norway, distributed across 138 turbines [Facts OED, Energy and Water, 2006]. License is awarded to another 10 projects, with a total capacity of around 840 MW, which means that the total
production capacity is expected to rise to over 3 TWh/year within the next few years. Support actions for wind energy (investment support of 25%) have been active a few years ago, resulting in a series of projects and a high number of license applications for building wind parks (see Figure 7).

Figure 7. Status of wind power projects in Norway, December 2006 [NVE 2006]. In operation (red), approved (green), applied (white), rejected (black).
Electricity infrastructure
The transmission grid in Norway (mainly 300 – 420 kV) connects surplus areas in Western Norway with deficit areas in Eastern Norway (see Figure 8), and it serves as a connection between regions in Norway and to import/export nodes. The regional grid (52 – 145 kV) distributes power from the transmission grid (main grid) to local distribution systems (12 – 24 kV and low voltage distribution). In sparsely populated remote areas the distribution system is designed for one way supply of existing settlements. Therefore the distribution system will normally have to be reinforced if new power generation is located in such areas. This applies in particular to the northern parts of Norway, where the potential for utilization of wind energy is high and grid capacity low. Norway has transfer capacity to Sweden, Denmark, Finland and Russia. The capacity of the two latter grids (Finland and Russia) is very small. The transfer capacity to Sweden is around 3600 MW, and to Denmark 1000 MW. The amount of energy that can be transferred between Norway and the neighboring countries is estimated to be around 20 TWh per year. In addition, a sub-sea cable to the Netherlands is under construction, with a capacity of 600+100 MW (from 2008), and a similar cable to Denmark is approved.
Figure 8. The grid system in the Nordic countries [Statnett]
**Energy Demand**

The energy consumption in Norway by far exceeds the domestic energy demand (Figure 2). Per capita energy consumption in Norway is among the highest in Europe, surpassed only by Finland, and higher than the OECD average. Net domestic energy consumption in Norway was 225 TWh in 2005, approximately the same as for the year before. Figure 9 shows the energy use by carrier and consumer category in 2005.

![Figure 9. Energy consumption by carrier and sectors in 2005 [Energy Accounts, Statistics Norway]](image)

**Stationary sector**

Stationary energy use in Norway was around 154 TWh in 2005, which was somewhat lower than the year before. The trends in stationary energy use by energy carrier from 1980 to 2005 are shown in Figure 10. Figures 9 and 10 illustrate clearly the dominant role of electricity. In 2005, stationary electricity consumption was around 112 TWh, whereas stationary energy consumption of oil products, gas, and bioenergy was 20, 6.6 and 12.4 TWh, respectively. A marked shift from oil products to electricity has taken place over the past 25 years. Since 1980, stationary oil consumption has declined by about 65 per cent, whereas consumption of electricity has increased by 50 per cent.
As is seen from Figure 9, services and households, have the highest share of the stationary energy consumption, and around 70% of the energy consumed is electricity. Another peculiarity about the Norwegian energy system is illustrated in Figure 11, showing that as much as 41% of the electricity consumed was used for thermal purposes. Around 20% of the households have only electricity as heating source (usually small houses or apartments). For households with two or more sources of heat, a combination of electricity and wood is most common. After the 1st oil crisis in 1972, there was a significant fall in the proportion of Norwegian households using paraffin or oil burners. These have largely been replaced by electric heating equipment.
Bio-energy is at present primarily utilized for domestic heating. Utilization of biomass for heating amounts to around 12-13 TWh per year [SSB]. The installed capacity for district heating is around 2.4 TWh per year [SSB] and is expected to increase in the near future, as economic incentives have been established.

Transportation sector

For demographic and geographic reasons (low population density), the demand for transportation is high. The total energy consumption of the transportation sector was around 60 TWh in 2005, and has increased steadily over the last 50 years. Over the last 15 years (1990-2004), the traveled distance has increased by approximately 60%. The fuel consumption and hence the CO₂-emissions related to road traffic have increased by 34% in the same period. The energy consumption for transport in Norway as compared to the average European energy consumption, divided by road, maritime, rail and air is shown in Figure 12. International maritime transport by the Norwegian fleet is not included.

