Bellona Report No 3:1999

# Green Heat and Power

## Eco-effective
## Energy Solutions in the 21st Century

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# Preface

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Norway has emerged as a major producer of oil, gas, and hydropower during the lifetimes of the authors of this report. Our accumulated experience in working on environmental conservation spans approximately 50 years, with our main area of concentration being energy and the environment. Although river systems have been harnessed into pipes and many oil fields have been developed, on the threshold of a new century we feel confident that the majority would agree that our future energy needs cannot be based and sustained on the exploitation of the natural environment.

This report sketches how Norway can reposition itself to become an important energy supplier that can help solve environmental problems instead of create them. It is also a guide to what we think is important to know about energy and the challenges facing the environment. It is all too easy to become swamped by information, which is why we have elected to focus firmly on essentials. We not only look at the solutions of the past, we look into what the future may bring. New thinking and approaches to the problems that are as yet little known are outlined in detail. We seek to present solutions developed from a more integrated ìbig-pictureî perspective. Our target audience is people with a general interest in the subject, individuals who work with these kinds of challenges on a day-to-day basis, politicians and other decision-makers, and people who are actively engaged in research and development.

This report represents a stark contrast to the report published by the government-appointed energy commission, a commission which was unable to demonstrate how Norway could both increase energy production and decrease energy consumption, while simultaneously reducing greenhouse-gas emissions in compliance with our international commitments. The report Green Heat and Power: Eco-Eeffective Energy Solutions in the 21st Century documents that up until the year 2020 Norway can free up one sixth of the electricity produced, reduce $CO_2$ emissions by over 50%, produce 50 TWh of renewable energy, and export large amounts of ìcleanî fossil fuels such as hydrogen and electricity. We have only proposed measures up until 2010, partly because the world will have changed by that time, and because the best means of predicting the future is to be part of creating it.

Oslo, June 1999

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# Summary

## Energy and the environmental challenge.

In the course of the last century, the world`s consumption of energy has increased by a factor of twenty. This has resulted in a series of environmental problems, including local air pollution, acid rain, the threat of climate changes and discharges to soil and water.

## Norway as an energy producing nation.

In a geopolitical sense, Norway is only a small country; as an energy producer, however, it is an important power in Western Europe, controlling 75% of the oil reserves, 45 % of the gas reserves and 30% of hydroelectric power production, while its population constitutes only 1%.

## Three key approaches.

The challenge of balancing environment and energy needs can be met by producing more renewable energy, using cleaner production methods, and prioritizing energy efficiency.

## Renewable energy.

The amount of solar energy that strikes the earth in the course of a year is equivalent to approximately 15,000 times the world`s annual energy consumption. In terms of capacity, renewable energy resources have the potential to meet all energy needs. By eliminating the current system of subsidies and creating a tax system for traditional energy sources that would cover the social costs associated with energy consumption, renewable energy could be competitive even in today`s market.

## Cleaner fossil fuels.

In the transition phase to a system of renewable energy, it is possible to meet all energy needs in a cleaner way by converting fossil fuel into electricity and hydrogen. A certain amount of the fossil fuel would have to go towards removing and storing the $CO_2$ that is generated by combustion.

## Energy efficiency.

Any use of energy affects the natural environment in some way. If we are to ensure a satisfactory quality of life also for future generations, then energy must be used more effectively. More than half of the climate problems we face would be eliminated if energy could be used efficiently in ways that simultaneously saved money.

## Three benefits of energy.

We produce energy to meet our heating and cooling needs, to produce electricity, and to perform mechanical labor. Pollution is an unwanted side effect of this energy production.

## Energy and environmental goals.

Since there are no justifiable grounds for pollution, the only logical goal from both an energy and an environmental perspective is that all production and use of energy should take place without discharges or encroachments that could harm the environment.

## Environmentally efficient energy consumption.

An environmentally efficient consumption of energy essentially means that clean energy of the right quality is used as effectively as possible.

## Green Heat and Power.

This report sketches how Norway can position itself to become a major energy producer that contributes to solving environmental problems instead of creating them., By year 2020, savings in consumption can free up one-sixth of the electricity produced in Norway, reduce $CO_2$ emissions by over 50%, produce 50 TWh of renewable energy, and simultaneously export large amounts of ìcleanî fossil fuel. A selection of the most important conclusions and proposals are presented here:

## From energy production to technology production

- To move away from our historical wastful use of fossil fuels towards more effective use of renewable energy implies a transition. This will require a change in labor skills from traditional power production to the production of renewable power producing technologies. For example, the international oil company Shell expects to create more jobs in solar energy technology than in oil and gas production as early as 2030.
- To ensure Norwegian profits in the energy market of the future, Norway must now prioritize and commit to to those areas of research and development where Norway has already established its expertise. The most promising possibilities fall within the following sectors: production and storage of hydrogen for European transportation sector; production of solar cells based on Norwegian siliesium and hydroelectric power; utilization of energy released from waste incinceration; and the production of light-weight materials and components for the transportation industry.

## Renewable energy

- Bellona assumes that the realistic potential for Norwegian development of biomass energy ,wind power, miniature hydroelectric power plants, saline power, heat pumps, geothermal energy, and solar heating is around 80 TWh.
- Renewable energy often requires large investments but little maintenance and operation. Bellona therefore proposes a waiver of value-added tax and investment taxes for all new renewable energy sources. This represents subsidization of 8-10 øre per kWh for the first five years.
- To create a large profitable market for renewable energy, Bellona proposes that energy suppliers in Norway (utility and oil companies) be required to sell a minimum percentage of power originating from renewable energy resources, starting at 2% in 2002 and increasing to 5% by 2005. This is the decidedly most effective political mea-

sure, both in terms of minimal development costs and a more certain attainment of the goal.

- Every year, just under 4 TWh of potential energy from garbage is dumped into Norwegian landfills where it decomposes, emitting the greenhouse gas methane. The least expensive large-scale operation Norway could undertake, for the benefit of the climate, would be to incinerate this waste with energy savings of 3-4 TWh. Furthermore, 30 TWh of surplus heat from Norwegian industry runs right into the sea. These existing waste energies are «environmentally free,» i.e., their use will not have an additional impact, and should therefore be treated in the same way as renewable energy sources.

## Energy efficiency

- The cheapest electrical power that can be developed in Norway today is probably the recycling of 1.4 TWh of surplus heat from the smelting industry at about 14 øre/kWh.
- Electric radiators utilize only 7% of the heating capability of electricity. Bellona suggests that Norway follow the example of Denmark and Sweden by prohibiting the use of electric radiators as the principal means of heating in most new buildings. The market can thereby choose freely between water-based heating alternatives and heat pumps.
- Nowadays, electric utility companies are required to build electricity grids for residential heating, even when district heating based on renewable energy would be much less expensive. Bellona considers that the interpretation of § 3 of the Energy Act should be amended to allow power companies to deliver district heating to new construction (buildings) when this would save money.
- Due to the low cost of electricity in Norway, the consumption of electricity has grown much faster than in Denmark and Sweden. Bellona proposes a reduction of one percentage point in the value-added tax while simultaneously increasing the price of electricity by 5 øre per kWh on all use of electricity, except that which is used in the production of materials in industry sectors that require a high outlay of electricity. There would be no tax increase resulting from this initiative.

## Cleaner fossil fuel

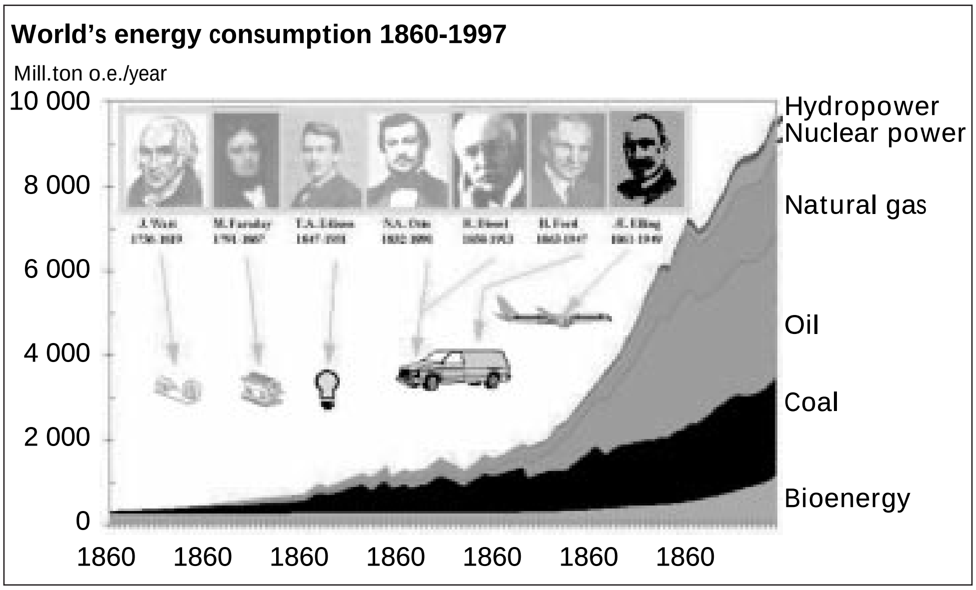
- Simply increasing energy efficiency and developing renewable energy sources will not be enough to achieve greater reduction in carbon dioxide emissions in Norway and Europe. Therefore it will be necessary to cleanse some of the discharges and to store the gas. Probably the cheapest emissions sources to cleanse are the large discharges released in connection with the production of electricity from gas and coal.
- Enormous amounts of natural gas are used to generate underground pressure in the North Sea. If this gas were to be incinerated and the waste gas $CO_2$ used to generate underground pressure instead, by the year 2020 Norway would have 25 emissions-free gas-based power plants based on 40 billion Sm3 of gas. This energy could be sold to the continent as electricity and hydrogen, and become a central pillar of the European Union`s climate policy.
- Carbon dioxide emissions on the Norwegian shelf could be halved by connecting the oil platforms, optimizing production, Combined Heat and Power, processing on the seabed, and increasing the utilization of process heat. If current carbon taxes were to be directed towards measures for reducing emissions through a $CO_2$ (carbon) fund, emissions could be significantly reduced.

## Hydrogen and electricity in the transportation sector

- Realistically, it is not possible to cleanse $CO_2$ emissions from the transportation sector. Therefore in the future, this sector should be supplied with carbon-free fuels such as hydrogen and electricity. Both these forms of energy would have the effect of eliminating all other forms of emissions from combustion engines of the present day. Hydrogen and electricity can be produced very easily from both fossil and renewable energy resources. Norway and Norwegian companies should be encouraged to prioritize research and development in the storage of hydrogen based on natural gas.
- The utilization of hydrogen in fuel cells (is far more efficient than combustion engines and traditional gas-driven power plants. Within five years this technology will be commonly used. By 2002 there will be fuel-cell buses, and most major car manufacturers will be mass producing fuel-cell cars from 2004. With the right kinds of investments, Norway could deliver hydrogen and electricity to this market.

# Chapter 1

# The Energy and Environment Challenge



**Figur 1.1**
Graphic: Statoil

## 1.1.

## Three sources of fossil fuel

Approximately 80% of the world's energy consumption is based on three sources of fossil fuel: coal, oil, and natural gas. This has resulted in a number of environmental problems, including local air pollution, discharges to soil and water, acid rain, and the risk of climate changes. To hinder irreversible changes in the climate, the United Nations panel on climate (the IPCC, The Intergovernmental Panel on Climate Change) has estimated that global $CO_2$ emissions will have to be reduced 50-60% over the next 100 years. This means that developed countries will have to reduce their emissions drastically to allow developing countries a certain increase. Such dramatic reductions will require a total overhaul of the world's energy systems. [(Storting Report No. 29 (1997-98)]

### 1.1.1.

### Three key factors

Over the course of the last 100 years, the world's consumption of energy based on fossil fuels has increased by a factor of 20. The last 40 years in particular have seen the greatest increases. There are three key factors that play a role in determining how to best utilize the qualities of the different fossil fuels:

- Physical properties
- Energy content
- Environmental consequences

The physical properties of the different energy sources has always been an important factor in mankind's ability to make use of the energy. Coal comes in the form of a solid, oil in liquid form, and natural gas in the form of a gas. Coal has historically been the easiest of the three to utilize, followed by oil, and finally natural gas.

The energy content of the different energy sources has significance for their future growth potential on a global scale. It is the amount of the hydrogen that determines the energy content. The greater the concentration of hydrogen, the greater the energy content. Coal has the lowest concentration of hydrogen, while natural gas has the highest.

The environmental impact of utilizing these energy sources depends, in turn, on the individual qualities of the different energy sources. The higher the carbon content, the more $CO_2$ that is produced from combustion. The content of particles and heavier components is also greater in a solid, such as coal, than in a gas.

If we continue to burn fossil fuel at our present rate, we could experience a quadrupling of world $CO_2$ emissions over the course of the next 125 years as a consequence of population growth and increased energy demands. [Lindeberg 1998]. According to the International Energy Agency (IEA), emissions generated by world energy consumption will increase by 70% until 2020. Natural gas continues to increase its percentage of the world's energy supply, oil continues to drop even though the oil consumption has increased, while coal remains unchanged.

## 1.2.
## Three principle sources of energy in Norway

Three sources of energy dominate Norwegian energy production:

- Oil
- Natural gas
- Hydropower

Norway controls 75% of Western European oil reserves, 45 % of the natural gas reserves, and 30% of the hydropower; yet its population constitutes only about 1% of the total Western European population [Elkem/Norsk Hydro 1999]. Norway is the world's second largest oil producer exporter and fourth largest natural-gas producerexporter, while it is Europe's largest and the world's sixth largest producer of hydropower. Even in 1995, Norway's export of $CO_2$ in the form of oil and gas constituted over 1/2 billion metric tons. [Export figures from OED calculated for $CO_2$]

In 1997, Norway's total primary energy production was approximately 2520 TWh, while its net export was 2300 TWh. [ABB 1999] In other words, Norway produces much more energy than it uses, which places it in a unique position compared to most other OECD countries. It is also unique in that a large proportion of Norwegian generation of electricity is based on hydropower.

Opposition to further development of hydropower has been a central pillar of the Norwegian environmental movement, with the campaigns over Mardøla and Alta being the most prominent. By 1981, 8,700 km of Norwegian rivers had been regulated, of which 950 km were completely or almost dry (that is, the flow of water was less than 10% of what it originally used to be). Of the world's 15 highest waterfalls, eight are situated in Norway. Only two of these remain undeveloped. Today, the total reservoir area variation, i.e., the difference of area covered by water in the reservoirs between the highest and lowest water levels allowed, amounts to 2,160 km2, an area which corresponds to Vestfold county in size [SRN 1992]. The great era of hydropower development is now considered to be in the past.

Despite the considerable contribution of hydropower, Norwegian $CO_2$ emissions per inhabitant corresponds to that of other Western European nations where certain coal-producing nations drive up the figures. Assuming a world population of approximately 10 billion inhabitants in the next century and a simultaneous ban on any increase in $CO_2$ emissions, Norwegian emissions would have to be reduced by more than 75%.

From 1990 to 2010, Norwegian $CO_2$ emissions are expected to increase by as much as 43%. The major reason for this jump comes as a result of increased emissions from the petroleum industry. Furthermore, emissions from the transportation sector and the use of oil for heating purposes are both expected to increase. [Storting Report No. 29 (1997-98)]

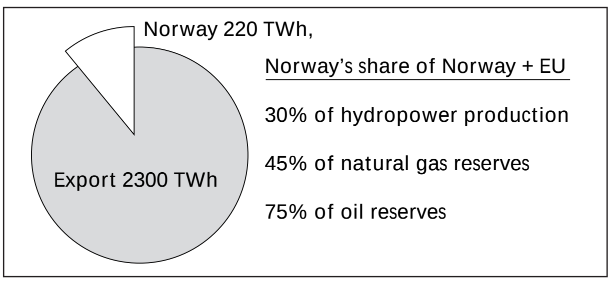


**Figure 1.2**
Production of energy in Norway 1997; oil, natural gas, and electricity
Source: Elkem/Norsk Hydro 1999

## 1.3.
## Three uses of energy

The purpose of producing energy is to meet three types of societal needs:

- Mechanical work (electrical equipment, for example)
- Heating supply
- Heat removal (cooling systems)

*Energy* does not disappear, it merely changes form. Different forms of energy have different qualities and degrees of usefulness.

Mechanical work is a highly efficient use of energy that we use to operate machines and carry out work. Heating and cooling are low-grade uses of energy. The lower the temperature level required for heating, the lower the physical value or quality of the energy function.

*Exergy* is the energy that can be actually be utilized for mechanical work and all other purposes of energy. Electric energy is pure exergy - it can, in its entirety, be transformed into mechanical work. Therefore electricity is one means of transporting mechanical work.

Even though large amounts of lukewarm water contain enormous amounts of energy as measured in kilowatt hours, this energy cannot be transformed into electricity or mechanical work. Hence the exergy value is nil, and the heat in lukewarm water is, from a physical point of view, a low-grade form of energy.

*Heat* for the purpose of heating rooms and maintaining them at a comfortable temperature is supplied to compensate for the loss of heat to the surroundings. No matter how high the temperature may be in the room's heat source, the room temperature remains at the desired temperature level. In other words, the heating of rooms is a use of energy with a very low value. It means that energy is wasted when highly efficient energy is used for heating houses. [SINTEF 1997]

It is important to point out that pollution is not a beneficial result of energy use: No one has any use for pollution. Pollution is an undesirable by-product. Since the grounds for existence of any energy company is to supply the three energy uses mentioned earlier, it could be argued that the company is «out of business» when it pollutes. Polluting is prohibited in Norway.

Pollution today can also be described as resources gone astray. The OECD economies are only 2-3% energy efficient in relation to their theoretical potential. To illustrate: a modern car utilizes only 1% of its gasoline energy to move the driver. [Lovins 1997] The emissions «steal» from the energy source in its final stages and constitutes a costly loss to society both in terms of energy waste and environmental damage. The energy, instead of being useful, has the effect of causing damage instead.

Hence there is no justification for pollution from an energy perspective. The logical goal for both energy and the environment must therefore be as follows:

All production and use of energy must occur without emissions or encroachments that adversely affect the natural environment.

## 1.4.

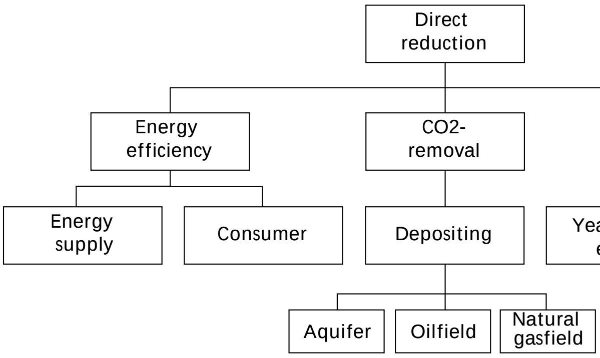


**Figure 1.4**
Choices and methods for reducing emissions of greenhouse gases from the energy industry

# Three key solutions

To a large extent, the challenge posed by meeting both energy and environment needs can be met in three ways:

- Cleaner fossil fuel
- Renewable energy
- Energy efficiency

## 1.4.1.
## Cleaner fossil fuels

To avoid irreparable damage to the environment as a consequence of burning fossil fuels, energy production must become cleaner and the use of energy more effective.

In a world where energy needs are constantly increasing, it will be difficult in the short term to replace all the forms that use of fossil fuels take. However, in a transition period, every energy need can be covered virtually pollution free–at a modest cost by converting fossil energy into electricity and hydrogen.

To avoid dramatic climate changes, some of the energy must be used to remove the $CO_2$ generated by combustion or conversion. It is possible to deposit the amount of $CO_2$ equivalent to the emissions from all the power plants in Western Europe for 525 years into aquifers and the offshore oilfields of the North Sea. Norway controls 2/3 of this European offshore storage capacity for $CO_2$.

Close proximity to primary energy resources gives Norway an advantage in the development of new, environmentally sound technologies within the energy sector. A future-oriented industry could be established for the production of large amounts of clean energy, which would constitute an unavoidable challenge to the other major fossil fuel industry: the coal industry.

## 1.4.2.
## Renewable energy

The amount of solar energy that reaches the earth in the course of one year is equivalent to about 15,000 times the entire world's annual energy consumption. Renewable energy is now experiencing a drop in production costs corresponding to the mid 1950s when oil took over as the leading energy carrier. By eliminating the current system of subsidies and creating a tax system for traditional energy sources that would cover the social costs associated with energy consumption, renewable energy could be competitive even in today's market.) .

In the next 15 years, the United States Department of

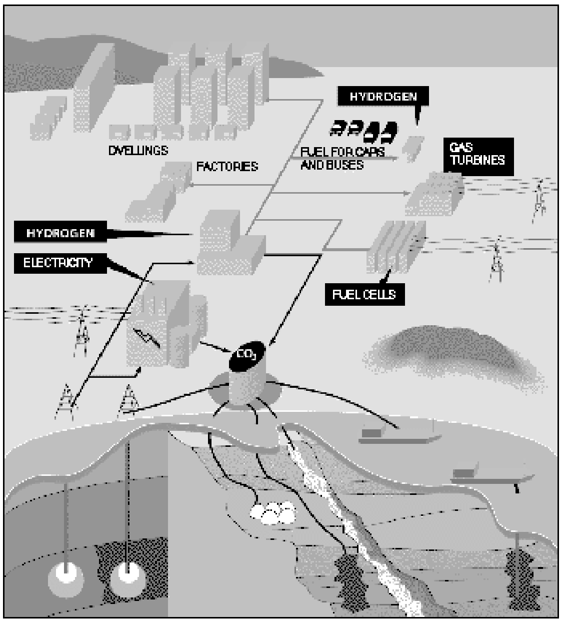


**Figure 1.4.1.**
Various energy needs can be met by using fossil energy sources with practically no harmful emissions to the environment

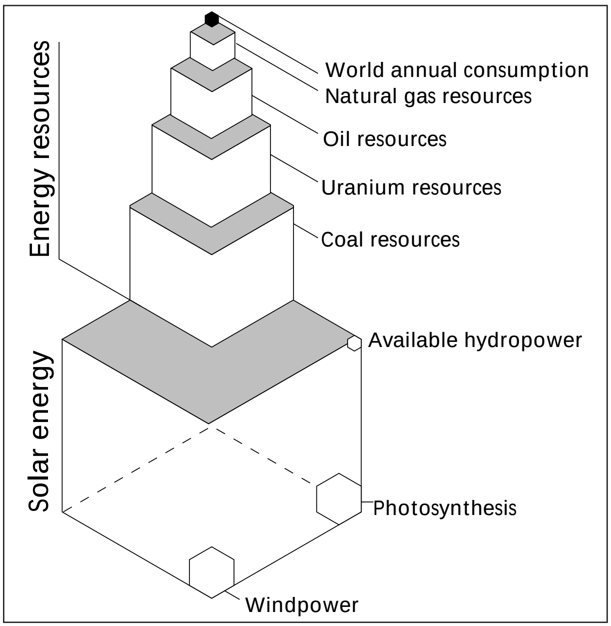


**Figure 1.4.2**
The amount of solar energy that reaches the earth, energy resources and annual consumption

Energy envisages that sustainable energy will be the fastest growing form of energy. Sustainable energy can realistically meet 30% of global energy needs by 2020, that is, eight times as much as in the 1990s. [NVE 1996]. In a Shell scenario, renewable sources of energy have the potential to provide more than half of the world's energy supply by 2050. Half of the renewable energy would be directly used in its original form, while hydrogen as the energy carrier would supply the other half.

New sources of renewable energy are a local resource and represent renewable energy systems of the future. Norway shows great promise as a potential producer and supplier of technology for new sources of renewable energy. As one of the world's wealthiest nations and a major exporter of fossil fuels, Norway has an international responsibility to invest in the development and utilization of new sources of renewable energy. The poorer developing countries cannot be expected to bear these kinds of costs.

### 1.4.3.
### Energy efficiency

All production and use of energy have an impact on the natural environment. The energy consumption of today's generations should not exceed that which is necessary to ensure a satisfactory quality of life for coming generations; hence the available energy must be used more effectively. Over half of the current climate problems would cease to exist if energy were used in a more efficient and cost-effective manner. [Lovins 1997]. Although many years of effort aimed at improving labor productivity have yielded positive results, there has been no corresponding development in energy efficiency.

Norway has the world's highest per capita consumption of electricity. To illustrate, Norwegians consume four times as much electricity as Danish, German, and Japanese citizens. Norway is a major exporter of energy-intensive materials, but even if energy-intensive industries were excluded, the country still has an extraordinarily high electricity consumption as compared to most other nations. Norway uses 40 TWh of electricity for heating. No other country matches this figure. The total per capita energy consumption in Norway is roughly equivalent to approximately 5.3 metric tons of oil while France, Germany and Denmark are at about 4 metric tons.

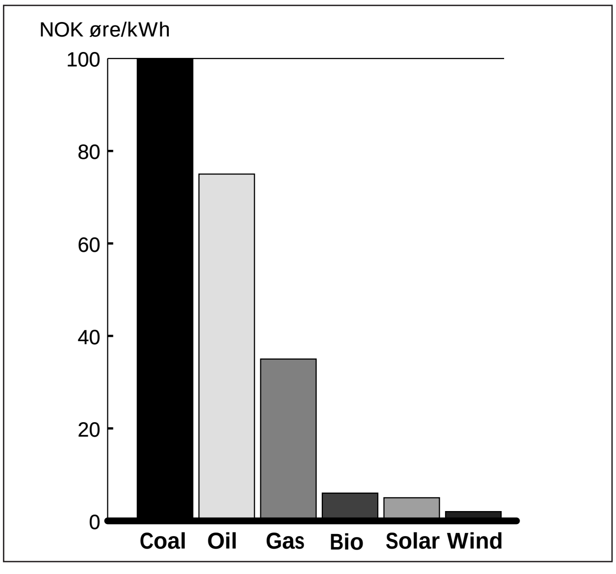


**Figure 1.4.3.**
Environmental costs of various energy sources (additional øre/kWh)

Energy efficiency entails not only consuming as little energy as technically possible, but also using the quality of energy in the most appropriate way. Fossil energy need not necessarily be wasteful; it can also be used very efficiently. In essence therefore, an environmentally efficient use of energy implies the use of clean energy of the right quality, and as effectively as technically possible:

Environmentally efficient energy consumption = clean energy + correct quality + efficient use

## 1.5.
## Three sources of emissions to the environment

The use of fossil fuel energy carriers generates emissions to the air, the general causes and consequences of which are possible to explain. In contrast, direct emissions to the soil and water are to a large degree are caused by a wider variety of production and consumption activities. Here, the focus is on emissions into the air, while other relevant types of emissions will be discussed in more detail in subsequent chapters.

- There are three sources of emissions to the air:
- Stationary combustion
- Mobile combustion
- Processing

**Stationary combustion** includes emissions from all burning of energy forms in different types of stationary installations. For example, gas turbines on production platforms and oil burning as a source of heat.

**Mobile combustion** includes emissions from all burning of energy forms in connection with means of transportation and mobile tools, for example combustion engines in automobiles and boats.

**Processing** includes all emissions that are not connected to combustion, as for example coal and coke which are used as reducing materials in metal production and waste disposal emissions.

Since industrial processes, evaporation, biological processes and certain types of dust and so forth are considered to be «process emissions,» they must be evaluated on an individual basis as to their relation to energy consumption.

### 1.5.1
### Three major kinds of emissions and their consequences

Emissions to the air from the energy industry result in a series of impacts to the environment. In Norway, the focus is predominantly on the following:

- Carbon dioxide ($CO_2$)
- Nitrogen dioxides ($NO_x$)
- Non-methane volatile organic compounds (NMVOC)

**Carbon dioxide** is created through the combustion of carbon-containing fuels. Carbon dioxide makes up approximately 70% of the emissions in Norway that contribute to the increased greenhouse effect. An increase in the global temperature will lead to a rise in sea level, changes in precipitation and wind patterns, losses in biodiversity), and deteriorating living conditions, especially in the poorer parts of

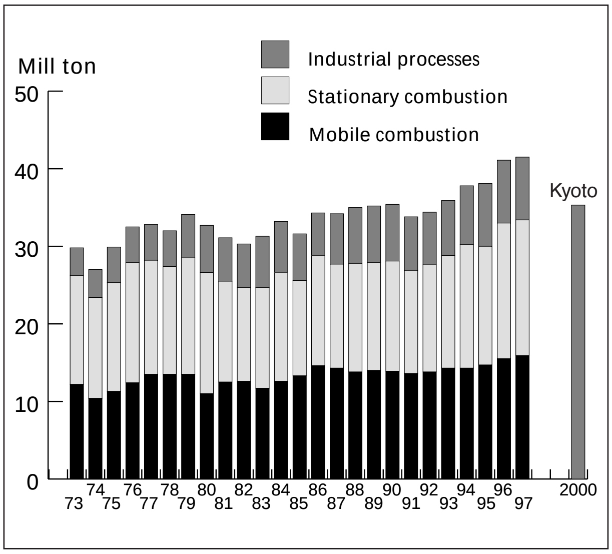


**Figure 1.5.1a**
CO2 emissions by source

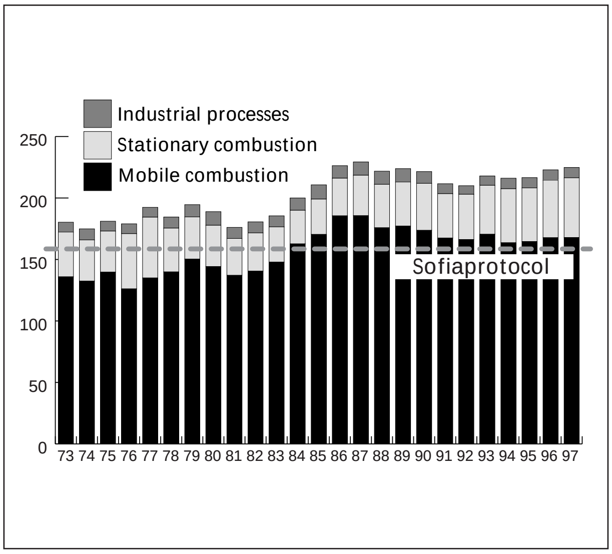


**Figure 1.5.1b**
NOxx emissions by source

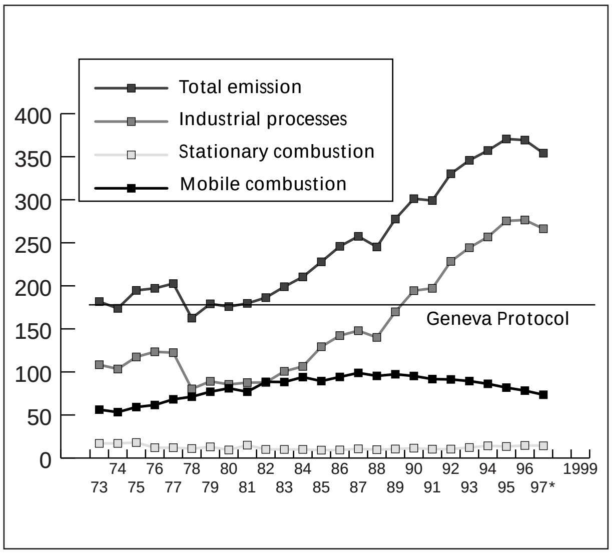


**Figure 1.5.1c**
Emissions of NMVOC by source

the world. Carbon dioxide emissions have increased by 16% since 1990, while Norway had previously set a goal of stabilizing emissions at 1989 levels by the year 2000. Norway has signed the Kyoto Protocol, according to which the industrial nations would reduce their collected emissions to 1990 levels in the period 2008-2012. However, Norway negotiated a 1% increase in its emissions in relation to 1990 levels.

**Nitrogen dioxides** is a general term for the gases nitrogen oxide (NO) and nitrogen dioxide ($NO_2$), both of which are formed in combustion processes. The actual amount of emissions released is governed by the amount and type of fuel, and combustion conditions. Nitrogen dioxides leads to respiratory conditions and contributes to acidification of water systems and damage to fish populations, plant life and materials, as well as increasing the formation of ground level ozone. The majority of NOx emissions originate from road transportation, oil extraction, and marine transport.

Norway has fulfilled the objective in the Sofia Protocol to stabilize emissions at 1987 levels by 1994. Furthermore, Norway has signed an agreement to reduce emissions by 30% to 1986 levels by 1998, but thus far a reduction of less than 1% has been attained. In the period from 1992 to 1996, emissions from permanent installations in the petroleum industry increased by 30%, and the increase from the naval sector was even greater. Negotiations are now underway for a new NOx protocol based on the natural environment's apparent ability to tolerate acid rain and ground level ozone. Ways to reduce NOx emissions are discussed in greater detail in the chapters on fossil energy and hydrogen.

**Non-methane volatile organic compounds** (NMVOCs) form ground level ozone through a chemical reaction with NOx which is influenced by sunlight. Overly high concentrations of ground level ozone can cause respiratory problems, have a negative effect on agricultural crops and forests, and can result in acute damage to other vegetation. The main contributions to this effect coming from Norway take the form of these volatile elements evaporating from the crude oil (accounting for 53% of the emissions) and the emissions from gasoline-driven vehicles (13%). As a signatory to the Geneva Protocol, Norway is committed to reducing its emissions by 30% of 1989 levels before 1999. Nonetheless, emissions have increased by 27%. The bulk of this increase may be attributed to increased offshore loading of crude oil. At this time, a new NMVOC protocol is under negotiation. Ways to reduce NMVOC emissions are examined more closely in the chapter on fossil fuel.

### 1.5.2.

## A closer look at greenhouse gas emissions in Norway

As of 1996, total Norwegian emissions of greenhouse gases approached 59 millions metric tons of $CO_2$ equivalent distributed gases as follows:

*Carbon dioxide* constituted 70% of all emissions. The four most important sources in Norway are the petroleum industry (23%), road traffic (22%), oil heating (21%, in which coal and natural gas heating are also included), and industrial processes (18%).

*Methane* ($CH_4$) comprises 17% of the emissions. These emissions are largely due to biological decomposition of organic material without access to oxygen. Waste depositories account for 67% of the emissions while livestock and slurry comprise 23%.

*Nitrous Oxide* (N2O) constitutes 10% of Norwegian emissions. The use of nitrogen-rich artificial and animal fertilizers in agriculture accounts for 52% of this type of emissions, while 29% is connected to the production of nitric acid in the manufacturing of nitrogen-rich artificial fertilizer.

*Fluorine gases* comprise approximately 3% of the emissions. In the period from 1990 to 1996, emissions of PFC and SF6 were reduced by 43% and 77% respectively through measures taken in process industries. HFC emissions are on the increase because it is this gas that has replaced CFC and HCFC in refrigerating and cooling equipment, but it constitutes only a very small fraction of the total emissions. (Because HFCs have replaced CFCs and HCFCs in refrigeration and cooling equipment, they are on the increase but nevertheless represent a very small fraction of the total emissions.)

Due to the dramatic increase in $CO_2$ emissions resulting from the use of oil heating as well as the petroleum industry and the transport sector, the total combined greenhouse gas emissions have increased by nearly 7% from 1990 to 1996. The prognosis is for a 23% increase in combined emissions from 1990 to 2010. This is because $CO_2$ emissions in 2010 are expected to be 43% higher than in 1990, while emissions from the other greenhouse gases will decrease somewhat. The most important reason for this growth is the increase in emissions from the petroleum sector. Furthermore, emissions from the transportation sector and oil heating are expected to increase, even though a majority in the Norwegian parliament, Stortinget, voted to phase out the use of heating oil in connection with deliberations over the Kyoto Protocol.

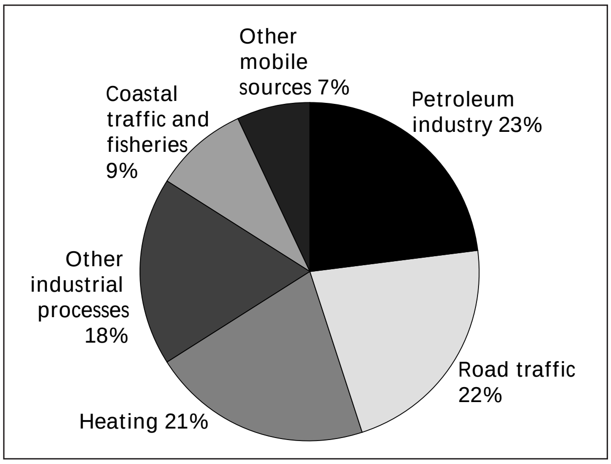


**Figure 1.5.2a**
Sources of greenhouse gas emissions in Norway (1996)

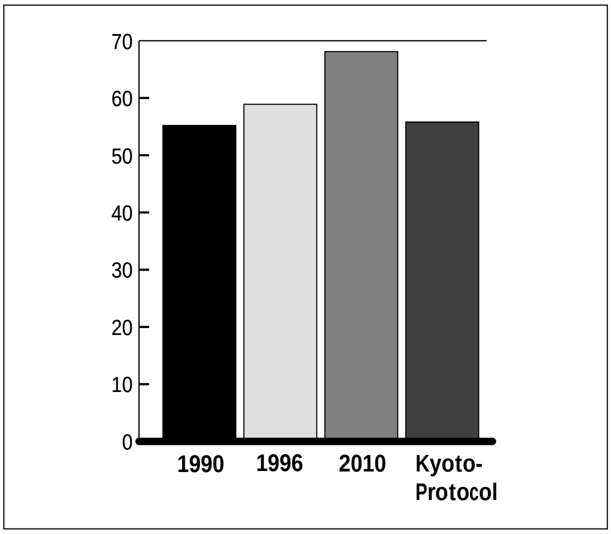


**Figure 1.5.2b**
Projections for greenhouse gases in relation to Kyoto Protocol requirements

## Chapter 2

# Fossil fuel

In 1996, the world`s energy consumption lay at 9,300 million metric tons of oil equivalents [BP], corresponding to 115,000 TWh of thermal energy. Of this, fossil fuels such as coal, oil, and natural gas constituted 36%, 24% and 21% respectively. These figures include only commercial energy sources and not local use of wood, manure, and other sources that make a significant contribution in many other parts of the world.

While debate in the 1970s centered on the desirability of depleting fossil fuel resources, reserve estimates for these resources have actually increased. Current estimates of fossil energy sources indicate that if all of these fuels were to be utilized, the proportion of CO2 in the atmosphere would be quadrupled [Bolin et al 1996].

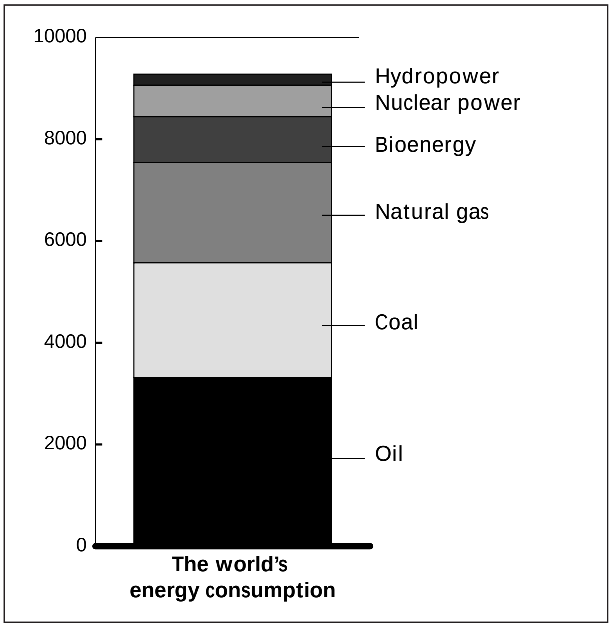


**Figure 2a**
The world`s energy consumption (million metric tons of oil equivalents)

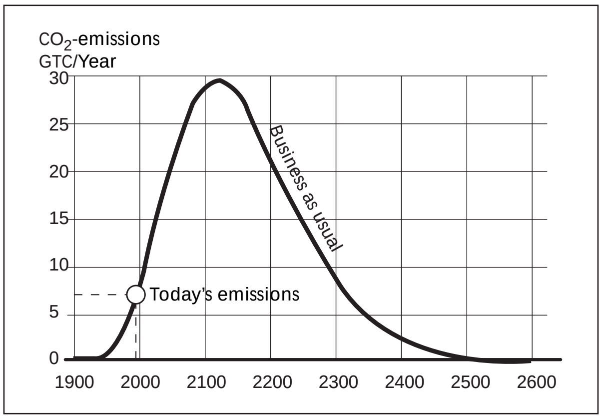


**Figure 2b**
Scenario for CO2 emissions

If fossil energy continues to be used in the same manner as it is today, a quadrupling of the world`s CO2 emissions could be experienced in the course of 120-130 years. This assumes an increase of the world`s population to 11.3 billion people by the year 2100 [World Bank estimate 1992]. This growth is estimated to occur only in the developing countries. It is also assumed that the increase in CO2 emissions will only occur in developing countries, but that the energy consumption of these countries will not increase to more than half of the levels that currently exist in industrialized countries. Zero population growth and no increase in the consumption of fossil fuels are expected for the industrialized countries. [Lindeberg 1998]

For purposes of comparison, the United Nation's Intergovernmental Panel on Climate Change (IPCC) claims that emissions must be reduced by 50-60%. In a world where energy needs are constantly increasing, it may be difficult over the short term to sufficiently find substitutes for all forms of fossil fuel consumption. In order to hinder climate changes, it will therefore be necessary to use some of the fossil energy to remove the CO2 that is generated by combustion.