![Figure 12. Energy consumption in the Norwegian transportation sector in comparison to average European energy consumption, divided by road (vei), ship (skip), air (luftfart) and rail (bane) [Transport and Environment]](image)

Norway has Europe’s lowest share of public transportation, and private cars account for 87% of the passenger km traveled, see Figure 13 [Transport and Environment]. The share of public transport has decreased dramatically from close to 40% in the mid 1960s, and currently 72% of all vehicles are personal cars.
Despite the very long Norwegian coast line, maritime transport only accounted for only 1.3% of the total passenger-kilometres in 2003, whereas 4.4% were covered by railway, 5.8% by airborne transportation and 88.4% by road transport [SSB 2003]. Continued growth in road traffic is expected, the government budgeting substantially more for road expansions than for railroad infrastructure improvements.

In 2003, the total mainland freight summed up to 28 billion ton-kilometres. Of the total mainland transport, Railroad took a 5.5% and Road transport a 46.6% share. The remaining 47.9% was the sum of Water transport and the so-called transport “For hire or reward and on own account” [SSB 2003]. Air transport accounts for less than 0.1%. In addition to the mainland transport close to 30 billion ton-kilometres of oil and gas is transported from the Norwegian continental shelf to the mainland (oil tankers, oil and gas pipeline transport). Trends in freight transport, according to means of transport, is shown in Figure 14 [Transport and Environment]
Figure 14. Trends in freight transport, according to means of transport; water (sjø), road (vei), rail (jernbane) and total (ialt) [Transport and Environment].

The transportation sector has been identified as a market segment within the Norwegian energy system with a substantial potential for reduction of emissions. Passenger vehicles are subject to import/purchase taxes, typically amounting to around 40% of the total vehicle cost for a medium sized family vehicle. This gives a relatively large freedom of action when related to possible use of political incentives.
Emissions related to energy use

The following chart illustrates sources of Norwegian greenhouse gas emissions in 2005:

![Pie chart showing sources of CO2 emissions in Norway, 2005]

**Road traffic**
- 23%

**Petroleum activities**
- 29%

**Other industrial processes**
- 18%

**Other mobile sources**
- 5%

**Firing**
- 16%

**Coastal traffic and fisheries**
- 9%

Figure 15. Sources of CO2 emissions in Norway, 2005 [Facts 2006 OED]

The major shares to emissions of greenhouse gases are stemming from road traffic (23%) and petroleum activities (29 %), followed by other industrial processes (metal production etc.) (18 %).
**Projected energy system evolution**

*Energy supply*

A forecast for future production from the Norwegian continental shelf is shown in Figure 16. Total production of oil and gas is expected to increase gradually up until 2011, and to fall gradually thereafter. Gas production is expected to increase until 2013 and could reach plateau at a level of 120 billion scm. From representing approximately 35 percent of the total Norwegian petroleum production in 2006, gas production is likely to continue to increase and may come to represent a share of more than 50 percent by 2013. In the longer term, the number and size of new discoveries will be a critical factor for the production level.

The Norwegian Petroleum Directorate’s estimates of total discovered and undiscovered petroleum resources on the Norwegian continental shelf are approximately 13 billion standard cubic metres of oil equivalents (scm o.e.). Around 4.3 billion scm o.e. have been recovered, 33 percent of the total resources. The remaining total recoverable resources amount to 8.8 billion scm o.e., 5.4 billion scm of which are proven resources, with an estimated 3.4 billion scm o.e. undiscovered. An overview of resources (oil and gas) and uncertainties in the estimates, are shown in Figure 17.

![Figure 16. Production forecasts Norway, oil and natural gas [Facts 2006, OED](image)](image)
There is only limited capacity for further hydropower development in Norway. Figure 18 shows that the majority of the hydropower potential in Norway is already developed, a significant part is permanently protected and only a small portion is currently under construction. The potential for increased hydropower capacity lies within small power stations and in upgrading the electricity grid. Possible damage to the environment (habitats etc.) is a barrier for realisation of small power stations.

Further increase of wind power production is expected, and there are means of public support. At present, a coverage of 25% of the investment cost is possible. This support action will be
replaced by a feed-in tariff from 2008 [Enova]. Limitations for increased utilization of wind power are primarily related to insufficient grid connections at locations of high wind, and also to problems with public acceptance (visual effects, changes to the landscape, animal life and flora). There are ongoing development projects for off-shore wind power plants. Off-shore wind power is not yet commercially viable, but the potential for large scale power plants is huge along the Norwegian coastline.

Estimated potential for increased use of waste for energy purposes is around 4-5 TWh per year, in addition around 100 000 tons per year of landfill gas (methane) [ENOVA] can be utilized (around 1 TWh per year). The annual economic potential of biomass for energy use is estimated to be around 15-25 TWh in addition to what is already being used today. Most of this biomass would be copse wood, and left-over from forestry. Utilization of farmed land is not anticipated for production of biomass for energy purposes in Norway. A significant increase in the consumption of biofuels is expected from 2007, as political awareness is increasing and at least two new, large-scale production plants for natural bio-diesel has been established. These will be based on imported vegetable oil.

**Demand**
The last major projection of the energy system was published in 1998. This short-term projection (up to 2020) of future Norwegian energy system evolution was developed by an official committee, established in 1997, and in 1998 a White Paper on the energy and power balance towards 2020 was presented [NOU 1998:11]. Four scenarios were drawn up: “Steady forward”, “Climate”, “Growth”, and “Green brainpower” together with an updated set of assumptions until the year 2020. So far, the actual energy consumption has developed in the direction of the “Climate” scenario, while the “Steady forward” scenario is characterised by higher energy consumption and lower energy prices.
Table 1 The four scenarios in the White Paper NOU 1998:11

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Increase in stationary energy consumption (2020 compared to 1995)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady forward</td>
<td>Baseline, same structure as today (weak climate agreements)</td>
<td>approx. 30 TWh/year</td>
</tr>
<tr>
<td>Climate</td>
<td>Ambitious climate agreements</td>
<td>approx. 8 TWh/year</td>
</tr>
<tr>
<td>Growth</td>
<td>Long term economic growth, technology change (weak climate agreements)</td>
<td>approx. 52 TWh/year</td>
</tr>
<tr>
<td>Green brainpower</td>
<td>Ambitious climate agreements in combination with high level of technological change</td>
<td>approx. 11 TWh/year</td>
</tr>
</tbody>
</table>

The development of renewable energies, primarily large hydro power has been important in the economic development of the country. Approximately 99 % of the electricity in Norway is produced by hydro power. In general, hydro power, wind energy and waste/biomass offer the largest potential in Norway. The estimated level of projections for the production of RES electricity in 2020 is [NOU 1998:11, Climate scenario],

- Hydro: 130 TWh/year
- Wind: 10 TWh/year
- Biomass: 3 TWh/year

which in light of the favorable conditions seems to be rather moderate. These projections were made in 1998. If the projections were made in 2006, a larger technical potential for the production of electricity from renewable energy sources would probably be forecasted in 2020.

In 2005 NVE (Norwegian Energy and Water Resources Directorate) made a new projection of the energy system towards 2020 [NVE 2005]. NVE describes a rather low growth rate in the consumption in all demand sectors; 1.1 % per year in households, tertiary sector and other industry, and no growth in heavy industry.

Longer-term projections (up to 2050) were made in 2006 by the Norwegian Commission on Low Emissions, that was charged with the task of preparing scenarios of how Norway can reduce its emissions of greenhouse gases by 50-80 % by 2050 [NOU 2006:18]. According to the reference scenario of the Commission, total energy end use will increase by 45 %, from 229 TWh in 2000 to 333 TWh in 2050. Energy consumption in the metal industry will double until 2050, while energy
use in basic chemicals and pulp and paper industry will remain constant. In other industry and the service sector there will be an increase in energy use, in average of the same level as the total growth. The increase in energy demand in the transport sector is estimated to be slightly less than the total growth. In the household sector the energy use is believed to be more than doubled as compared with today.
Overview of Policies and Measures

The main goal of the Norwegian energy policy is to ensure energy security, to increase the use of new renewable energy sources and to support and promote energy efficient solutions.