## 2.1.

## Energy Carriers

When consumers receive energy from fossil fuel energy sources, it rarely takes the form of the original source. Instead, it is usually delivered in the form of different energy carriers that are produced from these raw materials. For example, 75% of the industrial nations' coal consumption goes towards electricity production and district heat, while most of the remaining 25% is used in the production of steel and cement. To a large extent, oil is refined into products such as gasoline, diesel, and heating oil, at the same time that there is an increasing number of products based on more complicated oil conversion processes. Natural gas has traditionally been used for heating purposes, but is increasingly being converted to electricity, and to some degree, methanol. [Kårstad 1993]

In the preceding chapter, it was asserted that there were three basic factors governing the utilization of the various forms of fossil energy: physical property, energy content, and environmental impact. As stated earlier, physical property determines much of mankind's ability to utilize the various sources of energy, and the energy content dictates the degree to which they are used, while the environmental consequences are steadily increasing in importance.

A glance at the collected factors shows the following historical pattern:

⇨ From coal (solid substance - least hydrogen / mostly car bon)
↳ Via oil (liquid - more hydrogen / less carbon)
↳ And natural gas (most hydrogen / least carbon)
↳ To Hydrogen. Hydrogen is the lightest of all the ele-

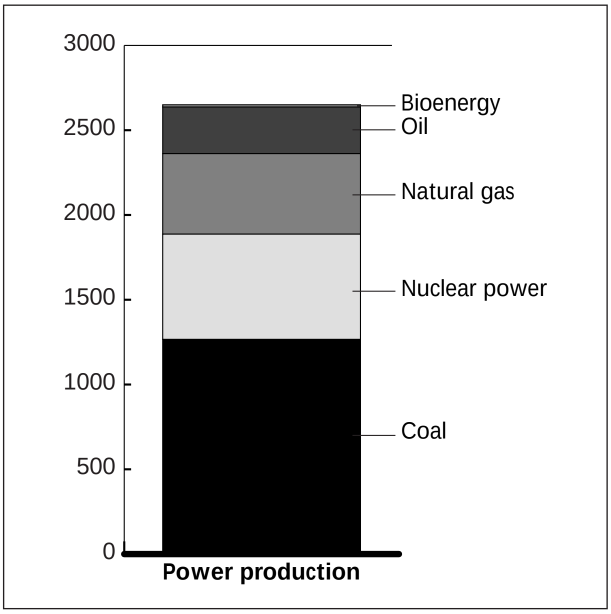


**Figure 2.1**
Fuel for power production

ments and is a completely clean energy carrier. Hydrogen is the most plentiful element in the universe, and on the earth itself there are unlimited amounts of water. [Norwegian Hydrogen Forum] However, hydrogen is not freely available in the natural environment, and the energy needed to produce the energy carrier must come from renewable or fossil energy. If the necessary energy is produced from fossil energy sources, the carbon must be removed. At present, many experts believe that that the two clean energy carriers, hydrogen and electricity, will dominate the energy market in the next century. (See also chapters 2.5, 3.4, and 5 on the production and use of hydrogen.)

## 2.2

## Carbon extraction

The idea that CO2 can be removed from combustion processes was first published by Marchetti in 1977. [Kårstad 1993] Since 1978, approximately 10 large facilities have been built to separate CO2 from exhaust gas where the CO2 is used industrially. [Lindeman 1998] In 1982, a gas-fired power plant with CO2 removal was built in Lubbock, Texas, where CO2 was used for the production of additional oil from older oilfields. [Pauley 1984] There has been a pilot plant in operation for seven years at a gas power plant in Kansai, Japan. [Lindeberg 1998] In 1998, a demonstration facility for the removal of CO2 from exhaust gas was built at Karstø in Norway. [Falk-Pedersen 1998] Yet in 1987, the United Nations Commission on Environment and Development (UNCED) wrote (in the Brundtland Report) that this was not possible.

### 2.2.1.

### Depositing

In order to avoid emissions into the atmosphere, CO$_2$ must be deposited in a safe place. Likely places for depositing are depleted oil and gas reservoirs and underground water reservoirs, called aquifers. A study made by the EU Commission in 1996 shows that the capacity for depositing CO$_2$ in Europe is 806 billion metric tons. The greater part of this is in the Norwegian shelf, where there is capacity for depositing 476 billion metric tons in aquifers and 10.3 billion metric tons in used oil and gas reservoirs. This is to say that there is space to deposit emissions from all power plants in western Europe for several hundred years. [Holloway et al. 1996] Since 1996, Statoil has deposited one million metric tons annually in an aquifer in the Sleipner field. This is not CO$_2$ which is removed from exhaust gases, but which is extracted from natural gas in order to meet specifications for further sale to continental Europe. This cleaning process is considerably simpler than what is required for exhaust gases.

It is also possible to deposit CO$_2$ in the ocean, but there is great uncertainty with regard to storage time and environmental impact. When taking into consideration that underground deposit capacity in Europe is more than adequate, depositing into the ocean is not a viable option.

## 2.3.

## Stationary discharge stations

CO$_2$ can only be removed for depositing from stationary discharge stations, which includes emissions from power production facilities and larger industrial plants. It is possible to collect much of the emissions from smaller plants and combine these into larger discharge stations. As an example, hydrogen kancan be produced from coal, natural gas or oil in large hydrogen power plants where CO$_2$ is removed and deposited. The remaining hydrogen can then be used as fuel for all types of transportation. (ref. Chapter 2.5)

Approximately 35,000 TWh - one-third of the world's total primary energy consumption - is used to produce electricity. Two thirds of this energy is lost in the production process. With today's output capacity of 3000 GW of electricity, the 35,000 TWh of energy produces 12,000 TWh of electric power. The output capacity is expected to reach 5,000 GW by year 2020, which will mean a dramatic increase in emissions.

If all existing power plants were to be upgraded with the most energy efficient technology, it would be possible to reduce emissions by 30%. In addition, if all coal and oil worldwide were to be replaced with natural gas, emissions would be reduced, but this is neither realistic nor sufficient. The only solution is for CO$_2$ to be removed and deposited.

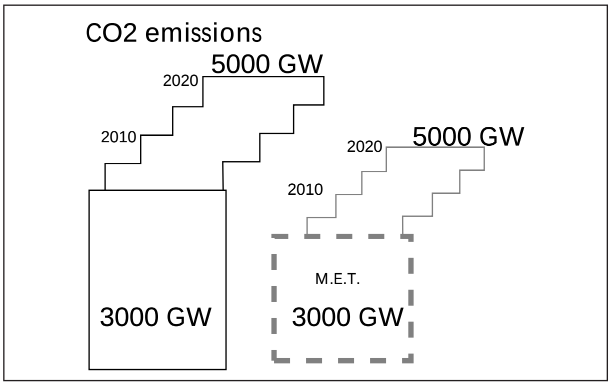


**Figure 2.3**
Global power generation; Scenario 2010 - 2020
(M.E.T. = Most Energy Efficient Technology)

## 2.3.1.
## Extraction of CO2 from natural gas

Carbon dioxide is always produced during the combustion of coal, oil and natural gas. A CO2 molecule is created for every carbon atom that is generated in the combustion process. The waste gas from a normal combustion process of natural gas has a CO2 content of 3-4-%, while the rest mostly consists of steam and nitrogen. There are three conventional methods that are considered viable for the removal and deposition of CO2 from gas-driven power plants:

- Carbon is extracted from the waste gas after combustion;
- Carbon is extracted from the natural gas before combustion;
- Nitrogen is extracted from the air before combustion.

Extraction of carbon from the waste gas. In this process, $CO_2$ binds to a fluid such that the product becomes highly concentrated $CO_2$. The $CO_2$ is consequently «boiled» out of the fluid and deposited.

Extraction of carbon prior to combustion entails a conversion of the natural gas to hydrogen and CO2. Highly concentrated CO2 is separated from the hydrogen, and power is produced by the combustion of hydrogen instead of natural gas.

Removal of nitrogen prior to combustion. Here combustion occurs with pure oxygen instead of air. Hence CO2 and water become the end products.

All of these approaches require energy and result in increased costs unless CO2 can be used for other purposes. Carbon dioxide, hydrogen and oxygen are already produced around the world for industrial purposes. However, very little of this production is optimized with respect to both production of energy and the extraction of CO2. While such solutions are commercially available at this time, extensive efforts are underway to improve the various processes. Deposition of CO2 will be the same, however, regardless of which approach is taken.

Instead of removing the carbon prior to or following combustion, one could of course deposit the entire waste gas, but the volume of flue gas would then be very great in comparison to concentrated CO2.

The use of high temperature–plasma technology–also makes it possible to produce hydrogen and carbon out of natural gas without emissions to the air and water. This process yields pure carbon (Carbon Black), which is used in the metallurgy industry and in the rubber industry. As of today this process makes less sense than other approaches if a suitable reservoir for the deposition of CO2 is available. (See chapter 2.5.)

In addition to the conventional methods, there is another «new» viable method of removing CO2 from natural gas in the production of power: the use of fuel cells. This promising new technology will be discussed in greater detail following an examination of the more conventional methods (cf. 2.3.1.6).

### 2.3.1.1.
### Exhaust gas purification

At present, the best way of purifying $CO_2$ exhaust gases is by means of an amine process. Most of the $CO_2$ can be purified at the very outset, but about 90% is considered optimal from an energy perspective. Briefly put, the purification process takes place as follows:

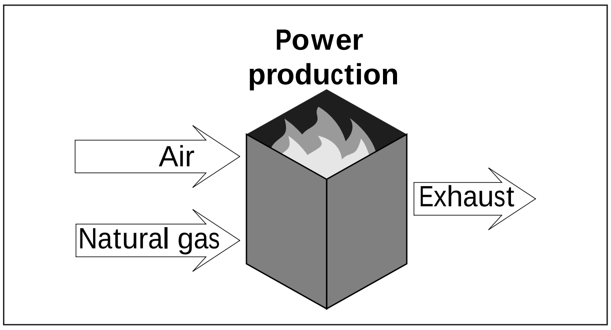


**Figure 2.3.1**
Conceptual drawing for gas-fired plant

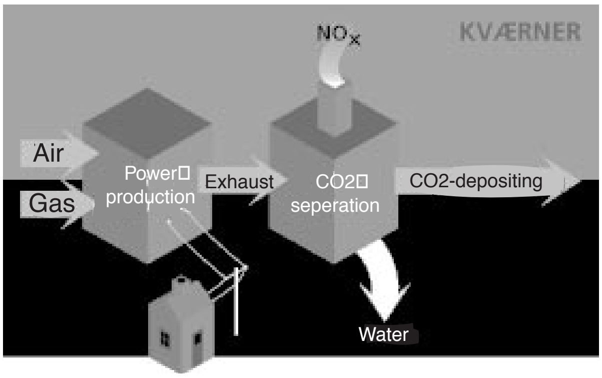


**Figure 2.3.1.1**
Conceptual drawing of the extraction of CO2 from exhaust.

- The exhaust gas is piped into the bottom and an amine solution into the top of an absorption tower. On the way up to the towerRising within the tower, the exhaust gas is mixed with the amine solution which binds the CO2.
- The mixture of amine and CO2 is then piped to a stripper tower where the two substances are separated in a steaming process.
- The separated CO2 is then compressed and dried prior to injection into an underground reservoir.

The factors that are the most energy demanding are as follows:

- The fan to transport the exhaust gas through the washing process;
- Steam to «boil» the CO2 out of the amine solution;
- Pumping the CO2 to the reservoir.

According to IKU Petroleum Research, the use of commercially available technology would reduce the output of a 350 MW gas power plant to 307 MW. In other words, efficiency falls by 7% , from 58% to 51%. Kværner reports a reduction in output to 288 MW, but believes that the output could be 306 MW with the new membrane technology that the company is now developing.

Many companies are participating in a testing program at Karstø in which membranes are used in the purification of exhaust gas. In 1998, a test facility was established based on a 0.5 MW gas engine that produces about 2,000 metric tons of CO2 on an annual basis.

To establish a CO2 purification plant for a 350 MW gas power plant, Kværner reports investment costs of 1,030 million NOK and deposition costs of 430 million NOK. With an uncertainty margin of 220 million NOK, the total cost works out to 1,680 million NOK. Operating costs without gas are 50 million NOK per annum. Statoil for its part

states a total investment cost of 3.8 billion NOK and an annual operations budget of 108 million NOK for a 350 MW gas power plant, including purification and disposal costs, but with a potential for improvement of around respectively 2.9 billion and 95 million NOK.
Profitability depends on the price of electricity and natural gas, and what the market is willing to pay for cleaner energy. IKU Petroleum Research has estimated an increased production cost of around 8-10 øre per kWh.
The technology can also be used for coal fired plants, but in this case would result in other costs and losses of energy.

### 2.3.1.2.

## Hydrogen power plants

In April 1998, Norsk Hydro presented plans for a hydrogen power plant in which CO2 was removed from the natural gas prior to combustion and used as a propellant gant in offshore oilfields (cf. 2.4.2.2), as is the practice in 60–70 oil fields in the United States. The power station design would be dimensioned according to the need for CO2 and would produce an output of 1,200 MW, with an annual electricity production of 10-–11 TWh. Hydro hopes to build the power plant at Karmøy where the company already has an aluminum plant so that the two facilities could be integrated with respect to energy.

Here, the fuel in the power plant would be produced by means of «autothermic» reforming of natural gas. Explained simply, the hydrocarbon compounds (mostly consisting of methane) are mixed with air and steam at high temperatures. The heat releases the hydrogen in the methane (CH4) and the steam (H2O), while the carbon reacts with oxygen in the air and steam and creates CO2.

Hydro wants to utilize air in the reforming process, which would result in a high nitrogen content (N2). The nitrogen diminishes the flammability and would have a cooling effect on the turbines.

Once the CO2 is removed, it is calculated that the fuel will contain approximately 54% H2, 42% N2 and 3% CH4. This mixture would create a combustion characteristic that several turbine manufacturers are already familiar with.

The fuel is burned with air in gas turbines that generate electricity. The exhaust gas then heats the steam, which drives the steam turbines. In principle, almost all of the CO2 can be removed, but a purification rate of about 90% is probably optimal from an energy perspective. The rate of efficiency for a hydroplant is estimated to be around 49%.

There are also several other variants of hydrogen production with CO2 extraction from natural gas besides that which is described here. Furthermore, hydrogen can also be produced through the extraction of CO2 from coal through coal gasification (IGCC).

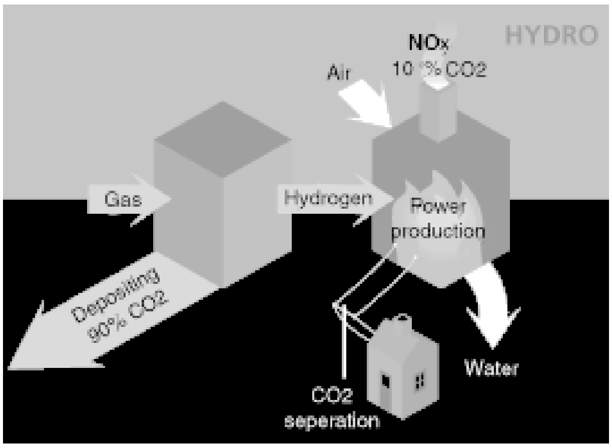


**Figure 2.3.1.2**
Conceptual drawing of CO2 extraction in the production of hydrogen

### 2.3.1.3

## Heating with pure oxygen

Work on CO2 extraction in Norway began in 1988 with the study «Environmentally friendly gas power combined with greater oil production,» which addressed heating with pure oxygen. [Lindeberg 1988] Hence, this is an «old» concept in Norway, one that has been newly relaunched by Aker Maritime.

The process consists of three steps: separation of nitrogen, combustion, and treatment of the exhaust.

Air is drawn into a facility where the nitrogen is separated. The separated nitrogen may then be sold for use in industry or released back into the atmosphere.

Virtually pure oxygen is pumped into a combustion chamber along with natural gas. The combustion releases heat into a steam boiler, a turbine, or a combination of the two, to make electricity. In this concept, combustion takes place at much higher temperatures compared to the traditional burning of natural gas in the air. The combustion chamber technology must therefore be adapted to these conditions.

The exhaust gas consists mostly of CO2 and steam. The steam is extracted from the exhaust gas by cooling to pure water so that only concentrated CO2 remains. The treatment of the CO2 in preparation for transport is based on several steps of compression with intermittent cooling, corresponding to the methods used on existing production fa-

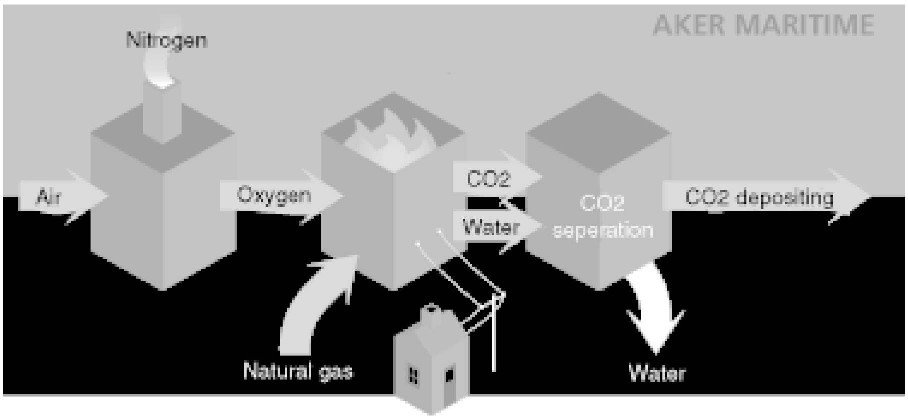


**Figure 2.3.1.3**
Conceptual drawing of CO2 extraction in heating with pure oxygen

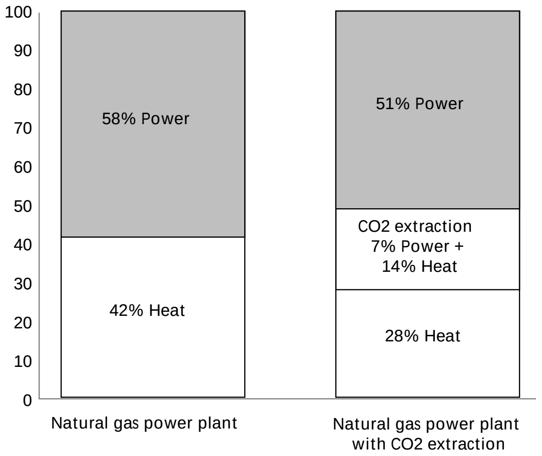


**Figure 2.3.1.5**
Efficiency rates for natural gas power plants with and without exhaust gas purification

cilities for oil and natural gas.

A number of other companies, including ABB, are working to optimalizeoptimize this process which eliminates both CO2 and NOx emissions.

### 2.3.1.4

## Some cost considerations

As stated earlier, the cost of CO2 extraction depends on the prices of gas and electricity and what society is willing to pay for cleaner energy, unless the CO2 can be utilized for other purposes. The estimated cost increases associated with CO2 extraction is in the range of 8-10 øre more per kWh. If the generation of power includes environmental costs that society will have to pay anyway, then the option of natural gas power with CO2 extraction would be particularly profitable. The carbon tax on the Norwegian shelf makes CO2 extraction particularly attractive there (cf. Chapter 2.4).

If the environmental costs are not to be reflected in the costs of new production capacity, then natural gas power with $CO_2$ extraction naturally cannot compete in price with gas power without.

It is possible, however, that natural gas plants with $CO_2$ extraction would be able to compete with new production capacities for coal power. The price for this is just under 30 øre per kWh. Besides, it is rather doubtful that developing new production capacities for coal power in Western Europe would even be permitted. Denmark for example has forbidden the building of any new coal power plants and has resolved to phase out the older plants.

Consequently, in reality the choice is between expanding conventional natural gas power plants in which the environmental costs are not reflected, building gas plants with $CO_2$ extraction, and renewable energy resources. Carbon extraction will increase the costs of generating power with the use of fossil fuels and contribute to more fair and realistic conditions of competition for renewable energy.

### 2.3.1.5

## Some considerations on efficiency

As mentioned earlier, CO2 extraction results in a lower electrical efficiency, a point which is often focused on in debate. From an environmental perspective however, it is the degree to which emissions are reduced that is the essential point, not the degree of efficiency, and the problem is not that there is too little but rather that there is too much fossil carbon available.

In the second place it can be argued that CO2 extraction in actual fact is a highly energy-efficient process. With the option of exhaust gas purification for example, the degree of electrical efficiency falls from 58% to 51%. However, the total efficiency is 72% if the waste heat is removed. The very reason for all the focus on CO2 extraction from thermal power production is precisely the opportunity it affords to integrate the separation process with power production , so that some of the heat that would otherwise be lost may be utilized. The energy for CO2 extraction will then be distributed as 7% electricity and 14% heat.