The Norwegian energy policy is described in the official paper: “St. meld. Nr. 29 Om energipolitikken (1998-99)” (Concerning energy policy), from 19 March 1999. The government prepare for an alteration in the consumption and production of energy in a way that is environmental friendly and acceptable for the welfare.

In March 2001 the Norwegian Parliament (Stortinget) approved a new financial model for energy use and energy production, see: "Ot.prp. Nr. 35 (2000-2001) Om lov om endringer i lov av 29. juni 1990 om produksjon, omforming, overføring omsetning og fordeling av energi m.m." (energiloven, Energy Act) and "Innst.O.nr.59 (2000-2001)".

Since 2002 Enova SF manages the transition to a more environmental friendly energy production and use in Norway. Enova is a public enterprise for promoting energy savings, new renewable energy sources and an ally of environmentally friendly natural gas solutions. Enova is owned by the Government of Norway, represented by the Ministry of Petroleum and Energy. Enova’s main mission is to contribute to environmentally sound and rational use and production of energy, relying on financial instruments and incentives to stimulate market actors and mechanisms to achieve national energy policy goals. Enova’s objectives are to contribute to energy efficiency and new environmentally friendly energy amounting to at least 12 TWh by 2012, where:

- a minimum of 4 TWh should be new water-based central heating systems based on new renewable energy sources, heat pumps and waste heat
- and a minimum of 3 TWh should be newly installed wind power capacity

Enova administrates the Energy Fund. The income of the Energy Fund comes from a levy of 1 øre/kWh (0.00125 €/kWh) to the distribution tariffs being mandatory. The electricity trade concessionaire adds a levy to the tariff of 1 øre/kWh for all tapping from the distribution grid to the end user, in connection with invoicing. The electricity trade concessionaire pays the Energy Fund 1 øre/kWh multiplied with the energy quantity consumed by the end users of the distribution grid.

Enova chooses the measures and administrates the fund in order to achieve the national goals in the most efficient way. The energy fund is used to project related measures as purchasing services, payment of grants and other financing of measures in the field of consumption, environmentally friendly provision of thermal energy and wind as well as use of natural gas. The fund supports projects in industry, the tertiary sector, the household sector as well as production of new, renewable energy.
Enova organizes the activities in different programmes:

- Reduced energy use – industry,
- Energy management – companies in network,
- Grants for energy savings in homes, buildings and outdoor equipment areas,
- Energy plans in municipalities,
- Grants to heating plants using bio energy, heat pumps, waste fuels or waste heat,
- Processing of bio fuel,
- New technologies,
- Wind power,
- Information and communication and
- Education and training.

**New renewable electricity production**

A new scheme for support of electricity production from new renewable energy sources was launched in October 2006. Wind power will be supported by a feed-in tariff of 8 øre/kWh (10 €/MWh) electricity produced, less mature technologies and electricity production based on bio fuels will receive 10 øre/kWh (12.5 €/MWh) and hydro power will receive 4 øre/kWh (5 €/MWh), all in addition to the market price, for production representing the first 3 MW of the installed capacity per plant. The support will be paid for 15 years, and the first year of the scheme will be 2008.