In the natural gas power debate it is maintained that a 350 MW gas power plant will lead to a reduction of 1.1 million metric tons of CO2, because it automatically replaces coal power plants which release double that amount. For purposes of comparison, only 43-44 MW electricity are needed to purify 90% of the emissions from the gas power plant, that is, 990, 000 metric tons of CO2. The profit for every MW used in CO2 extraction is thus seven times greater than the profit of a transition from coal to gas, and around 307 MW of electricity remains for further sale (and possible replacement of a more polluting form of production).

With respect to the environment, it can likewise be argued that the extraction and disposal of CO2 is no less worthy a use of energy than CO2 extraction for more oil production.  It should not be a goal to try to increase the efficiency of conventional natural gas plants by *adding a system* in order to supply heat to more or less artificial entities, instead of just removing the CO2.

### 2.3.1.6

## Fuel cells

Fuel cells have many advantages over turbines. High temperature fuel cells can use natural gas or biogas directly without any external reforming of the gas into hydrogen. The exhaust consists almost exclusively of $CO_2$ and water,

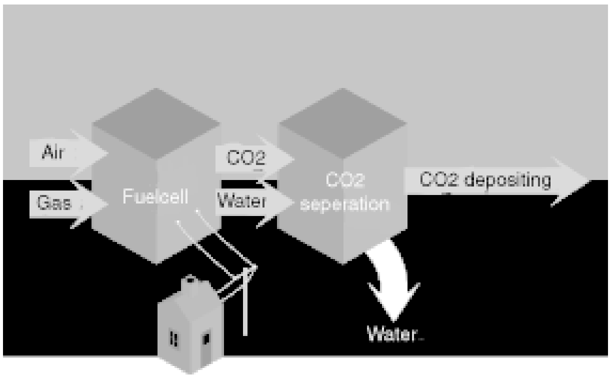


**Figure 2.3.1.6**
High temperature fuel cell

and the water can easily be separated before the $CO_2$ is disposed of. [Shell 1998] Such fuel cells can have an electrical efficiency of over 70%, and in addition can be connected to turbines and/or district heating plants for further energy efficiency with no polluting effects. Ultra fuel cells, a combination of fuel cells and turbines in an optimized network, can achieve an electrical efficiency of over 80%. [ Hydrogen and fuel cell letter 1998]

For several decades, Siemens Westinghouse has been researching and developing fuel cells, and is now ready for the commercial sale of fuel cell-based power plants. Orders may be placed as early as the year 2000. The facilities are expected to have an electrical efficiency of 62-72% and a price of 9,000-12,000 kroner per kw. In a few years the allied concern MTU-Vølund Electrical Power will also enter the market with high temperature fuel cells. [Westinghouse 1998]

High temperature fuel cells typically operate around 1000 degrees Celsius, and are thereby capable of delivering high temperature steam as well as electricity. In other words, the technology is also applicable in connection with conventional steam turbines and process industries. [Blomen et al. 1993]

## 2.4

# The petroleum industry in Norway

Norway controls 75% of Western European oil reserves and 45% of the gas reserves. Norway is the world's second largest oil exporter and fourth largest natural gas exporter. Norwegian exports of CO2 in the form of oil and gas in 1995 exceeded a half a million metric tons.

In 1997, 176 million Sm3 of oil, 10 million metric tons of condensate and 44 billion Sm3 of natural gas, making totaling approximately 2,250 TWh. [Miljøsok 1999] Hence Norway has the lion's share of Western European oil and gas reserves and disposal capacity for CO2 (cf. 2.2.1). In the period from 1970 to 1995, an approximate total of NOK 1,045 billion has been spent on the Norwegian continental shelf, while estimates for the next 25 years suggest a figure of around NOK 1,400 billion kroner. [Berge 1998]

The Norwegian continental shelf faces a number of changes in production patterspatterns which represent significant energy and environmental challenges:

- The oil fields are growing steadily older with the ensuing increased water production. Towards the end of its lifetime, an oil field can produce several times the amount of polluted water as it does of oil.
- Measures for increasing the rate of production from older fields leads to increased energy needs for water and gas injection.
- The transition from production primarily of oil to a greater percentage of natural gas also means significant increases in energy used for the transportation of the gas.
- The industry is moving steadily northwards, implying a greater need for energy for the transportation of natural gas and increased sea transportation of oil.
- With the current technological developments and greater ocean depths, a larger portion of operations will take place on the ocean floor.

The primary emissions to the air from activities on the Norwegian continental shelf consist of $CO_2$, NOx, and VOC. With respect to emissions to the sea, «produced water» is the most important. Approximately 87% of $CO_2$ and 84% of NOx emissions from oil and gas production on the

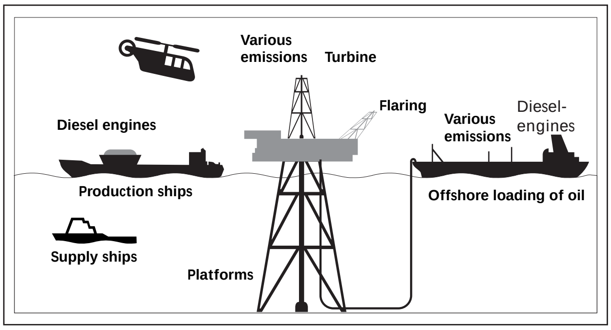


**Figure 2.4a**
Emissions from the petroleum industry

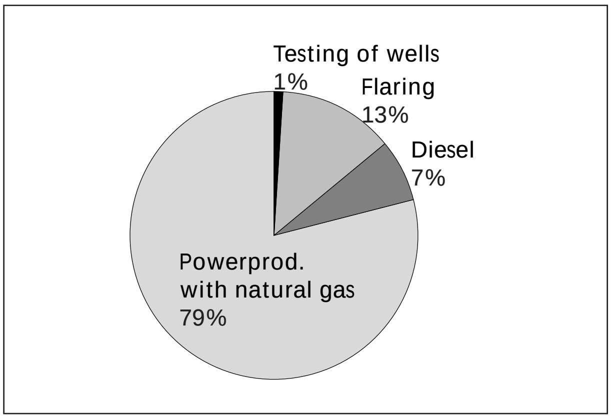


**Figure 2.4b**
Sources of CO2 emissions in the petroleum industry

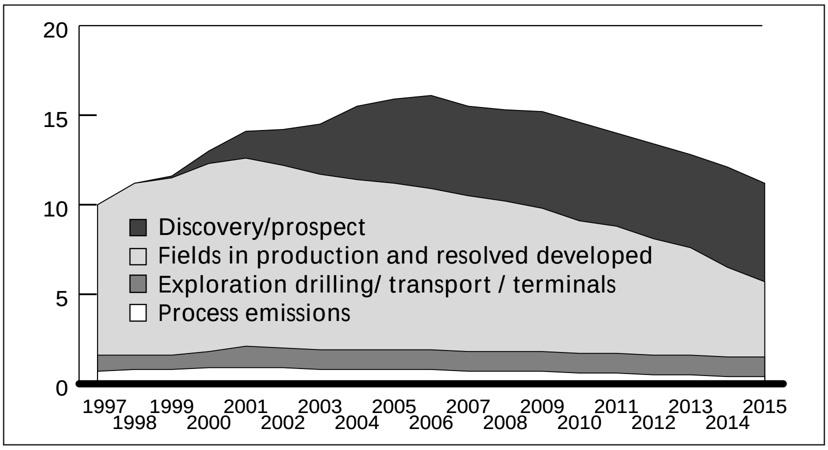


**Figure 2.4c**
Prognosis of CO2 emissions from the petroleum industry

continental shelf come from the production of electrical power, while the rest is due to flaring. Virtually all power production is achieved through the burning of gas–-and some dieselóthrough turbines. A total of 95% of VOC emissions is due to the offshore loading of oil.

Emissions from the petroleum sector is the main reason for the dramatic increase in Norwegian $CO_2$ emissions. From 1990 to 1997, emissions increased from 7.5 to 10.6 million metric tons. [SSB and Miljøsok] They are expected to increase to about 16 million metric tons in 2005, thereafter tapering off to around 14 million in 2010. The bulk of the emissions occur offshore. A release of 16 million metric tons of $CO_2$ in 2005 corresponds to nearly 7 billion metric tons Sm3 of gas. With both the present day carbon tax and a market value of, for example, 57 øre per Sm3 of gas, Norwegians will spend NOK 11.5 billion just in the year 2005 on the natural gas they burn. This is not only an environmental problem, but is also a significant waste of energy.

This subsection examines more closely a number of measures that would both radically reduce $CO_2$ emissions while simultaneously increaseing energy efficiency.

Although it will not be discussed further here, it should be mentioned that the technology now exists to recycle VOC emissions and return them to the oil cargo or use them to propel the ship's motors. Technology has also been developed to stop continual flaring, and this has simultaneously made it possible to recover the flare gas. In the testing of wells, it is now possible to recover the oil that otherwise would have been burned off. Measures directed at the supply of power and other combustion of fossil fuels will not only reduce CO2 emissions, but in many instances also NOx. However, recent years have also seen the development of low level NOx burners with this problem in mind.

In May 1998, the MILFOR program–in which Bellona participated–presented a report which evaluated a set of measures for future reductions of emissions. It stated that the environmental impact from Norwegian oil and gas activities is increasing. The total amount of production and accompanying emissions are increased with each new field that is brought into production, existing fields continue to age, and the volume of water and process chemicals are increasing, the question of waste disposal following drilling activities is still a growing problem, and the need for disposing of facilities where production is ended is also increasing. With respect to the environmental goals set for the continental shelf it is stated that more radical measures must be taken than those that have been in effect thus far in order to meet the objectives.

## 2.4.1.

## Power supply

In 1996, the figures for gas-based energy consumption on the Norwegian shelf represented 10 TWh alone, and are expected to climb to around 14 TWh in 2002-2003. [OD 1997] The efficiency of the turbines is so low that the CO2 emissions per energy unit can be compared with the average emissions from coal-fired power plants in the EU. [Palm and Lynnebakken 1993] The actual energy content in the gas that was used was closer to 40 TWh. The emissions from a single field can correspond to many hundred thousands of cars.

Emissions may be reduced in the following ways:

- CO2 extraction
- Land-based power supply

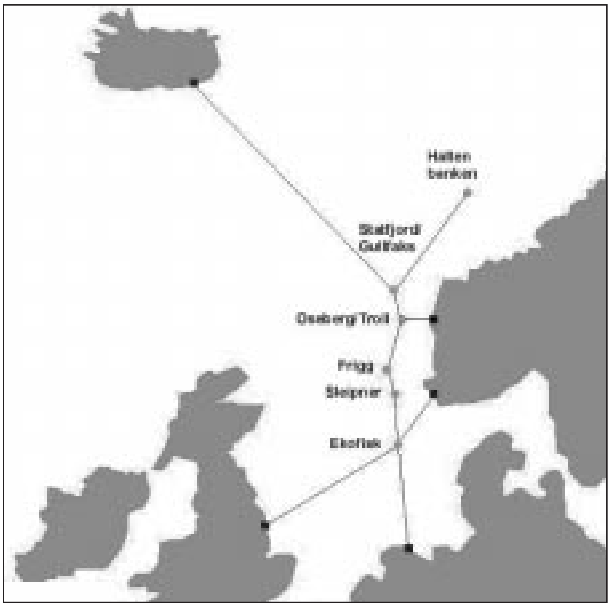


**Figure 2.4.1.1**
North Sea Transmission System

- Efficient use of energy

### 2.4.1.1

### Land-based power

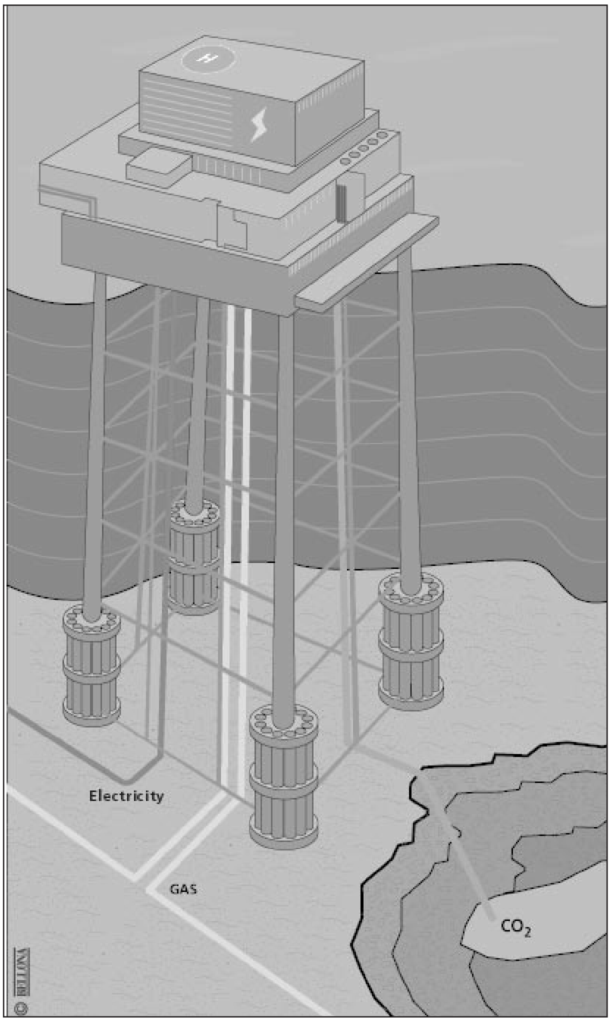
In March 1995, Bellona presented a plan for reducing Norwegian greenhouse emissions by just over 20% by the year 2005. Here it was suggested that 60% of the energy requirements on the continental shelf through 2005 should be covered by land-based power. This kind of electrification would yield substantial reductions and could be implemented on both new and old facilities. The electrification would result in direct reductions along the lines of replacing coal power by gas power, but the benefit would be guaranteed as opposed to the more speculative element of exporting power. At the same time, it would free a certain amount of gas that could then be put to other more profitable uses. [Palm and Lynnebakken 1995]

Earlier studies have shown that the transfer of land-based electrical power to run electrical devices at sea would result in increased investment costs as compared to gas turbines, while the operation costs could be reduced. Central factors in electrification are energy requirements, available power, proximity of the power source, and existing and/or new infrastructure.

In general, the benefits of electrification are greater in the transfer of large amounts of power over the shortest possible distance between oilfield and power source. It can be cheaper to establish electrification in a new facility than to convert an existing energy production system.

Studies show that the investment costs are considerable. There would be little point in supplying electricity to fields that are soon to go out of production, unless the installations can be utilized for other purposes with corresponding energy requirements.

The use of electrical power from the mainland has the greatest potential for fields that will have high power consumption requirements for a long time in the future, and where the distance between the devices and the power source is not too great. An important prerequisite would be a co-ordinated power supply between several devices in a single area, such that the investment costs can be split bet-



**Figur 2.4.1.2**
Offshore gas power plant, with CO2 extraction

ween several installations.

One way to cut cable costs is to connect the platforms to the intercontinental sea cables that are laid between Norway and the continent. The oil and gas installations are both large producers and consumers of energy and therefore naturally fit into the power grid that is growing between the North Sea countries. Bellona once proposed that the Ekofisk field should be connected to such a cable between Norway and Holland. The operator would then also have the opportunity to run the field's most energy intensive operations at the times of day when electricity is the cheapest (usually at night).

### 2.4.1.2.
## Centralized power production with $CO_2$ extraction offshore

The use of central combined gas and steam power plants with $CO_2$ extraction would dramatically reduce emissions while simultaneously reducing the use of gas for fuel. This is because a gas power plant has a higher efficiency rate than simple turbines. Such facilities can either be built offshore or on land. Efficiency will be greatest with a maximal distribution of produced power. Gas turbines on the Norwegian shelf are on the average operated at a 70% of capacity. This reduces efficiency and leads to higher $CO_2$ emissions than at optimal utilization.

In 1995, Bellona initiated a study in which a gas power plant where with CO2 extraction was established on a platform that was due to go out of ordinary production (Statfjord A), and where alternating current replaced certain gas turbines at Statfjord, Gullfaks and Snorre. In May 1996, IKU Petroleum Research concluded in its report to Bellona that this initiative would lead to a reduction in CO2 of 1.6 million metric tons, corresponding to 4.4% of Norwegian emissions. The project had a return of 17.6%. The net worth was NOK 211 million on the basis of an investment of NOK 3190 million. A corresponding concept with a central gas power plant without CO2 extraction would have a return of 32.2% and reduce emissions by 0.97 million metric tons.

The project was based on conventional exhaust gas purification, but Aker Maritim also considers that their solution with pure oxygen should work in a large-scale offshore gas power plant.

Bellona has also suggested that a platform that has been taken out of ordinary production and is located outside the seabed settling area of the Ekofisk field could also be used for similar purposes. This is one of several possibilities the operator is now evaluating for the installations.

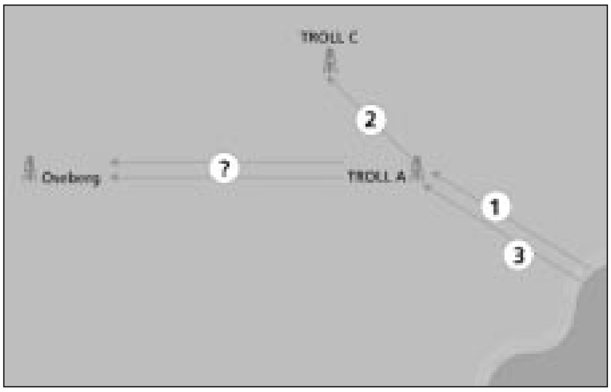
The methods described in section 2.3 are naturally also a possibility for offshore power production with CO2 extraction, and they would of course yield different results.

Land-based centralized power production with CO2 extraction

An alternative to offshore purification is to base the natural gas power plants on land and supply the platforms with power through sea cables. As of today in the introductory production phase, only the Troll A platform in its introductory production phase uses power delivered from the mainland.

The gigantic Troll field will make up the backbone of Norwegian natural gas exports for the next 20-30 years. The developments on Troll will therefore be of great significance for the possibilities of controlling emissions for several years into the future. In 1997 there was a need to determine how electrical power needs on the Troll platform would be covered in the operations phase.

After carrying out a comprehensive study on the possibilities of supplying the platform with power from a land-based natural gas plant with CO2 extraction, Bellona concluded that the project was definitely a viable option. Both Bellona and the operator felt that the project had particularly low start-up costs compared to other options based on the continental shelf. This option is included as an illustration in the strategy plan for Troll.



**Figur 2.4.1.4**
Supplying the Troll field with power from a land-based natural gas plant with CO2 extraction

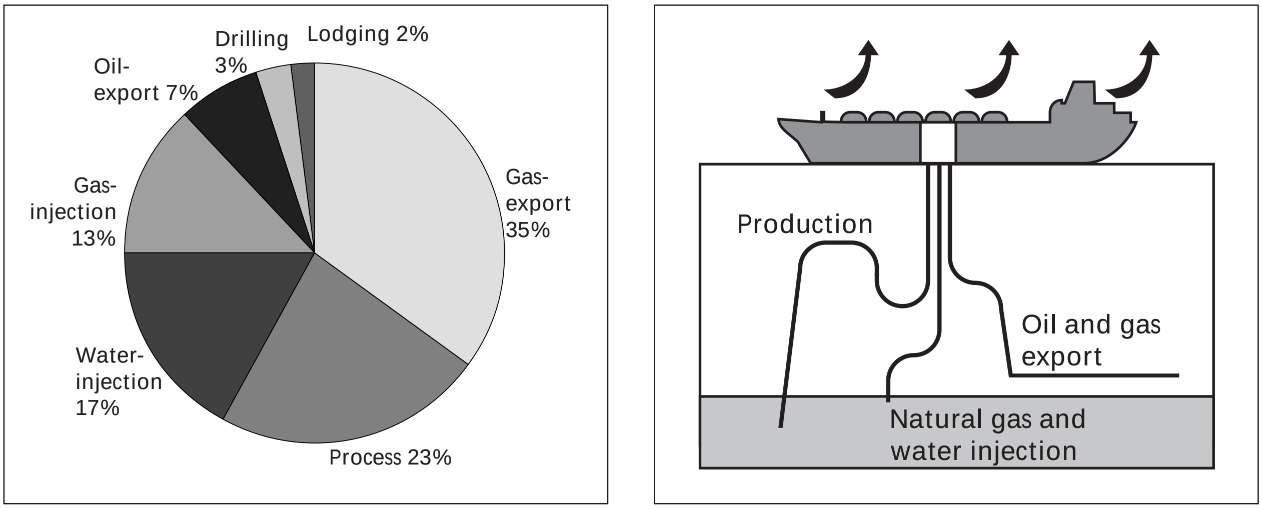


**Figure 2.4.2a and b**
Sources of energy consumption on oil and gas producing installations

Land-based gas power plants with CO2 extraction that primarily supply installations at sea are able to optimize the operation of the facility by selling their excess power on the grid. Assuming limited transfer losses and few possibilities for optimizing solutions at sea, a dedicated land-based gas power plant would result in lower consumption of energy on the continental shelf. Furthermore, the solution would give a boost to the production of electricity on land.

### 2.4.1.4.

### On-site $CO_2$ extraction offshore

In 1996, Bellona participated in a workgroup to determine the profitability of purifying exhaust gases originating from new offshore facilities as compared with conventional solutions. [Miljøsok 1996] Three different scenarios of energy requirements on different oil and gas facilities were studied. Since CO2 purification facilities use the warm exhaust gas to produce electricity, efficiency will also increase. The results from the study indicate that with an energy requirement of:

- 22 MW, the emissions are reduced by 98,000 metric tons per year at a cost of 89 kroner per metric ton;
- 26 MW, the emissions are reduced by 126,000 metric tons per year with a profit of 28 kroner per metric ton,
- 78 MW, the emissions are reduced by 345,000 metric tons per year with a profit of 5 kroner per metric ton.

Purification and disposal will then result in considerably reduced emissions and in many cases will be profitable. The reason for this is primarily the offshore carbon tax, which has no corresponding surcharge ashore. At the time, the calculations were made by Miljøsok, and have received varying responses from different fronts. Kværner has recently confirmed that it expects to be able to deliver facilities that will be profitable even with the present day carbon tax. Aker Maritim is working on a solution that uses pure oxygen with large-scale offshore applications of this type in mind.

Certain political parties in the Stortinget suggested purification and disposal of the CO2 emissions from the Troll C platform in connection with its development and operation. Even though this suggestion was put forth by the operator as a feasible option, it was disregarded in the planning phase, which, according to the operator, made it very difficult for it to be implemented. The operator was therefore required to supply the platform with electricity using land-based power through sea cables.

In 1997 the oil company Saga Petroleum decided to start making plans for the purification and disposal of CO2 on the Snorre B platform. This would be the first time in the entire world that such a venture had been undertaken, and hence the development costs would be greater than the amount saved on a reduced CO2 tax. Considering the developments over the last year within the oil industry, the operator no longer appears interested in following through on the project.

### 2.4.1.5.

### New developments in electric components for power grids

Some of the critical factors in electrification revolve around the size of the transformer and its weight in relation to the platform's limited space and load capacity, and to its varying requirements for different frequencies. However, ABB has also developed new transfer technology, known as HVDC light. Some of its advantages include the ability to operate without transformers, access to different frequencies, and the unlimited distance from source to user meaning that start-up may be initiated from «cold» platforms. The transfer of energy between individual platforms in the same field can be done now while transfer between neighboring fields is expected to become available in two to three years. Within five years it will be possible to access land-based power sources using this technology. [ABB]

### 2.4.1.6.

### Moving energy consumption ashore

An alternative to supplying the continental shelf with land-based power is to move its energy consumption ashore. As of spring 1999, this had only been carried out on Troll, where both the processing facility and the compressor for the pipeline gas, as well as another gas transport system, are based on shore. Compressing gas for export is the principal consumer of energy on the continental shelf. The use of land-based facilities has resulted in a significant reduction in emissions compared to localizing platforms.

A further development in multiple-phase technology increases the possibility of situating the processing facilities on land at new oil and gas installations. Locating these facilities on land makes it possible to utilize the heat from combined power plants for heating purposes. A condition for effective utilization of energy is that the facilities are located near the largest consumers of heat.

### 2.4.2

## Process optimization

A number of the changes we are now facing on the continental shelf will have a great impact on energy consumption. It is fully possible to optimize the different processes with respect to energy consumption. New systems are constantly being developed to reduce the consumption of energy, and the individual stages in the process can be placed in the most energy-efficient stage of the production process. Frequency-controlled operation will reduce the requirements for energy in compressors, pumps, and propulsion systems. As a whole, this will result in significant reductions in the consumption of energy and hence also the emissions. [ABB]

### 2.4.2.1.

## Reduced water production and seawater injection

In the time period between 1996 and 2008, oil production in the existing fields, and those that have been approved for development, will fall from a peak of just under 200 million Sm3 to just over 40 million Sm3. At the same time the amount of water produced will increase from around 70 million Sm3 to just over 120 million Sm3. The prognosis therefore indicates that in 2008, three times more contaminated water will be produced than oil. A great deal of energy is required to produce large amounts of contaminated water. Large amounts of energy are required to produce the contaminated water that is discharged into the sea, and considerable energy is also expended on pumping seawater into the reservoir to maintain the pressure (cf. Appendix 2).

We are now on the threshold of developing several new technologies that prevent the discharge of contaminated water in such a way that the need for energy and pressure surges is reduced. Among the approaches which are being considered for some of the different fields are re-injecting the produced water, «in-hole» separation, seabed separation, and isolating the water in the bore hole/reservoir. Reducing the amount of produced water in the well is clearly preferable, as it allows for smaller facilities for treatment. The need for production chemicals is also reduced because a smaller volume of water requiring treatment is discharged. Less production of produced water reduces the need for pressure support in the reservoir and results in a smaller amount of water to be re-injected. This leads to lower injection requirements/smaller facilities and a lesser need for injection chemicals, while lower energy consumption results in reduced emissions of combustion gases. [Miljøsok]

In June 1999, an underwater separation device was installed on the Troll A platform and was due to become operational later the same year. This facility will separate oil and water, with the water then being re-injected. This has the effect of both increasing production and reducing energy requirements, while also causing less stress on the natural environment. The separation facility is supplied with electricity from the platform. Establishment of an electricity distribution center on the ocean floor enables underwater processing to take place far from platforms or afloat. This reduces cable and installation costs because it does not require separate conveyance to each individual separation unit. Weight and space on the platform is thereby reduced and the system optimized. [ABB]

### 2.4.2.2.

## Injecting CO2 as an alternative to gas injection

Considerable amounts of energy are required to inject natural gas as a means of pressing more oil out of the reservoirs. In 1997, 22.7 billion Sm3 of natural gas were injected for this purpose, corresponding to as much as 53.4% of the amount of gas that was exported. The volume is expected to increase to around 35 billion Sm3, of which anywhere from 10% to 40% presumably cannot be regained.

Alternatively, if $CO_2$ were to be utilized as a propellant instead–extracted from the natural gas of a power plant or other separation facility–large amounts of power and/or hydrogen would be made available.

The potential of CO2 to be used in increased oil production on the Norwegian continental shelf is estimated to be about 200 million metric tons. This would suggest that Norway in actuality has a large deficit of CO2. [Lindeberg and Glasø 1995, Lindeberg personal communication 1998.] It is difficult to say how much of this potential will be possible and/or desirable to realize. Furthermore, it constitutes only a small part of what can be stored in «aquifers.» This means that, regardless, the possibilities of producing and refining Norwegian energy resources with zero emissions are very promising. In conjunction with its plans for a hydrogen power plant utilizing CO2 for pressure support offshore, Norsk Hydro stated that this also opens up the possibility for electrification of the continental shelf.

### 2.4.2.3.

## Increasing gas pipeline diameter

Transportation of natural gas constitutes one of the major uses of energy in the oil and natural gas industry. By increasing the diameter of the pipeline, the power required to transport the same amount of gas could be reduced. A 10% increase in the diameter of the pipeline would reduce the requirements for intake pressure. The energy needs for compression power would thereby be reduced by 10-25%, depending on the composition of the gas.

This potential could be utilized if new gas pipelines, larger in diameter, were to replace older and more power-demanding transportation systems. The dimensioning of new transportation systems would therefore have to be made in terms of optimizing both emissions and operating costs, weighed against higher investment costs due to a higher material consumption.

Twice did Bellona have direct action against Shells drilling for oil in the Barent Sea in 1993

The uniqe norweagian population of Puffins may be in danger if there are exploration-drilling for oil just out side Røst.

New techniques and marine vessels have been developed for the installation of wider diameter pipelines, but there is a need to include the energy cost in the upgrading of the pipelines. The savings in energy would net a real savings in operation costs in the form of saving on carbon taxes and possibly increasing the sale of natural gas. [Miljøsok 1996]

### 2.4.3

## Zero emissions

New oil fields with independent production designs are prohibited from injecting environmentally harmful emissions into the sea. At the Esbjerg conference, the resolution was made that environmentally harmful emissions injected into the North Sea shall be stopped in the course of one generation (25 years).

Both government and industry have negotiated to reduce VOC emissions, and this agreement is due to be reevaluated at a later date as stipulated in the Pollution Act. For testing of wells, the requirements as to the length of validity of the tests have become stricter. Even though flaring on the Norwegian continental shelf is modest compared to the British sector, a majority in the Storting nevertheless felt that flaring could be further limited with respect to complying with the Kyoto Protocol.

The recognition that activities leading to pollution are not lucrative, and the waste of resources this represents, has resulted in several companies, also within the oil and gas sector, having adopted a zero emissions philosophy as a cornerstone for their activities.

Hence the trend in development is towards increasingly stricter requirements whereby zero emissions is the end result. This may also be seen in the development of environmental strategies:

Dilution strategy => purification strategy => recycling strategy => zero emissions strategy

### 2.4.4.

## Localizing new, versus reduced, access to fossil resources

In 1958, representatives from Norway’s Geographical Investigations wrote to the Norwegian Ministry of Foreign Affairs concerning the sovereignty of coastal nations on the continental shelf. The letter stated that One can ignore the possibility that oil, coal, or sulfursulfur will be found around the Norwegian coast. In 1965, however, the first round of licensing for the Norwegian continental shelf started, and on June 6, 1971, Norwegian oil production started on Ekofisk. [OD]

While discussions over the development of river systems and the demand for a conservation plan dominated the energy debate in Norway at the beginning of the 1970s, this was soon superseded by considerable discourse on oil production. From the middle of the 1970s, the fight against drilling for oil north of 62 degrees latitude from the Møre coast and northwards to the Barents Sea became a major issue. In 1976 for example, the Norwegian environmental organization Youth and the EnvironmentNature and Youth demanded that oil production in the Statfjord field should be stopped. [Persen and Ranum 1997]

In 1980, the first testing for oil in the Barents Sea began, although it was not until 1989 that the Stortinget formally opened up for oil and gas exploration activities in this area. The Barents Sea is one of the world's richest coastal bird wildlife areas, and Norway has considerable administrative responsibility for a number of different populations of wildlife of great national and international value. The Barents Sea and large areas of the coast in northern Norway are perhaps the most important spawning areas for fish in the North Atlantic Ocean. The combination of darkness, fog, cold, ice, and the risk of freezing over makes the Barents Sea a high risk area. Even in periods where there is light all day long, the visibility conditions are very limited due to the likelihood of fog and precipitation.

In 1991, there were protests against Conoco's drilling for oil in the Barents Sea; in 1992 attempts were made to stop Hydro's drilling activities; and in 1993, a protest was launched in both Stavanger and on the open sea in the Barents against Shell's exploration rigs. The same year, Bellona filed suit against Statoil to halt drilling activities. In 1998, Youth and the EnvironmentNature and Youth launched a protest against Hydro's plans to drill in the Snøhvit field in the Barents Sea. The Norwegian Petroleum Directorate brought a halt to these particular drilling plans after Bellona identified some major defects in the rig.

In 1994, the Norwegian parliament opened up for exploration activities in the Skagerrak and in some new areas in the middle of the Norwegian continental shelf. However, strong restrictions were imposed on activities in Skagerrak, and certain areas lying close to the coast of central Norway were not opened. As of spring 1999, there is oil and natural gas production in the North Sea and the Norwegian Sea, but no production as of yet in the Barents Sea or Skagerrak.

Below, we have systemized existing concepts with respect to localizing new, versus reduced, access to fossil resources on the continental shelf. If an increased use of fossil resources is desired, then any new access to these resources from an environmental and resource perspective should be localized through the following (in order of priority):

- Increase resource efficiency in existing production and transportation
- Increase efficiency in utilizing the reserves from fields already in production
- Projects in connection with present guidelines
- Projects in already developed areas
- Projects in opened areas
- Projects in unopened areas
- Projects in vulnerable areas
- Projects in highly vulnerable areas.

If a reduction in fossil fuel resources is desired, then the order of priority could be reversed, except for the fact that increased efficiency in the use of existing resources utilization is always best. With this line of thinking, it may be seen for example that the Snøhvit project should be the first to be stopped on the continental shelf if the aim is to reduce the use of fossil fuels on the continental shelf, and it should be the last project to be started if an increase in production is desired. There are a number of means by which to decrease the tempo. Generally, the most effective are:

- Refraining from opening new areas to oil and natural gas production
- Closing areas to oil and natural gas production
- Not issuing drilling permits
- Withdrawing drilling permits
- Not allowing developments
- Limiting activity in time and space
- Spreading investments over time
- Introducing cuts in production.

These measures will vary in applicability depending upon the actual situation in question, but taken in conjunction with the preceding points, a paradox will become apparent in introducing production cuts while simultaneously starting up Snøhvit.

### 2.4.5
### Summary

The following measures have been presented as possible approaches for reducing CO2 emissions:

- Electrification: The use of land-based power and coordinating supply of power
- Power production with CO2 extraction and increased energy efficiency
- Transfer of power consumption to land
- Reduction in water production and seawater injection
- CO2 injection to reduce gas injection
- Increase in the diameter of the gas pipes.

In summary, these measures could reduce emissions form the petroleum industry by approximately 95%. The international engineering firm ABB considers that it would be possible to reach both 80% total energy efficiency and cut CO2 emissions in half through measures such as the following:

- Interconnection of platforms
- Optimized production
- Cogeneration
- Subsea processing

Adaptation of process heat and electricity to specific needs in the production of power

Furthermore, in that CO2 can be extracted and land-based power can be utilized, a 50% reduction of emissions by the year 2010 ought to be the minimum, with a 90% reduction as the target for the year 2020.

In the future, it might be prudent to consider adding a sizeable mixture of hydrogen in gas pipelines. The importing countries would then be unable to levy various carbon taxes on this type of energy. Indeed, Europe's environmental costs can become future income for Norway.

### 2.4.5.1
### Necessary measures

Since 1991, the petroleum industry in the North Sea has faced carbon dioxide taxes that currently amount to approximately NOK 380 per metric ton. The oil companies therefore pay close to NOK 4 billion in taxes annually, but because of technicalities in the tax structure, the actual costs are reduced to only one-fourth this amount.

An environmental tax is a tax that should eventually disappear, or its purpose has not been achieved. For a long time, the petroleum industry considered $CO_2$ emissions and greenhouse gases more a pure political issue rather than a real existing problem. It was also generally agreed that Norwegian oil and natural gas production was the cleanest in the world and that no further technical developments were possible. And as a result, the carbon dioxide tax was regarded as nothing more than money in the pocket for the government, on top of an industry that was already highly taxed.

The tax is not a fiscal tax, since the less one pollutes, the less one pays, and it has been shown to be technically feasible to reduce emissions radically. This tax has been the driving force behind much of the technological development aimed at $CO_2$ emissions. This tax also tends to vary somewhat, according to pressure on oil prices. It is therefore necessary to differentiate between regulations aimed toward achieving specific goals and measures for regulating other situations.

The petroleum industry is by nature a long-term activity. It is therefore critical that the strategies and economic policies are stable in the long run, and fluctuating in accordance with new "trends." In order to achieve the desired goals, it is necessary to maintain, even strengthen, economic incentives, but most importantly, it is necessary that these "incentives" generate the environmental awareness and technological advancements they were intended to encourage.

Bellona therefore proposes that a $CO_2$ Reduction of Emissions Fund is established to replace the existing tax, and this fund would be the recipient of the tax monies. Unlike the current system, however, the oil companies would be encouraged to initiate plans for research and development projects, and depending on the scope and cost-efficiency of the proposed project, the "winners" would be awarded grants to proceed with the project.

Bellona proposes establishing a system for "Environmental Performance Evaluation" (EPE), for all decisions with regard to offshore activities, such as gas allocation and creating portfolios. This means of evaluating activities would not only make the traditional immediate benefits more visible, but also the environmental consequences. This is a system that allows for specific measuring and rewards accordingly. It is then possible to evaluate the different options and how they will benefit the different alternatives, and then choose the best one.

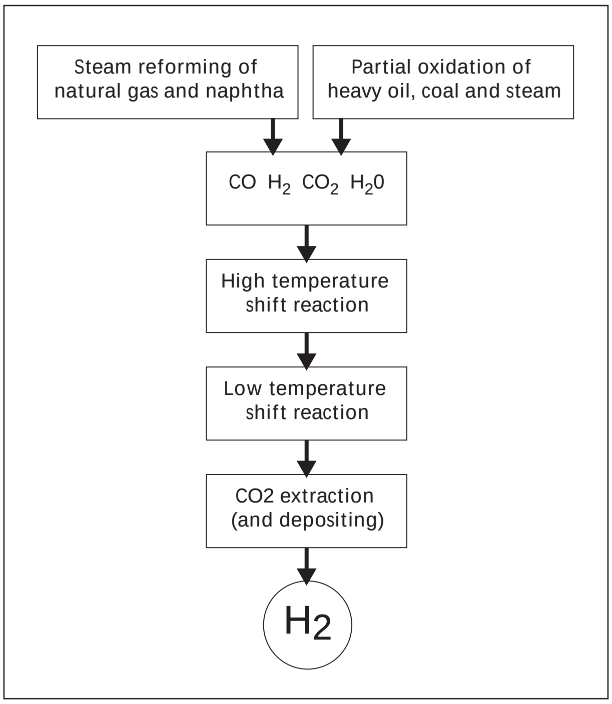


**Figure 2.5**
Conceptual model of methods for production of hydrogen from hydrocarbon compounds with depositing of CO2

It is quite possible, with today's technology, to develop offshore oilfields that are emissions-free, using "BAT" - the Best Available Technology, and Bellona proposes that this principle be adopted for all activities surrounding the petroleum industry. In actuality, BAT regulation would require a zero-emission principle for new offshore development, and this would lead to a considerable reduction in emissions.

According to Norwegian law, polluting is prohibited. The laws were not directly enforced with CO2 emissions in mind until Bellona took action in connection with the legal processes regarding two proposed land-based gas production plants in the summer of 1997. Enforcing of pollution laws would prevent unnecessary emissions if the regulations were followed.

The current practice of choosing building designs and approving development plans before applying for emissions permits, however, results in a very unfortunate limitation of the environmental authorities' ability to restrict emissions. Bellona proposes therefore that emissions permits must be made an integral part of the application and permit processes in the construction business.

Bellona also feels that Norway should take the initiative to draft a protocol demanding CO2 extraction from all fossil power and fuel production. This could at first include only the industrialized countries, while developing countries could adopt the standards at a later time, perhaps when they reach a certain standard of living.

The simplest way of reducing emissions is to stop them before they appear. In addition to previously discussed issues, Bellona proposes temporarily closing the Barents Sea and the Skagerrak for any oil exploration or production. It should also be pointed out that during the 1990s the USA has closed several especially sensitive areas for all oil activity.

## The proposed measures comprise:

- A CO2 fund to replace the current CO2 tax system
- Establishment of a system for "Environmental Performance Evaluation" which applies to all central decision-making concerning oilfield activities (for example, gas allocation, coordination of oilfield portfolios, etc.)
- Establishment of the BAT principle for all development and permit allocation.
- Allocation of emissions permits in accordance with the " Pollution Act" before other permits are issued
- Submission of an international technology draft protocol that requires CO2 extraction for all fossil power production, heat production, and fuel production
- Temporary closure of the Barents Sea and Skagerrak for any oil-related activities

## 2.5.

# More on the production of hydrogen from fossil fuels

Over 90% of the world's hydrogen of around 45 million metric tons is produced from fossil fuels. The largest producers of hydrogen are the artificial fertilizer and petroleum industries, with respectively 47% and 37% (1993). Sales of hydrogen have increased by 6% annually in the last five years, which is closely related to the increased use of hydrogen in refineries as a result of stricter standards for fuel quality. This development is expected to increase. In addition, it is expected that the next five years will see a dramatic increase in local small-scale production of hydrogen as fuel cell technology is introduced on the mass market. [Heydon 1998]

Removing the environmentally dangerous chemicals from fuel in central plants will spare the local environment, and it is also easier to handle a few central discharge stations than several smaller ones. If we were to deposit the $CO_2$ generated by the large natural gas reformers that supply one million cars with hydrogen, then there would in actuality be one million emission-free cars.

Hydrogen can be produced from several different hydrocarbon compounds by varying techniques. Different hydrocarbon compounds have different amounts of hydrogen. Natural gas has a ratio of hydrogen to carbon four times higher than in coal. The following will describe some of the most common techniques for producing hydrogen from hydrocarbons, and present some new ones we feel are of importance.