**Public budget dedicated to energy efficiency**

Most of the public budget dedicated to energy efficiency is collected by the Energy Fund. From 2005 onward no grant has been paid over the state budget to the Energy Fund. The levy on the distribution tariff was 1.0 øre/kWh (1.25 €/MWh) in 2006. In 2006 the Energy Fund had 687 MNOK in total (approximately 86 M€). In order to strengthen the priority areas of the Fund, the government proposes a new Fund called “statutory fund of energy conservation and renewable energy”. With this increase, Enova will administer 1,160 MNOK (approximately 145 M€) in 2007 and 1,600 MNOK (approximately 200 M€) after 2010.
<table>
<thead>
<tr>
<th>Policy name</th>
<th>Start year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Act</td>
<td>1990</td>
<td>Liberalization of energy market. The energy act applies to the production, conversion, transmission, trade and distribution of energy. The act will secure that production, conversion, transmission, trade and distribution of energy take place in a social efficient way considering public and private interests that are concerned.</td>
</tr>
<tr>
<td>Building regulations 1997</td>
<td>1997</td>
<td>Planning in accordance to the law will arrange coordination of national, regional and local activities and be a foundation for decisions on use and protection of resources, development, and secure aesthetic considerations.</td>
</tr>
<tr>
<td>Energy labelling</td>
<td>1996-2004</td>
<td>The regulations states demands on mandatory information on energy consumption and intend to promote energy savings of: - wash machines &amp; driers - refrigerators &amp; freezers - lightning, dishwashing, - cars - air conditioners</td>
</tr>
<tr>
<td>Energy efficiency requirements on refrigerators, freezers and their combinations</td>
<td>1999</td>
<td>A requirement on energy efficiency on new refrigerators, freezers and combinations thereof.</td>
</tr>
<tr>
<td>Energy Fund</td>
<td>2002</td>
<td>Supports measures as purchasing services, payment of grants and other financing of measures in the field of consumption, environmentally friendly heat, wind and natural gas. Includes projects in industry, the tertiary sector, the household sector as well as production of new, renewable energy.</td>
</tr>
<tr>
<td>Emission trading</td>
<td>2005</td>
<td>The emission trading system stimulates the industry, which is not covered by the present CO2-tax, to reduce their climate gas emissions. Companies not covered by the CO2-tax, are assigned emission quotas based on historical emissions in 1998-2001.</td>
</tr>
<tr>
<td>Electrical vehicles</td>
<td>2005</td>
<td>Allowed in bus lane</td>
</tr>
<tr>
<td>Purchase tax on vehicles</td>
<td>Annually updated</td>
<td>The purchase tax on vehicles is fixed according to the weight of the car, the motor volume, the motor power and CO₂ emission, with increasing tax for increasing weight, volume, power and emission</td>
</tr>
<tr>
<td>Hydrogen vehicles</td>
<td>2006</td>
<td>H₂ vehicles are exempted from purchase tax</td>
</tr>
<tr>
<td>Diesel tax</td>
<td>Annually updated</td>
<td>Diesel tax: 302 øre/liter CO₂ tax: 54 øre/liter</td>
</tr>
<tr>
<td>Petrol tax</td>
<td>Annually updated</td>
<td>Petrol tax: 417 øre/liter (sulphur free) CO₂ tax: 80 øre/liter</td>
</tr>
<tr>
<td>Bio ethanol</td>
<td>2006</td>
<td>Bio ethanol is exempted from tax</td>
</tr>
<tr>
<td>Annually tax vehicles</td>
<td>2007</td>
<td>The annually tax is related to NOx-emission.</td>
</tr>
</tbody>
</table>
Hydrogen Pathway Components

Feedstock Production

- Electricity from Renewable Energy
  Due to restrictions for installing new, large scale hydropower plants, and the fact that the demand for electricity is steadily increasing, it is not foreseen that hydrogen will be produced in substantial amounts from existing hydropower. In order to be able to utilize electricity for large scale hydrogen production (via water electrolysis), new capacity is needed. Increased electrical capacity in terms of new renewables like wind power and small scale hydropower plants is more likely to become sources for hydrogen production. An increased power production from new renewables depends to a large extent on public support, in particular the feed-in tariffs, which for the moment are at a very low level compared to similar incentives in other European countries (see previous section). Parts of the existing capacity could also be released by replacement of domestic electric heating in households. Northern Norway is considered a promising area for exploitation of wind energy. However, the grid limitations in this region limit the potential for capacity expansion, for example in the northernmost region Finnmark, increased electricity production by wind power is limited to 200 MW [Nettutviklingsplan]. Investments are required to upgrade the grid to be able to install more capacity. This may have implications for introduction of hydrogen. Direct production of hydrogen from wind power may at a certain point become economically feasible. The produced hydrogen will in turn need to be transported to the market. A break-through in hydrogen storage and distribution technologies will open for and facilitate such solutions.

- Natural Gas with CCS
  Norway’s abundant natural gas (NG) resources constitute a natural source for hydrogen production. Central reforming units could be placed at the NG landing sites along the coast, which are also the natural starting point for deposition of CO$_2$ on the continental shelf. Several oilfields on the shelf have been evaluated and found suitable for CO$_2$ depositions, and in some cases CO$_2$ could be utilized for enhanced oil recovery (EOR), which would be to some extent economically beneficial. There has been considerable support for research and development on CCS, and Norwegian industry and research institutes have developed excellent competence in this field. Since 1996, Statoil has annually deposited 1 M ton CO$_2$ in the Utsira formation, where the storage capacity is huge. A letter of intent between Statoil and the government related to establishment of a full scale CO$_2$ sequestration at the gas power plant on Mongstad was recently announced.
• **Biomass**
The economic potential for increased utilization of biomass for energy purposes is in Norway somewhere around 15-25 TWh/year. These resources will most likely be utilized for heating purposes, or for CHP, thus contributing to increased power production. Large scale hydrogen production from gasification of biomass is not anticipated. A development project related to reforming of landfill gas to hydrogen has been conducted in Drammen (company Lindum).

**Feedstock Transport**

• **Pipeline**
Infrastructure for distribution of natural gas is very limited in Norway, and only one local pipeline network exists (Rogaland). License is given for the construction of a pipeline from the south-west coast, via Grenland to Oslo, and possibly also to Sweden and Denmark, but the final decision has not yet been made, due to lack of financial support.

• **Electricity grid**
The electricity grid is well-developed, apart from remote and coastal areas, in particular in the northernmost regions (Finnmark), which poses barriers for utilization of wind energy. See Figure 7.

• **Ship**
NG is at present also distributed as LNG to a few locations along the coast, and more could be established. Liquefaction of natural gas and transportation in spherical tankers is based on technology developed by Norwegian R&D institutions (NTNU and SINTEF) in cooperation with Statoil.

**Hydrogen Production**

• **Natural gas reforming (SMR)**
Statoil, Norsk Hydro ASA and Prototech AS have activities related to hydrogen production by reforming of natural gas. Statoil has opened the first hydrogen refueling station in Stavanger, which provides fuel for a few company cars. In the longer time scale, the ambition is to provide the hydrogen from an onsite reformer. Kværner has a process where the natural gas is cracked to carbon black and hydrogen at high temperatures. They also have production facilities (in Canada), but the factory is not in operation yet. The company Carbontech has patented a similar process.
• Electrolysis
Norsk Hydro Electrolysers as (now Hydrogen Technologies) is a supplier of alkaline electrolyzers (kW) for industrial use, with capacities up to ca 500 Nm\(^3\) per hour. Smaller pressurized alkaline electrolysers are also commercially available. Their alkaline technology has been used in hydrogen filling stations (Reykjavik, Berlin). They are currently developing electrolysers based on PEM technology, which represent compact and efficient technology, with the potential of operating at elevated pressures.

• By-product hydrogen
The hydrogen capacity in Norway in 2002 was about 67000 Nm\(^3\)/hr = 0.6 Gm\(^3\)/year (including recovered hydrogen in the refineries). The future potential hydrogen by-product will be a matter of price. Including the dedicated hydrogen production for further use like ammonia production or desulphurization at the refineries there is a potential of about 2 Gm\(^3\)/year or 0.9 Gm\(^3\)/year without the dedicated hydrogen production.