Most of the techniques described here, with the exception of the two plasma reforming methods, basically involve heating the raw materials and/or heating steam that is mixed with the raw material. The ensuing reaction splits both water molecules and the raw material, thereby creating hydrogen, CO and $CO_2$. In other words, the hydrogen that is left comes both from the steam and the hydrocarbons.

Hydrogen produced without emissions into the environment can be an important export product for Norway and represents a refining of our natural resources. It is important that we do not let these possibilities pass us by. Bellona proposes that the government prepare a long-term Research and Development Program for hydrogen, as is found in many other countries.

### 2.5.1.

## Gasification of coal

Gasification of coal is the oldest method for production of hydrogen. Generally, coal is heated up to 900 °C by with a catalyser and without air. There are also more complex ways of gasifying coal, such as the Lurgi, Winkler and Koppers-Totzek methods. These techniques are similar in that by using steam and oxygen at temperatures over 14000, they change carbon into H2, CO and $CO_2$, and in addition create some sulfur and nitrogen, which like CO and $CO_2$, must be treated in the same way, environmentally speaking. [Winter et al 1988]

It is almost twice as expensive to produce hydrogen from coal as from natural gas. This has to do with the relation between hydrogen and carbon, which in natural gas is 4:1 and in carbon 0.8:1. (IEA/Foster Wheeler 1996(

Germany, South Africa and the USA presently have large gasification plants, and technology for gasification of coal in thermal power plants is the subject of much R&D by the coal industry.

### 2.5.2.

## Partial oxidation of heavy hydrocarbons

Heavy hydrocarbon's low volatility and often high sulfur content prevents using steam reforming. Instead, the oil is treated autothermically in a combustion reaction and fed with steam and oxygen at 1300-1500°C (the Texaco method). The oxygen to steam ratio is controlled so that the gasification continues without the use of additional energy.

The formula for this process is:

CH1,4 + 0,3 H20 + 0,4 02 => 0,9 CO + 0,1 $CO_2$ + H2

This is followed by the shift reaction:

CO + H20 => $CO_2$ + H2

1 mol CH 1,4 => 1,9 mol hydrogen

### 2.5.3.

## Steam reforming of natural gas

Steam reforming of natural gas is currently the least expensive method of producing hydrogen, and used for about half of the world's production of hydrogen. Steam, at a temperature of 700-1,100 °C is mixed with methane gas in a reactor with a catalyser at 3-25 bar pressure.

Thirty percent more natural gas is required for this process, but new processes are constantly being developed to increase the rate of production. [Gaudernack 1998] It is possible to increase the efficiency to over 85% with an economic profit at higher thermal integration.

A large steam reformer which produces 100,000 tons of hydrogen a year can supply roughly one million fuel cell cars with an annual average driving range of 16,000 km.

There are two types of steam reformers for small-scale hydrogen production: Conventional reduced-scale reformers and specially designed reformers for fuel cells. The latter operates under lower pressure and temperatures than conventional reformers and is more compact.

The formula for this process is:

CH4 + H2 0 => CO + 3H2

And the most commonIt is usually following followed by the shift reaction:

CO + H2 0 => $CO_2$ + H2

1 mol methane => 4 mol hydrogen

The percentage of hydrogen to water is 50%

In steam reforming of natural gas, 7.05 kg $CO_2$ are produced per kilogram hydrogen [Princeton University 1997]

### 2.5.4.

## Autothermal reforming

Burning hydrocarbons with reduced access to oxygen is called partial oxidation. Autothermal reforming is a mixture of partial oxidation and steam reforming. The name refers to the heat exchange between the endothermic steam refor-

## Chapter 3

# Renewable energy

Norway has great potential for new sources of renewable energy; these sources include coastal wind, great amounts of biomass, heat pumps and geothermal energy, and solar heat, all readily available to be put into the production of energy.

In Europe, new renewable energy has allowed for increased production capacity. In Germany and Spain, energy from wind power is increasing rapidly, and biological fuels are taking increasingly larger portions of the energy market in France. There is a similar development in the Scandinavian countries. Wind turbines are one of Denmark's most important exports, and have captured a large portion of the domestic market. Modern bioenergy plants meet much of the demand for heat in Sweden and Finland. [Tangen et al., 1998] In 1998, Sweden increased its use of bioenergy by 5 TWh.

Norway lags somewhat behind in use of renewable energy. Norway's energy policy has concentrated almost entirely on the production of electricity in number of kWh, and very little on technology and industrial development. [Tangen et al., 1998] An important exception is in incineration of biological waste, where the Norwegian company Energos has become a world leader in the production of heat and electricity with very low emissions. Export of such plants could be a considerable growth industry for Norway.

Development of new sources of renewable energy will create many new jobs. One example is that an annual bioenergy production of 20 TWh will open up 6,000 to 10,000 permanent positions. [NFR 1996] In the EU, as many as 900,000 jobs will be created from renewable energy production. [EU Commission, 1997] In addition to new jobs, this development will lead to advancements in technology and export possibilities. Another example is in Glomfjord, where industry is concentrating on solar cell technology. This can put Norway in the position of being one of the leading countries in the world within solar cell production.

Norway has large resources of renewable energy, and by utilizing these, mainland oil consumption can be reduced and large amounts of electricity can then become available. This can be done by:

- Developing renewable energy sources such as wind, bio- and waste energy, geothermal energy, osmotic pressure, and tidal power;
- Using energy more efficiently;
- Making the transition from electricity to water-borne heat, such as heat pumps, bioenergy, waste energy, solar panels, and geothermal energy;
- Renovating hydropower plants and developing small hydropower stations.

Some of the additional electricity produced can be exported directly, or be used for expanding export-oriented energy-intensive industry. These measures can create many job opportunities and also be profitable in themselves. The development of potential power sources should be based on Norwegian industry. This would then create a new domestic market, which would eventually open up possibilities for export.

**Table 3:**
**New energy production in Norway**

| | |
|---|---|
| *Wind power* | *14 TWh* |
| *Hydropower* | *5 TWh* |
| *Solar energy 5 TWh  Bioenergy* | *20 TWh* |
| *Geothermal energy* | *5 TWh* |
| *Osmotic pressure* | *10 TWh* |
| *Wave power* | *0,5 TWh* |
| *Heatpump* | *12 TWh* |
| *waste* | *3-4 TWh* |
| *Total renewable energy* | *74,5 – 75,5 TWh* |
| *Clean power from fossil fuel >* | *50 TWh* |

Section 3.1 presents our viewpoint on the different renewable sources of electricity, while section 3.2 covers the energy sources which are best suited for production of heat, or heat in combination with electricity. Section 3.3 presents what the Scandinavian countries and the EU have done to encourage renewable energy, and section 3.4 presents our suggestions for basic conditions for renewable energy in Norway. The last section, 3.5, shows some of the many possibilities for hydrogen production, based on renewable energy.

## 3.1

## Sources of renewable energy

Development of new renewable sources of energy is moving along quickly with the amount of energy per unit increasing and the price dropping. The most likely energy sources for Norway are bioenergy, wind power, geothermal energy, and hydropower. But there are others such as saline power, tidal energy, and wave energy that are also feasible.

### 3.1.1

### Wind power

The energy content of wind is directly proportional to the wind speed raised to the third power (wind speed cubed). Measuring wind conditions will therefore be of considerable importance for optimal efficiency.

There are currently proposals for several large wind power projects in Norway. One such project is plans for two large plants at Smøla; Statkraft is planning a plant that will produce 150 MW; and Hydro and Statoil also have similar plans.

Technological progress has already lead to decreasing prices, and wind power can be produced between 20 and

**Foto 3.1.1**
New technology for design of windmills can increase efficiency and make wind power more competitive. The windmill shown is a Vortec 7.

30 øre per kWh. While the largest of the windmills from the mid-1980s produced 50kW, a new generator producing 1500 kW is now under development. Denmark has concentrated its efforts on developing wind power, and production of electricity from windmills amounts to 1.2 TWh per year. The Danish government's energy development plan, Energi 21, includes building large windmill "parks" out in the ocean, which will produce 4000 MW. With a theoretical potential of 70 TWh, and a realistic wind power potential in the most strategic areas in Norway being 14 TWh annually, this is a very viable source of energy.

## 3.1.2
## Tidal energy

The first Norwegian plant for development of potential tidal energy for electricity is in the planning stages now in Barmfjorden at Hitra. At this plant, a low-pressure turbine, which can operate at a pressure differential down to 0.5 meters, will be able to produce just over 5 GWh. It is expected that the plant will produce electricity at 35 øre/kWh.

In the fall of 1996, a suggestion was made, actually by coincidence, that it should be possible to utilize the energy in the water current in Kvalsundet in Hammerfest. The result of this observation was a pilot project that will continue through 2001, with a plant that will produce between 0.5 and 1.2 MWh in year 2000. This is obviously not a full-scale production plant, but will be suitable for research purposes.

The French tidal-water power plant, La Rance, produces 240 MW and has an annual production rate of 540 GWh.

## 3.1.3
## Osmotic pressure

The pressure difference in the osmosis process between saltwater and fresh water is around 27 bar, which is equivalent to a waterfall of about 270 meters. Theoretically, therefore, each cubic meter of water that runs out into the sea could produce 0.7 kWh of electricity. The 10 largest rivers in Norway carry about 22% of the total run-off to the sea. This process can thus create a potential energy of approximately 25 TWh per year—or about 22% of the country's existing hydropower-based electricity. At the power plants where water from the turbines runs out into the sea, it is possible to utilize the energy in this osmosis process between saltwater and fresh water, and thereby increase energy production considerably. Producing energy from salt gradients This "salinity power" opens up a large and unused source of renewable energy. [Statkraft 1998]

There are several methods of extracting the chemical energy found when saltwater is diluted with fresh water. The methods that have been most promising so far are pressure-retarded osmosis and inverted electrodialysis. Both techniques are membrane processes.

There is still uncertainty as to the price, but under 50 øre/kWh is not unrealistic. Comparatively, wind power costs over NOK 1 just a few years ago, but has now it's dropped to between 20 to and 30 øre.

Because this technology is so new, it's difficult to estimate a potential that does not at the same time have a negative impact on important natural wildlife preserves. Depending on the design of the plants, there could be conflicts with these wildlife areas, which would reduce its potential. Bellona therefore reduces the potential for this technology from 25 TWh to 10 TWh.

## 3.1.4
## Wave power

Wave energy transportation in the ocean off the coast of Norway is between 20–40 kWh/m between Stadt and Lofoten. Further north and south, 20–30 kWh/m can be expected, while it is even less into the Skagerrak channel area.

The potential energy attainable is naturally dependent on the type of technology used. That is, the potential will be greater for plants further from land than for those nearer land or the coast. The Norwegian Water Resources and Energy Directorate (NVE) performed a preliminary study for the Stortinget, report no. 65 (1981–1982), where the potential for production from a coastal stretch of 130 km was determined to be 6 TWh. This was based on the assumption that three different applications were used, whereby two could be utilized far from land.

There are many principles and patents developed to utilize wave energy. Norway has primarily focused on two of these: wedge trough and oscillating water column.

The Norwegian company Indonor AS is building a water-trough power plant like the one Norwave AS operated at Toftestallen in Nord-Hordaland between 1987 and 1991. The new plant, which will be built on the south coast of Java, is designed to produce 1.1 MW, and have an expected annual production rate of at least 6 GWh. The facility is expected to cost NOK 50 million.

Wave energy has been used previously for special needs, such as bilge pumps and navigational buoys.

Development of wave-energy power plants on a small scale should be feasible in Norway within the next 20 years, provided the necessary means for research and development are available. This will, however, contribute to a rate of no more than 0.5 TWh energy production in Norway in 2020. [NOU 1998:11]

### 3.1.5
### Hydropower

Like all forms of renewable energy, hydropower is environmentally sound as long as valuable natural wildlife preserves are not destroyed. The large hydropower stations, however, have gone far beyond these limits. Thus the era of these large power plants in Norway has come to an end, and the last of the undeveloped waterways must be spared. In the meantime, much can be gained from building small hydropower plants, as well as renovating older power plants.

Currently, hydropower potential of approximately 10 TWh is exempt from concession. Of approximately 320 projects for which concession can be applied, only 8 of these have a production rate over 250 GWh, while 230 have a production rate lower than 50 GWh. Bellona feels that many of these projects should not be completed due to the destructive consequences for the respective waterways. Bellona has set a potential rate at 5 TWh for renovation and expansion projects, as well small hydropower plants. We would like to point out that we have not checked thoroughly into all of the suggested projects for renovation and expansion, so the suggested rate potential is somewhat unsure when taking into account the environmental consequences.

The Norwegian government's Comprehensive Plan must be reevaluated and Preservation Plan No. 5 for the Norwegian watersheds must be implemented. The controversial projects should be protected permanently, and this applies also to Øvre Otta and the concessions given for development of Saltfjellet.

### 3.1.6
### Solar energy

With relatively little sunshine in Norway year-round, electricity from solar energy is not likely to constitute a large portion of Norwegian power production in the near future. However, in certain rural areas where electricity is not readily available, solar power is already an important source of power.

The price of solar power is expected to fall dramatically in the near future. The Dutch company Sunergy together with Shell, ECN, and the Dutch government, are preparing plans for building a production plant by 2005. This will reduce the price of solar panel power to a fourth of today's price. [Benno Wiersma, Sunergy, personal communication, June 3, 1999]

Germany has started a 6-year project to mount 100,000 solar panels on the roofs of buildings. These panels will have a combined utilization of 300 MW and the government will contribute funds of DM 1 billion. [INSE 1999] In comparison, Naturkraft's gas power plant would produce about 350 MW.

Norway is among the world's leading producers of metallurgic silicon, which is refined for use in the computer industry, and leftover cuttings from the computer industry are used in the production of solar cells. The highest purity (99.8%) of this quality is currently produced in Norway, and plans are in the making for production of solar cells in Narvik. The plan is to start production of the first solar cells in Norway within the first half of year 2000. With the production of solar cells and other components for solar panels, solar energy can become one of the most important industries for renewable energy in Norway. This is discussed further in chapter 6.

## 3.2
## Abundant and inexpensive supplies of heat available in Norway

### 3.2.1
### Bioenergy and waste

Biomass that is not refined for food or industrial purposes can, in principle, be used for energy production. Traditionally, it has been normal to utilize wood by-products from forestry management and secondary wood from forestry as bioenergy. Other types of biomass that can be used are [NoBio 1996]

- Organic waste and organic products from the woodworking industry
- Straw and manure from farming
- Energy crops from farming
- Waste from the food industry
- Waste from households and industry
- Sludge from sewer plants, and
- Aquatic biomass.

Energy production takes place by converting biomass by one of the following methods:

- Burning
- Gasification
- Wet oxidation
- Bioconversion

Bioenergy covers about 15% of the world's energy consumption. Sweden and Finland supply 17% and 19%, respectively, of their energy needs with bioenergy. Biomass can be used both for centralized production of electricity and district heat, and for local heating. Burning of biomass does not release more CO2 than that which is absorbed by production of plants and trees. Both agricultural products specifically grown for this use and waste from industry, agriculture, forestry, and households —including straw, lumber, manure, and food leftovers—can be used for the production of bioenergy.

### 3.2.1.1.
### Biofuel

A study done by Statistics Norway in December 1996 shows that 28% of Norwegian households had increased consumption of wood (17% stated they used less wood). Several electric companies produce district heat from bioenergy, and bioenergy is used to an increasing degree for localized heating of homes. The price of bioenergy varies with quality, transportation distance, and standards of heating comfort. Investment costs must be considered as well.

Burning wood for heat today accounts for 7.2 TWh. [Xergi nr. 4-98] This is more than half the total bioenergy use in Norway. As much as 80% of Norwegian households use, or are capable of using, wood for heating. By changing to water and central air heating, more stable regulati-

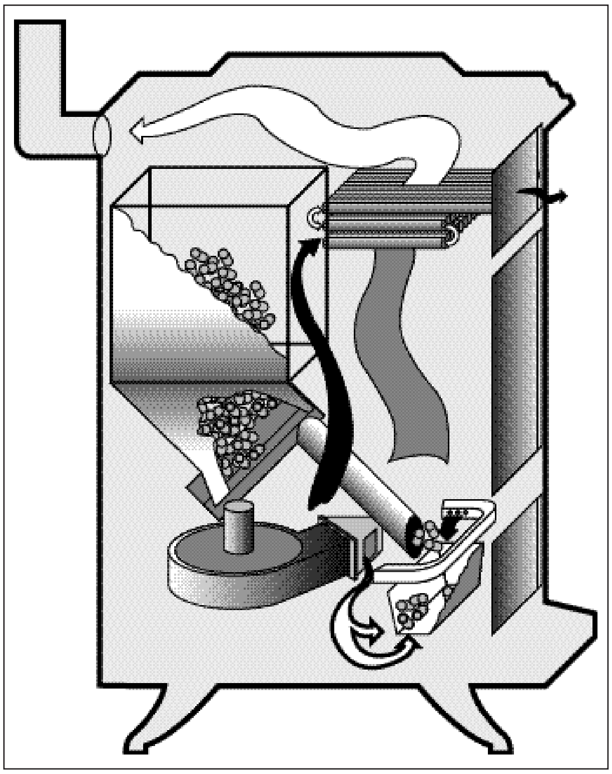


**Figure 3.2.1.1:**
**Basic design of a pellet-fueled oven**
The pellets are fed by the screw conveyor from the storage chamber to the combustion chamber. The fuel input and air feed are regulated automatically according to the desired room temperature.

ons, a better infrastructure, and a larger number of district heating plants, it is estimated that the combined potential for bioenergy lies around 20 TWh, at prices between 15 and 45 øre/kWh. Theoretically, the potential for bioenergy in Norway is over 100 TWh. Antiquated wood or coal stoves create considerable CO, tar, and particles (soot). New heater designs have reduced this problem by almost 90%. [Xergi nr. 4-98].

With regard to other types of emissions from biofuels, NOx emissions are normally 20–40% lower than that for burning fossil fuels. Emissions of soot and particles from larger biofuel power plants are at approximately the same level as oil-burning power plants. Because of the low sulfur content in wood (approx. 0.05%), the emissions of $SO_2$ are insignificant. Currently, the combined emission-level standards for biofuel power plants are not as strict as the new standards for waste-incineration facilities. For the relevant parameters, the emission standards in the future should be just as strict for larger biofuel power plants as for modern waste-incineration plants.

By depositing $CO_2$ from biofuel plants into gas fields, "negative" $CO_2$ emission is attained, which could compensate for emissions from the process industry, for example. Bellona sees this as a better alternative than compensating by reforestation, which is often presented as a viable alternative to other $CO_2$-reducing measures. Reforestation will be an important aspect in countries where it can compensate for an aggressive policy of forest depletion.

Granaries around the country dry grain by use of biofuel. Several of these have the capacity to supply heat to district heating plants during the off-season periods, which can be up to 10 months a year, including winter.

Supporters of bioenergy in the county of Hadeland have been an important driving force in putting bioenergy into use in Norway. Throughout the 1990s, the majority of the politicians who support environmental measures visited Hadeland and vocally encouraged the development of bioenergy. There seems to be a cross-party agreement to develop this type of energy use.

### 3.2.1.2
## Energy from biological waste

Most of today's industrial and household waste is left to decompose and thereby continuously emit methane, a potent greenhouse gas. Today's emission of methane from Norwegian landfills is estimated to be 325,000 metric tons per year, equal to approximately 7 million metric tons of $CO_2$ equivalent [Storting Report no. 29 (1997–98)] or 11–12% of the combined emissions of $CO_2$ in Norway. This is somewhat of a "guesstimate" as there is some uncertainty regarding methane's effect on the climate as compared to $CO_2$ .

Both ECON (1998) and BRUVOLL (1998) have pointed out that direct burning of waste is a very economical energy policy. When combined with Energos' newly developed technology for waste incineration with 50–100% recycling efficiency, this will contribute to production of 3–4 TWh new energy in the form of heat and electricity, which allows for a comparable reduction in oil burning. This form of energy recycling from new waste (mainly biological)—i.e. the waste that is left after reducing the amount of refuse and the recyclable material is separated out—is clearly the cheapest major environmental step Norway can take at present. Energos's method of waste incineration is currently the only one that satisfies the EU standards, and appears to be a perfect example of Norwegian-developed technology for environmentally-sound energy production.

Existing landfills will produce methane for several more decades. As of Dec. 31, 1997, there were 23 biogas burning facilities registered in Norway, while the number of landfills in 2000 is expected to be somewhere near 100. One possibility is to install remote-controlled fuel cells which produce electricity and heat efficiently, and which thereby minimize the environmental problems created by methane fumes from landfills. This technology is in use today and is installed at a number of landfills in the USA. [ONSI Corp. 1999]

To best utilize energy from new waste and biogas from existing landfills, and at the same time mitigate environmental problems related to methane fumes, Bellona proposes the following:

- That existing landfills with methane emissions over 10,000 metric tons $CO_2$ equivalents be required to collect and burn the biogas;
- That existing landfills with methane emissions over 100,000 metric tons $CO_2$ equivalents be required to collect and recycle biogas as a form of energy;
- That from 2005 all counties with over 10,000 residents must recycle waste as a form of energy recycling; and
- That exemptions can be given in special cases.