The hydrogen production units are the following:

- Norsk Hydro (Rafnes) 4200 Nm\(^3\)/hr, by-product from Cl\(_2\) production, however, increased capacity to 9650 Nm\(^3\)/hr is expected summer 2005 due to expansion of the plant. In addition it will be possible to extract 44000 Nm\(^3\)/hr from the ethylene plant pending agreement from the co-owner Borealis.
- Statoil (Mongstad), 35000 Nm\(^3\)/hr, refining (average estimate), mainly dedicated for desulphurization.
- Statoil (Tjeldbergodden), about 30000 Nm\(^3\)/hr, mainly used as fuel gas
- ExxonMobil (Slagen), 10000 Nm\(^3\)/hr, refining, (recovery)
- EKA Chemicals (Mo-i-Rana) 2100 Nm\(^3\)/hr, Cl\(_2\) by-product
- Borregaard Industries (Sarpsborg), 1300 Nm\(^3\)/hr, Cl\(_2\) by-product
- Fabriker (Vadheim), 460 Nm\(^3\)/hr, Cl\(_2\) by-product
- Elkem (Svelgen), 375 Nm\(^3\)/hr, Cl\(_2\) by-product
- Yara (Herøya), 100000 ton/year hydrogen = 134000 Nm\(^3\)/hr, this is the total hydrogen production dedicated for ammonia production and not real by-production production. The amount to be used for other hydrogen uses will be a matter of price.
Hydrogen storage and transport

• **CHG**
  Raufoss Alternative Fuel Systems (part of Hexagon Composites ASA), have developed composite storage tanks for hydrogen (700 bars), which should be well suited for onboard storage of hydrogen in vehicles, and also for transport by truck.

• **Liquefaction**
  In the longer time scale, transport of liquefied hydrogen by ship produced at remote locations with no infrastructure could be a viable option. Initial R&D projects have been conducted in the field of liquefaction of hydrogen, but so far there is no industry involved.

• **Hydrogen pipelines**
  Establishment of extensive hydrogen pipeline network will be extremely costly in Norway, due to the special demographic conditions, and is not likely in the near future. NG pipelines are also very limited, so that transport of hydrogen mixed with NG (hythane) is not an option either.

End use

Due to the good availability of clean energy for stationary use, the most relevant areas for introduction of hydrogen in the Norwegian energy system appears to be the transportation sector, which contributes to 23% of the greenhouse gas emissions, and possibly also for stand-alone systems in selected remote areas. The substantial emissions related to oil and gas production (29%) could be mitigated by electrification of the installations on the continental shelf.

• **Transportation**
  o From 2006, hydrogen vehicles are exempted from purchase tax, which for conventional cars is fixed according to weight, motor volume and power and CO₂ emissions
  o Fossil fuels are subject to relatively high taxes (see Table 2), whereas bio fuels are exempted from tax. This will also be the case for hydrogen, which so far is available only for demonstration purposes.
  o Apart from one producer of small, electric vehicles, Think, there are no manufacturers of vehicles (personal cars or trucks) in Norway, such that all cars are imported. The type of vehicles available in Norway therefore relies entirely on the strategies of the international car companies.
  o Think, the producer of small electric vehicles, is also developing a hybrid car with a 10 kW fuel cell from Hydrogenics together with a 17.6 kWh Zebra battery. The
hydrogen tank, a 700 bar pressure tank from Raufoss, doubles the driving range to 250 km, and can be refilled in a few minutes. Whereas the electric vehicle Think City was commercially available a few years ago, and will be put into series production in 2007, only a few cars of Think hydrogen are planned in 2007.

- A large demonstration project was initiated in 2003, which aims at establishing a hydrogen infrastructure along the road between Oslo and Stavanger (HyNor). The first refueling station (in Stavanger) was opened in August 2006, as mentioned above. Further refueling stations are planned in Lyngdal, Grenland, Drammen and in Oslo. The opening of the refueling station in Grenland is planned in 2007, and is based on by-product hydrogen from a Cl₂ production plant. The other refueling stations are supposed to be in place from 2009. Partners in the project are the energy companies Statoil, Hydro, Vardar, Akershus energi, as well as other industry, like Lindum, Think, Raufoss fuel systems, EnTech, GassTEK, R&D institutions, transportation companies and local authorities in the respective regions. Within the HyNor project, it has been emphasised that various production technologies should be demonstrated (NG reforming, electrolysis, by-product hydrogen and hydrogen from landfill gas), and that Norwegian technology and competences in the field of hydrogen should be developed and utilised.

- **Stationary use**

Due to the fortunate energy situation in Norway, with a major part of the stationary consumption covered by hydropower, and lack of infrastructure for other energy carriers than electricity, it is not anticipated that hydrogen will play any significant role in the whole country’s stationary energy system in the near future. The most likely use of hydrogen will be “short-lived” hydrogen if pre-combustion technology is selected for CO₂ free gas power plants.

- **Stationary use in remote areas**

In Norway there are a number of small communities with either bad connections to the mainland electricity grid, or no connection at all. For such communities, introduction of hydrogen as an energy carrier in an autonomous system could be very attractive, related both to security of supply, and the possibility of utilizing renewable energy resources. A pilot project has been established by Norsk Hydro at the small island Utsira, and this is the first full-scale plant combining wind power and hydrogen. The objective of the project is to show how the combination of wind power and hydrogen can ensure a stable supply of electricity. Two Enercon 0.6 MW Wind turbines have been erected, and connected to an electrolyser from Norsk Hydro Electrolyzers, where hydrogen is produced at a rate of 10 Nm³/h, and a
pressure of 15 bar. Hydrogen is stored in vessels of 2400 Nm$^3$ at 200 bar. A fuel cell of 55 kW is installed. The energy production is approximately 5.1 GWh annually, and supports 10 domestic customers.
Conclusions

Norway possesses tremendous energy resources, both fossil and renewable, which opens the opportunity for large scale hydrogen production. At present fossil fuel-based hydrogen is most cost-competitive and is likely to remain so for the short to medium term at least. Norway is one of the major exporters of natural gas, which in principle could be utilized for production of hydrogen by reforming. For this to be an environmentally attractive option, CO$_2$ will have to be captured and stored. There are several possible locations for CO$_2$ storage (in particular oil fields) on the Norwegian continental shelf, and for some fields, CO$_2$ could possibly be utilised for enhanced oil recovery. But, although large research projects are conducted in the field of carbon sequestration and storage, the technologies are still immature, and there are uncertainties related to costs and technological barriers, which at present constitute the major obstacle for the utilization of natural gas for production of hydrogen.

Around 99% of Norway’s electricity consumption is covered by hydropower. Due to restrictions for installing new, large scale hydropower plants, new capacity is needed in order to be able to utilize electricity for large scale hydrogen production (via water electrolysis). Increased electrical capacity in terms of new renewables like wind power and small scale hydropower plants is more likely to become a source for hydrogen production. Introduction of new renewables depends to a large extent on public support, in particular the feed-in tariffs. Parts of the existing capacity could also be released by replacement of electric heating. Northern Norway is considered a promising area for exploitation of wind energy. However, the grid limitations in this region limit the potential for capacity expansion to around 650 MW. Investments are required to upgrade the grid to be able to install more capacity.

For end use, the transportation sector has been identified as the most relevant marked segment for introduction of hydrogen, since stationary energy consumption to a large extent is covered by electricity from hydropower, and the fact that the transportation sector is one of the major contributors to GHG emissions. Taxation of both vehicles and fuels is high in Norway, hence an exemption of tax for alternative fuels and vehicles acts as a driver. Stand-alone systems in remote areas are another viable option for introduction of hydrogen in Norway.

One of the major obstacles for introduction of hydrogen will be the establishment of a supply and refuelling infrastructure. The topography in combination with a low population density leads to high costs for infrastructure. There is practically no pipeline infrastructure for natural gas, and the only energy infrastructure available is the electricity grid, which, nevertheless does have a high capacity in central regions.
References


[Energy accounts, Statistics Norway]


[SSB Svalbard] Statistics Norway, http://www.ssb.no/emner/00/00/20/nos_svalbard/


[Statnett] www.statnett.no