### 3.2.1.3
### Biodiesel

Biodiesel is exempt from diesel tax through special legislation in several European countries, including Germany, France, and Sweden. It has therefore become competitively priced and is sold in large quantities. Raising energy crops such as rapeseed, which is possible in Norway, yields a protein-rich fiber as the main product, and oil as a by-product. In other words, there is a great potential in biodiesel for development in both the farming and renewable energy industries.

Bellona has a good deal of experience with use of biodiesel and has two cars that run on 100% biodiesel (in April 1999). There have been no problems in comparison to using regular diesel. Hadeland Bioolje was recently established to build and operate a refinery for biological oil.

Pure biodiesel in Norway is currently not taxed. This is because the government wishes to make it easier to introduce renewable biofuel to the Norwegian market. Using biodiesel reduces the exhaust of particles/soot by 40% and eliminates emissions of $SO_2$ .

For now, biodiesel that is blended in mineral oil is taxable if the oil is considered to be mineral oil. This is a result of the government's resolution on taxing mineral oil. The Ministry of Finance and Customs –(FIN) has determined that a mixture of up to 5% Rapeseed Methylic Ether (RME) in mineral oil does not result in the oil losing its character of being mineral oil (letter to Hydro Texaco AS, Nov. 23, 1998). The government has therefore taxed blended biodiesel accordingly.

It is not feasible to run a vehicle on pure biodiesel today, as there is no fuel distribution network. To develop such a network would be costly and require major changes in today's infrastructure, which means that allowing biodiesel to go untaxed is not enough of an incentive to encourage further development of this alternative fuel. A step towards achieving environmentally-sound fuel would be to blend biodiesel with mineral oil, as is done in France. Biodiesel is just as renewable, and has just as low emissions per volume, regardless of whether it is used in its pure form or if it is mixed with diesel. This means that the environmental benefits are the same per liter for both pure and blended biodiesel, since they are basically the same, so to tax blended biodiesel is contradictory to the basic principle of greater tax on fuels that pollute more.

### 3.2.1.4
### Biogas

Norwegian farmers can utilize fertilizer and organic waste to produce biogas and thus electrical power, as well as to heat water. The Ffertilizer's nourishing qualities for the soil are not lessened by this process. In addition, unwanted odors and possible pollution of the ground water are reduced.

The Norwegian agricultural industry needs to concentrate on new technology as a sign that it is capable of modern development as well as initiating innovative alternatives. For farmers to now become producers of electrical power and contribute to the export of energy will be a positive incentive when forming an energy policy. Agriculture must focus on becoming an exporter of energy as a product, instead of being a net importer as it is today.

A customized energy production system can be developed to suit any farming activity, which in turn solves the problem of broadscale generalized solutions which could require expensive and unnecessary facilities and/or machinery. A relatively small farm can produce enough energy to supply itself with electricity and even allow for sale of excess power to the power grid.

### 3.2.2
### Solar heating systems

Solar heating systems can reduce household electricity use by at least 5 TWh; government and commercial buildings will also benefit. The world market for solar power is approximately NOK 10 bill. and is increasing 25% annually. Solar power plants can reduce electricity costs in households by 25–35%.

Solar heating systems are divided into two types: active and passive. One example of passive solar heat is to orient the windows in the building to collect the maximum amount of heat from the sun during winter.

A normal active solar-heating system consists of three main parts: Solar panels, a heat transfer system, and heat storage. All these components can be integrated into a building's designs very simply. Architectural designs that take into consideration solar heating or other water-borne heat, passive solar heat, and ventilation, are important for efficient energy use.

In Denmark, there are 27,000 solar heating systems, most of which are in private homes. [SolEnergi Center Danmark] If we take into consideration solar heating alone and leave out other sources, the potential for solar heat in Norway is 25 TWh. [Røstvik, H., personal cenversation 1999] This article shows how solar heat plays an important role in the transition from electricity to water-based heating. If we look at solar heat in conjunction with other sources of heat, Bellona estimates solar heat to have a potential of 5TWh.

### 3.2.3
### Heat pumps

There are currently 22,000 heat-pump systems in Norway, with a yearly heat production of 4.5 TWh, or about 7.5% of Norway's total heating needs of 60 TWh. Sweden has 300,000 pumps, which produce 17 TWh heat, while Europe as a whole has 1.5 million heat pumps producing a total of 65 TWh.

Use of heat pumps is dependent on low temperature heat sources. Air, draft air, ground heat, underground water, and geothermal heat can be found everywhere. There is also low-temperature process heat, seawater, agricultural heating systems, and other sources of excess heat which can be used. [NOU 1998:11]

Heat pumps are especially well suited for use in Norway because of the long winter season, the heavy demand for heating, a large potential for energy savings, and the easy access to suitable heat sources such as seawater and ground water.

The economic potential for energy savings in Norway is 25 TWh, which is a saving of at least 17 TWh. In order to initiate these potential energy savings as quickly as possible, Bellona proposes the following measures:

**Table 3.2.5:**
**Some potential areas for utilizing process heat**

| | | |
|---|---|---|
| Grenland | Hydro Porsgrunn and Elkem | approx. 300 GWh market 1) |
| Kristiansand | Elkem Fiskå | 50-90 GWh market |
| Odda | Odda Smelteverk | unlimited potential |
| Sarpsborg/Halden | Borregaard, Hafslund Metall | unlimited possibility 2) |
| Holmestrand-Tønsberg | Esso Slagentangen, Hydro | 800 GWh possible 3) |

1) Preliminary estimates based on contact with local parties
2) Jørn Brangerød, ENØk center in Østfold,personal communication, March 15, 1999
3) Sverre Brydøy, Esso Slangentangen, personal communication based on report from Oslo Energikonsult.

- Subsiudies for installation of heat pumps in homes,
- Subsidies for installation of water-borne heat.
- Certified installers,
- Standards for new building codes with regard to technical/economical considerations for heat-pump installation,
- Standards for use of cooling and heating systems in buildings with air conditioning,
- Restrictions on use of direct electricity heating, and
- Continual research and development of heat-pump systems specially designed for conditions in Norway

### 3.2.4

## Geothermal energy

Geothermal energy is divided into “hydrothermal energy” and “normal thermal energy”. Hydrothermal energy is easiest to use and most common on a worldwide basis today. Geothermal energy is mainly drilling into the earth and utlizingutilizing the underground heat to heat up water.

In Scandinavia, Iceland is recognized for using this type of energy, but there are many countries worldwide that use geothermal energy.

China is the world leader when it comes to geothermal heat production, while the USA is biggest in electricity from geothermal energy [ABB 1998].

Italy drilled its first geothermal well in 1907.

As much as 40% of Paris is heated by heat pumps and geothermal energy.

The estimated exploitable energy reserves down to a depth of 5km would produce 64 TWh in Norway. This potential has a rather low temperature and is only useful for heating purposes. The realistic potential over 10 years is 4–5 TWh. It is mostly warm granite in the south which has been investigated, and around Iddefjorden the temperature is approximately 110 °C at 5 km. Brumunddal sandstone is the only sedimentary form of rock that is of interest with 60 °C warm water at 3 km. depth.

At Norway’s new national hospital, Rikshospitalet, they are boring down to 600 meters and are planning to bore down to 4000 meters. The temperature at that depth is about 120–130 °C and the plan is to pump cold water down and bring it up as warm water through another well hole. This water, at 75 °C, will be heat exchanged with water to provide hot water and room heating. The system is estimated to cost NOK 21 million, and will produce heat equal to 2 MW at a cost of 17.8 øre/kWh. [Aftenposten Interaktiv, 18.03.98] In comparison, district heat from Viken Energinett costs 37 øre/kWh today.

If Rikshospitalet’s system is expanded to reach 6–8 MW, equaling 27–35 GWh, the price will drop to only 11 øre/kWh. This will then cover 70–90% of Rikshospitalet’s needs for hot water for heating and other purposes.

If this research project is successful, and is followed-up by other similar systems, large parts of Oslo will be able to utilize geothermal heating. Viken Energinett predicts that up to 150,000 homes and commercial buildings in central parts of Oslo can be heated this way. This is equal to a 2 TWh reduction in electricity and oil consumption just in Oslo. Other big cities that do not have access to inexpensive process heat have the same potential, and in Stavanger, Bergen, Drammen, Tromsø, and Bodø, it should be possible to extract the same amount of geothermal energy as in Oslo.

### 3.2.5.

## 1–2 TWh process heat available close by consumers

Norway has an active and extensive manufacturing industry which spews 30 TWh of heat into the air or ocean every year. Enormous quantities of water are used daily to cool down plants, and this heat could be fed to nearby areas relatively quickly. This source of heat is also priced competitively in comparison to current electricity prices (for example, 31 øre/kWh in the Tønsberg area), but local initiative and cooperation is necessary to achieve this. One of the few places that have managed this is Ila Lilleby Smelteverk and the municipality of Trondheim. Some of the other potential candidates include drying systems, cleaners, bakeries, swimming halls, and greenhouses that are located near the processing industry.

### 3.3

## Renewable energy in other countries

An energy policy that addresses long-term consequences must encompass development and use of technology to achieve energy savings, increased efficiency, and reliable energy sources. In 1990, renewable energy supplied 18% of the world’s total energy use, and of this, hydropower supplied 30%. Consumption of fossil fuels such as coal, oil, and natural gas, has increased dramatically in the last 40 years. The period from the 1960s to the 1980s saw the greatest increase of 5% annually.

### 3.3.1

## Denmark

Danish authorities are actively engaged in reducing electricity consumption, and in addition, laying the groundwork for an energy policy which will stimulate construction of decentralized district heat and renewable energy production. The goal is 1500 MW wind power in 2005 and 4000 MW in 2030, [ Den danske Regering (The Danish Government )1996] as opposed to about 800 MW in 1996. [NOU 1998:11] Wind power will then supply approximately 10% of Danish electricity. There is a subsidy of 7–10 øre/kWh for decentralized district heat and 10 øre/kWh for wind power plants owned by power companies. Private wind power plants receive a subsidy of 27 øre/kWh.

In 2003, Denmark the Danish people must buy at least one-fifth of their current from renewable energy resources. Purchasers of electricity are required to buy an increasing percentage of renewable energy. At the end of the contract period, this percentage must have reached 20%. [BM 2/99] Today, renewable energy sources contribute to less than 10% of the country's energy production. By 2030, the percentage must be up to 356%.

Renewable energy sources will contribute to 12–14% of the combined net energy consumption in Denmark in 2005. The percentage of renewable energy sources in energy supplies will be increased to approximately 35%, which cuts the amount of CO2 emissions in half by 2030 as compared to the level in 1998. Construction /expansion of renewable energy sources in the near future will most likely be through use of bioenergy and wind power. [Den danske Regeringen (The Danish Government) 1996]

In order to limit the demand for electricity, especially for heating, high taxes are placed on residential electricity; in 1997 this was 50.9 øre/kWh. Industry is protected through lower fees and certain rebates.

### 3.3.2

## Sweden

Sweden also has a considerable fixed consumption of bioenergy. In 1996, consumption of biofuels (including peat) was just under 70 TWh. About 60% of consumption is from industry, primarily forestry, while less than a fourth is used in district heat production. In addition is the consumption of bioenergy in homes, first and foremost in the form of wood and wood chips. [NOU 1998:1]

Sweden's energy policy has established the following main goals: Nuclear power will be phased out, the remaining undeveloped damming projects will be protected, bioenergy will be prioritized, and price-competive power for industry must be made available.

Important measures for achieving these goals include working toward efficient consumption and a change in energy production. They are implementing a conversion program to run over 7 years at a cost of SEK 9 billion. The main points state that large electric boilers/furnaces used in district heat will be taxed considerably, use of electrical power for heating will be reduced and to a great degree replaced by district heat, and incentives for new power production from alternative fuels will be provided.

### 3.3.3

## The EU

**Current and future electrical production in the EU**

Source: European Commission 1997

| | 1995 | | 2010 | |
|---|---|---|---|---|
| Type of energy | TWh | % of total | TWh | % of total |
| Total | 2.366,00 | | 2,870.00 | |
| 1. Wind power | 4,00 | 0,20 | 80,00 | 2,80 |
| 2. Hydropower | 307,00 | 13,00 | 355,00 1 | 2,40 |
| 3. Solar energy | 0,03 | - | 3,00 | 0,10 |
| 4. Bioenergy | 22,50 | 0,95 | 230,00 | 8,00 |
| 5. Geothermal energy | 3,50 | 0,15 | 7,00 | 0,20 |
| 6. Total renewable energy | 337,00 | 14,30 | 675,00 | 23,50 |

The EU is concentrating heavily on renewable sources of energy. In the absence of abatement measures , Europe's total energy consumption is expected to increase by 70% within 2002. [EU Commission 1997] The EU Commission has considered several different ways in which to increase the percentage of renewable energy from 9.9% in 1995 to 12% in year 2010. The greatest increase will come from bioenergy (90 Mtoe), followed by wind power (40 GW). [EU Commission 1997] The investment need is about 165 billion Euro (1997–2010). At the same time, this will create somewhere near 900,000 new workplaces, while CO2 emissions will be reduced by 402 million metric tons per year.

### 3.4

## The political and economic structure

Norway's main goal is to supply domestic consumption in a normal year with renewable energy, which means starting an aggressive investment in developing new renewable energy sources.

The energy policy must contribute to stable conditions for commercial activities related to the new renewable energy sources so as to stimulate rejuvenation of future research and development in this industry.

Several countries are working actively on developing alternative energy sources. In Sweden, the government is putting SEK 9 billion into research and development of alternative energy sources, and has established a grant for ecological power production. During the next 4 years, Japan will be installing solar panels on the roofs of 100,000 homes, generating an average capacity of 4 kW. The government is subsidizing this project by covering 50% of the cost.

Bellona proposes tax exemption on investments related to development of new renewable energy sources, as well as exemption from VAT for the first five years. In order to contribute to long-term goals, Bellona proposes that all suppliers of electricity for normal use in Norway must assure that, by 2005, 5% of this comes from renewable energy. Solutions for renewable energy are described in further detail in chapter 7.4.

### 3.4.1

### Free energy from the process industry, geothermal sources, and waste incineration to be given the same advantages as renewable energy.

Bellona feelsIt is Bellona's opinion that process heat from today's industries, waste incineration, and geothermal sources have qualities which make them at least as attractive as renewable energy sources. For one thing, this source of energy is already being created and is centralized without any further impact on the local environment, and it will not create any additional environmentally hazardous emissions to put it into use. It is actually "free energy." Utilization of these resources should therefore be given the same advantages as renewable energy in Norway:

- Exemption from investment taxes
- Exemption from VAT on sales the first five years

The combined effect of these measures will indirectly save approximately 8 øre/kWh the first five years, and thereafter an indirect savings of 1.5 øre/kWh based on a price of 30 øre/kWh, excluding VAT.

Competitively speaking, process heat will benefit from a shift in the government's income from valueadded tax to tax on electricity, as discussed in chapter 4.2.

## 3.5

## Hydrogen production from renewable energy

Many renewable energy sources fluctuate greatly depending on the time of day or season. An energy system which is subject to these conditions must be able to store the energy to compensate for these variances. These distances between the source and the consumer are often great and create a need to transport energy. For both of these reasons there can be significant benefits from converting the energy to hydrogen.

A renewable energy system must also include a renewable transportation system. When the transportation industry is responsible for about one third of the energy use in the EU, it is quite clear that the need for renewable hydrogen will be an important source of energy in the future. By 2050, almost 20% of the world's total energy consumption will be supplied by hydrogen made from renewable energy, according to a study conducted by Shell.

Hydrogen from biomass has the potential to compete with hydrogen from natural gas. At the same time, two independent studies [Ford EVS-15] and [NHE 1997] show that hydrogen produced at a fuel station, by electrolysis of water using electricity from Norwegian hydropower, would be cheaper than gasoline.

By producing hydrogen by current-driven electrolysis, Norway would be able to develop a renewable fuel infrastructure based on cutting-edge Norwegian technology. This will be more consistent with long-term goals, and therefore cheaper in the long run than building a methanol infrastructure.

Chapter 5 shows how the transportation sector in Norway, by using electricity and hydrogen, can utilize renewable energy with almost no polluting emissions. It also describes how hydrogen can be produced from renewable energy sources.

### 3.5.1

### Electrolysis of water

If renewable energy is also used to split the water into hydrogen and oxygen, the hydrogen will be an even cleaner form of energy.

Norsk Hydro produced hydrogen by electrolysis from 1928 to 1988. The maximum capacity was approximately 100,000 Nm3/h. Norsk Hydro Electrolyzers (NHE) is currently one of the world's leading producers of electrolyzers, and they have an efficiency of about 85%. Efficiency is an important factor because consumption of energy makes up 80–90% of the production costs at an electrolysis plant.

NHE is working with Gesellschaft für Hochleistungswasserelektrolyseure (GHW) on developing a compact electrolyzer which can produce hydrogen comparable to the energy supplied by a regular gasoline/petrol station. These electrolyzers will operate under pressure. In cooperation with GHW, NHE plans on developing electrolyzers which have an efficiency of 90%. The highly varying effects from new renewable energy sources present major challenges in development of electrodes if high efficiency is to be maintained.

A great deal of the complex technology used in the development of PEM fuel cells (see Attachment 3) can be used for electrolyzers. If it were possible to increase the maximum temperature of the PEM membrane, an efficiency of 90–95% could be attained. However, this would put too great of a demand on the materials used and is not feasible at this point. [Financial Times 1997].

There are also reversible PEM systems which can generate electricity or hydrogen as necessary, but for the time being only at low efficiency levels.

### 3.5.2

### Gasification of biomass

Hydrogen can also be produced by thermal gasification of biomass such as forestry waste products, straw, municipal solid wastes (MSW), and sewage (municipal waste). Under extreme heat, biomass decomposes to gas. The gas consists mainly of $H_2$, CO and $CH_4$ (methane). Steam is then applied to reform the methane into hydrogen and CO. The CO is then reinjected into the process to increase the yield of hydrogen (see chapter 2.5.5).

There are several gasification reactors that can produce methanol from biomass. Several of these can be used for hydrogen production, and those that use air instead of oxygen are more economically attractive. All other components needed, such as methane reformer, shift reactor, $CO_2$, and hydrogen purification are well-established technology. [Ogden & Nitsch 1993]. Hydrogen production from biomass can easily compete price-wise with producing hydrogen from natural gas.

### 3.5.3
### Photoelectrochemical production

Instead of converting sunlight to electricity and then using an electrolyzer to produce hydrogen from water, it is possible to combine these two functions. The photovoltaic cell is combined with a catalyzer which acts as an electrolyzer and splits hydrogen and oxygen directly from the surface of the cell. The American National Renewable Energy Laboratory has attained an efficiency of over 12% with a cell consisting of a layer of gallium indium phosphide (GaInP2) over a layer of gallium arsenide connected to a platinum electrode in water. Theoretically it is possible to obtain an efficiency of 24%, and research is now being done to replace the high-priced materials with less expensive ones, and to increase efficiency. [Sverige's Tekniska attacheer 1998]. This is definitely a commercially feasible method for producing hydrogen. Using this type of solar cell can reduce the costs of photolytic production of hydrogen to one-fourth of what it costs for photovoltaic panels and electrolysis. [Hydrogen & Fuel Cell Letter, June 1998].

### 3.5.4
### Photobiological hydrogen production

Biological electrolysis (splitting water into hydrogen and oxygen) is the first step in photosynthesis. This is the basis for which all life absorbs energy, and the basis for almost all life on earth.

Photosynthesis occurs when chlorophyll in cells absorbs sunlight. Enzymes use this energy to break water down into hydrogen and oxygen. The hydrogen is then combined with carbon dioxide into carbohydrate. Certain microorganisms release hydrogen instead of carbohydrate under photosynthesis.

Blue-green algae, green algae, and bacteria can be used for technological production of hydrogen. The efficiency is rather low at present, but an increase of 10% would make this process economically feasible. Research is now being done on finding enzymes which produce hydrogen, even when oxygen is present, as the presence of oxygen normally hinders the electrolysis process.

There remains a good deal of work to be done in choosing the right algae types, and further experience in production from existing facilities will be a deciding factor in developing inexpensive and efficient production plants. The investment costs are expected to be almost 90% of the expenses involved in this type of production.

### 3.5.5
### Biological hydrogen production from organic waste

The bacteria Rodobacter speroides has been successfully used in production of hydrogen from waste from fruit and vegetables, and has also been tested on sewage with positive results. The process is currently still at the laboratory stage, and work still needs to be done on increasing cost efficiency and application.

Institut fuer Verfarenstecnik der RTWH, Aachen in Germany has developed two different bioreactors which produce hydrogen based on whey from dairy production.

### 3.5.6
### Thermal electrolysis of water

In a thermal solar power system with a central collector, like Solar Two in California, the temperature can reach over 3000 °C. Electrolysis can occur by heating water to over 2000 °C. This is an attractive production process which can produce inexpensive hydrogen directly from solar energy.

# Chapter 4

# Energy efficiency on the mainland

In order to increase efficiency in energy consumption in Norway, two things must be considered. The first is that new business, new transportation, and new construction must be based on energy-effective systems and technology in order to put a stop to the increase in use of electricity. The potential for energy efficiency, which technological development and research has already made marketable and profitable, must be opened up by setting standards which make it attractive for private operators. Bellona proposes the following steps to achieve a savings of 20TWh by 2010:

| | |
|---|---|
| District heating from industrial processes | 1-2 TWh |
| District heating from biomass, waste and geothermal heat | 8 TWh |
| Heat pumps | 1 TWh |
| Renovation and expansion of the power grid and turbines | 5 TWh |
| Heat recycling (electric) from smelting plant foundriesy | 1.3 TWh |
| Min. requirements for incandescent and fluorescent lights | 4 + TWh |
| Other energy-saving improvements in residences | 1 TWh |
| Maximum limits on stand-by use by appliances | 0.5 TWh |

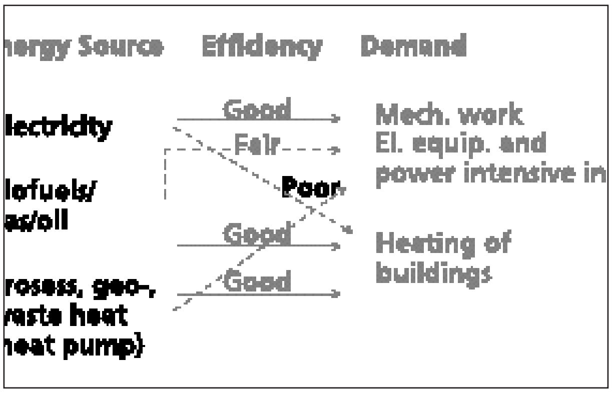


**Fig. 4.1.1: Energy quality**
To achieve energy efficiency, energy which can only be used for heating must be used for heating purposes. This will ensure that electricity is available for those areas where only electricity can be used.

## 4.1

## New technology to curb increasing consumption of electricity

### 4.1.1

### Using the most appropriate type of energy

In order to meet today's increasing demand for electricity, the power companies are required to expand netgrid capacity to assure power to all, even in peak periods (Energy Act § 3). This basically means that additional new power lines will have to be laid, which will cost several billion NOK over the next 10–-20 years.

Much of today's household electricity is used for heating by "old-fashioned" resistance heaters (also called wall panel heaters), devices that heat because the electricity is fed through electric resistance coils. All other use of electricity is more efficient in principle, and provides the same service and the desired by-product, heat. Resistance heaters utiliseutilize only 7% of the current's capacity to heat up a room, and is the least effective use of the most valuable form of energy we have: electricity. By using heat pumps, efficiency can be increased by 30–40%, and thereby reduce consumption of electricity by 60–80%. Heat pumps are most appropriate where running or free-flowing water is found, and are just one of several examples of ways to reduce consumption of electricity.

Electricity is the most efficient form of energy we have and anything that requires energy for operation can be driven by electricity.

This is not true of the other types of energy, such as biofuel, process heat, oil, and natural gas. These can only be used for heating in their initial states, and if they must be converted to electricity there is an energy loss of 45–90 %. In order to reduce consumption of electricity, heating needs must first be covered by other sources of energy, and this means that installation of electrical wall heaters must be stopped. For Norwegians, this may sound rather dramatic, but wall heaters are already partially banned as main sources of heating in new buildings in Denmark and Sweden. This is mainly because they experienced a power crisis a few years before Norway did.

## 4.1.2

## Increased use of electricity for heating costs more than district heat

With the current power-grid capacity problems experienced with electricity, it is more and more likely that installation of new electrical heating in new buildings will result in a need for expansion of the electrical power grid. Use of electrical wall heaters also has the disadvantage of peaking out during the winter season and dropping to nothing in the summer months. Meanwhile, in order for the grid to handle these peak periods, it has to be constructed to meet these peaks, and this can be extremely costly in the years to come.

Sintef Energy Research (SEfAS, previously EFI, 1996) has attempted to determine the total costs of previous expansion of the transmission system, main power grid, and distribution network. Based on the size of the investments which were made from 1981–1990, and the increase in capacity which was achieved during this 10-year period, they estimated (NOK in 1990) that the network cost approx. NOK 1,300 per kilowatt for the main power grid and NOK 7,400–12,100 per kilowatt in the local distribution grid. At 7% interest and 25 years payment period, including an estimated inflation of 15% for this type of installation from 1990 to 1998, the annual costs of expanding the network are as shown in Table 4.1.2a.

**Table 4.1.2a**
**Construction costs of the electrical power grid**

| | Historical construction costs [kr/kW/år] (in 1990 NOK) | Annual Costs [kr/kW] (in 1998 NOK) |
|---|---|---|
| Transmission system (300-420kV + transformer) | 1,300 | 126 |
| Main power grid (66-132 kV + transformer) | 1,333 | 127 |
| Distribution grid | 7,400 – 12,100 | 850 – 1,390 |

**Table 4.1.2b**
**Electric and district heat cost comparisons.**

| | New electric consumption using panel heaters øre/kWh (NOK) | New district heat supplied by piping øre/kWh (NOK) |
|---|---|---|
| Energy production | 20 | 14-25 |
| Transmission system | 5-6 | 0 |
| Main power grid | 5-6 | 0 |
| Distribution grid | 35-75 * | 10-11 |
| Sum – Marginal cost | 65-107 * | 24-36 |
| Actual price paid by cusomter | 40-45 | 30-45 øre/kWh |
| Our estimate (based on experts in the field) | | 30,000 |
| 10,000 * | | |

As new consumers need electricity regardless for lighting and technical purposes, the marginal extra cost for grid distribution for panel heaters on the local grid will be lower than stated in the table. There are currently no statistics for more precise figures.

In order to have a clearer picture of what electricity costs per kWh for a household, it must be taken into consideration that the number of hours used annually for panel heaters is between 2,000 and 2,500 (Gulstrand, 1999). Table 4.1.2b shows a comparison of the approximated costs of electricity and district heat in new construction.

Even though it is difficult to determine a realistic average in each case, table 4.1.2b shows quite clearly that today's energy regulations force the power companies to expand the network even though this is not very economical. This basically means that those who have maintained a steady power consumption end up subsidizing, under today's network tariffs, those who have increased their consumption. The table also clearly shows that those who have increasing demands pay only a small portion of the actual cost resulting from the increased consumption. In an open market, district heat would be the clear preference in many cases, also for the grid operators.

On the power market, requirements for covering consumer needs previously lead to power companies being forced to expand hydropower plants at costs of over 35 øre/kWh. These power plants operate with a considerable net loss and are relics from the past. At the same time that it is generally recognized that these costly power plants are not the best solution, the power companies are forced to continue this meaningless expansion at costs of up to NOK 1 per kWh, and income of barely 20 øre/kWh.

## 4.1.3

## Inconsistent regulations hinder district heating

Use of district heating, natural gas, solid fuel, oil, and electricity for heating in Scandinavia. Norway is the only country which still allows electrical panel heaters as a main source of heat and the only country where the potential for utilizing surplus heat (district heating) is virtually unused.

A public power grid operation is a monopoly controlled by government concessions. Paragraph 3 of the Energy Act requires the power companies to supply consumers with electricity or district heating. But there are other laws which are interpreted such (by NVE) that power companies cannot, in practice, choose to supply district heating instead of electricity for heating, even if that is the cheapest alternative.

According to NVE's interpretation of the law, district heating is defined as a market open to competition. The price of district heating is however, for the time being, set by law not to exceed the price of electricity (§ 5.5 of the Energy Act). This is a paradox but has not been a great problem in reality. The main problem is that when a new district heating network is built, it is dependent on all the residential units hooking up to obtain a low heating cost. Mandatory hook-up requirements can only be issued by the municipality through zoning plans, and would thereafter give concession to one district heating company. Revision of zoning plans is very time-consuming and resource-demanding, and the building contractor has often come too far in the design and development of the project before local

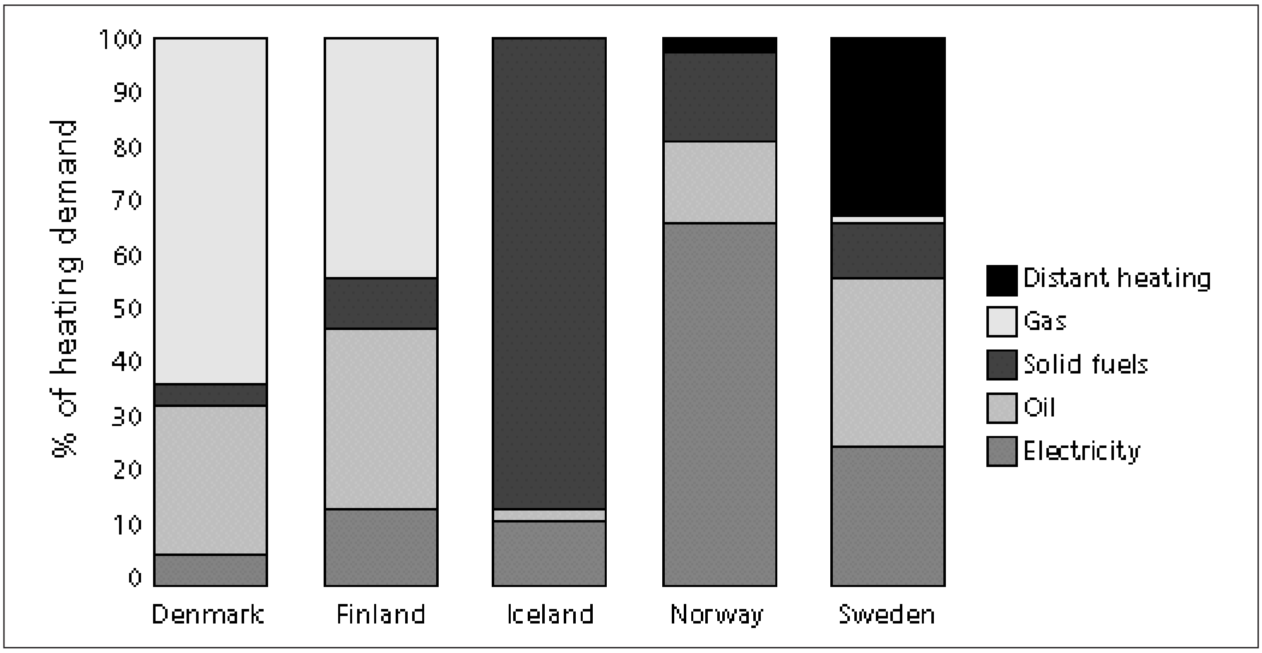


**Figure 4.1.3:**
Heating in Scandinavia
Use of district heating, natural gas, solid fuel, oil, and electricity for heating in Scandinavia. Norway is the only country which still allows electrical panel heaters as a main source of heat and the only country where the potential for utilizing surplus heat (district heating) is virtually unused.

agencies and businesses come into the picture to evaluate the feasibility of hook-up requirements. In Drammen, this has lead to expanding the electrical network instead of district heating, even when this the latter would have been less expensive.

Bellona recommends that OED and NVE change their interpretation of § 3.3 so that the power companies can determine which hook-up requirement would be the most economical solution for a certain area.

Bellona also recommends that as much as possible of the base rate for electricity be incorporated into rate/use per kWh. This will enable more efficient distribution and motivate consumers to use electricity more efficiently, without increasing electricity bills.

### 4.1.4

## Lower power-grid rates for decentralized electrical power plants

Most of the renewable sources of energy will be utilized in smaller local plants. This includes small-scale hydropower, salinity power, solar energy, biogas, wind power, and refuse-derived fuel (RDF). It would normally be advantageous to build these power plants as close as possible to large power-consuming industries, where there is a very short distance between supplier and consumer. The shorter the distance, the more cost-effective the energy production is.

According to the current regulations, the network monopolies can demand payment for use of the grid for all supply of electricity between producer and consumer. This is also the case even when the power company itself neither pays for, nor maintains, the power lines. In these situations, the economic advantage of local electricity production has basically been defeated.

Bellona requires that local electricity production near local consumers must reflect the actual costs that the power company incurs.

Bellona requires that electricity producers that supply electricity locally should be exempt from paying power grid rent where the power grid owner does not incur additional expenses from the transfer.

### 4.1.5

## Prohibition of resistance heaters in new construction except single-family homes

With the enormous increase in electricity consumption Norway is experiencing today, there is a constant need for large investment in the power network, but in many areas it would be considerably less expensive to expand the district heating network instead of electricity. In Drammen, Energinett's district, a combination of district heating, energy saving and increase in capacity would be NOK 300–400 million cheaper than only expanding the existing network over the next 20 years [Oslo Energikonsult 1997].

A total revision of the existing regulations to allow the utility companies to offer heat instead of electricity for heating, as per the intention in § 3.3, will probably have only a moderate effect since the entire branch seems to be "sold on" electricity. It could therefore be easier and more efficient to do as Denmark and Sweden, and prohibit resistance heaters as the main source of heating in new construction, except for single-family homes and commercial buildings under 200 m2. This would, in reality, allow the developers to choose between district heating, heat pumps, bio-fueled boilers, gas boilers, and, in an introductory phase, electric heated boilers, without having to establish special rules and regulations for every individual heat source.

Advantages of prohibiting new resistance heaters include:

- Not having to issue new regulations for all heating alternatives
- Not having to establish a subsidy program for each alternative
- Not having to penalize those that already have resistance heaters

Establishing open competition between environmentally-sound heating alternatives, providing that oil burning is gradually reduced/prohibited, in accordance with the parliamentary majority's recommendations [Stortinget. ref. case 9, 17/6-98]

Saving several years of delays and tie-ups in the bureaucracy and trade associations in comparison to an alternative strategy, which would simply entail a new review and amendment of the Energy Act.

### 4.1.6

### Minimum requirements for electric lighting

In the last decade there have been major technological developments in technology in incandescent and fluorescent lighting, which are now up to 10 times more effectient than old incandescent light bulbs, and have an energy efficiency rating of 30%. Just as there are minimum requirements for buildings, electric wiring, water supplies and sewage, it is also time to set minimum standards for light bulbs and fluorescent lights. The light quality (color) of the most efficient technology today is not up to the same standards as conventional incandescent bulbs so it would be best to set minimum standards somewhere between the best and worst existing technology.

Based on discussions with lamp- and bulb manufactuerersmanufacturers, Bellona feels that the minimum energy efficiency for lighting sold in/or installed in Norway after January 1, 2001, should be 12%, or 40 lumen/Watt. Comparable requirements for installation of, or renovation in workshops, should be 70 lumen/Watt from January 1, 2001. In the course of the next 5–-10 years, by with normal replacement of light bulbs and fluorescent lights, electricity consumption will be reduced by 4 TWh.

### 4.1.7

### Maximum requirements for power drawn by Limiting the stand-by function on new electronic equipment

The stand-by function on TVs alone uses more than 0.3 TWh per day. If we include PCs, stereos, and other items, the rate is probably closer 0.7 TWh. With the apparent increase in this market, it is important to stop this unnecessary use, which is merely due to lack of concern on the part of the manufacturers. It is therefore crucial to set a standard for the stand-by functions which allows a maximum of 10% of total energy consumed under normal use. Consumption is currently the same for many appliances whether in stand-by mode or in use.

## 4.2.

## Cheaper food and clothing - —more expensive electricity and waste of energy

It has proved very difficult to increase electricity taxes in Norway above the current 5.6 øre/kWh. In Denmark and Sweden, however, there are taxes of 53.5 and 12.8 øre/kWh. The Federation of Norwegian Commercial and Service Enterprises is the most sceptical, the political parties are also rather concerned. Both have a common fear of increased costs, whether with regard to commercial activities or the voting public. Bellona has therefore attempted to re-direct these tax monies back to businesses and the voters as easily and fairly as possible. We propose cutting value-added tax by 1% and at the same time increase electricity tax by 5 øre/kWh for all consumption except that which goes to the production of materials in power-demanding industry. On the whole, this means that other goods will be less expensive while electricity bills will increase. Combined, we actually pay the same as before.

The exception for materials produced in power-demanding industry is mainly due to the fact that these are materials which, to a great degree, go to export, and this is therefore just another means of exporting energy. This is also energy which can be used by many generations to come because it is stored in materials which are well-suited for recycling. The energy which is lost in power-demanding industry should be taxed at the same rate as for normal consumers for the time being, which will provide the incentive to increase energy efficiency in the same way as for normal consumption. The additional costs incurred will be compensated by the fact that these industries will save on the reduction of the value-added tax.

## 4.3.

## New cable technology

HVDC Light (High Voltage Direct Current) is a new type of HVDC cable (High Voltage Direct Current) which can be buried on land, laid subsea under water or as aerial cable. This means that it could be used to replace many of the high- tension aerial cables which currently cross some of our most valuable nature reserves. Initially, new power lines should use this new type of cable wherever possible. At the same time, a list should be made of the high- tension cables which cross important nature reserves and Nnational Pparks, gradually replacing these with buried cables.

The advantages with of HVDC-Light:

- Cost efficient transfer of smaller quantities ( >1 MW) of power over long distances
- Possible operation without transformer stations
- Suited for small-scale electric production, i.e., windmills, mini- and micro- power plants
- Will reduce the problems with animals/birds and coming

in contact with power lines, as well as eliminate the negative visual aspects of high-tension aerial cables.

- Possible to connect to passive loads or a dead grid. This makes it much simpler and cheaper to electrify oil and gas platforms offshore.

Cables of 2 x 25 MW, at 100 kV, can be manufactured down to 1 kg./m. [ABB 1998] These cables can be installed quite cost-effectively due to a simple technique and the possibility of using to be used in aerial spans where burial is impossible.

Traditional powerlines require very high voltages to limit energy losses over long distances. By using HVDC-Light, the cost will be much more reasonable, which will allow mini- and micro- power plants to operate at a profit. There are also benefits to be gained by connecting several small-scale power plants—, such as mini- and micro- power plants, and windmills,— with HVDC-Lights, which can then be easily connected to the main grid.

Based on new cable technology, Bellona proposes that high-tension cables in National Parks in Norway be replaced with buried cable. It is most logical then to start with those parks which are the most controversial areas when it comes to birds and areas protected by the Dept. of Natural Resources' Nature Conservation Act, such as nature reserves, nNational Pparks and nature protection protected areas. These cables should be replaced by year 2010.

## 4.4.

# Tax loopholes from Sweden and Denmark

Sweden and Denmark place high taxes on use of electric power. In principle, the prices in both markets are therefore raised so that the cost of electricity reflects the environmental impact somewhat better. When Norway imports electricity from Sweden and Denmark, the intended market mechanisms are disrupted. The coal power produced in Denmark and nuclear power from Sweden, are not taxed— - neither in the originating country nor by the importer. In this way, Therefore, it is the worst environmental solutions which become favored by the tax system.

## Chapter 5

# Hydrogen and electricity in the transportation sector

People value mobility very highly and the demand for mobility increases proportionately with an increase in population and affluence. The average time a person spends travelling in the course of a day is, however, constant (1.5 hr.); and this applies regardless of income or geographical location. [Shell 1998] Available time is a key factor in determining which type of transportation a person chooses; statistically speaking, the higher the income a person has, the faster the means of transportation will be chosen.

The transportation sector is now responsible for 30.8% of the total energy use in the EU. Vehicle traffic is the greatest source of noise and local air pollution, and a considerable contributor to the global release of greenhouse gases. In 1996, 31% of Norwegian carbon dioxide emission came from the transportation sector, where road traffic accounted for 65%. [Utfordringsdokument: National Transport Plan 1999].

In Norway, there are 750,000 people who suffer from noise and/or air pollution from vehicle traffic, according to the Norwegian Pollution Control Authority (SFT). Vehicle traffic is currently the greatest detriment to the environment in Norway. [SFT, July 30,1998]. The World Health Organization's international cancer institute in Lyon, France, has concluded that emission from diesel vehicles is most likely a cause of cancer, while there is no equally conclusive documentation for gasoline exhaust. Particles in diesel exhaust damage DNA, and this damage leads to the development of cancer. Every year approximately 250 to 350 persons in Norway die of cancer as a result of particle emissions from diesel vehicles. [Professor Tore Sanner at the Dept. of Environmental and Work-Related Cancer, Radium Hospital, to Aftenposten, Feb. 22,1999].

In this chapter, we will show how electricity and hydrogen can alleviate some of the main problems related to automotive mass transportation: noise and exhaust emissions. Discussion and references regarding alternative transportation solutions are outside of the scope of this report.

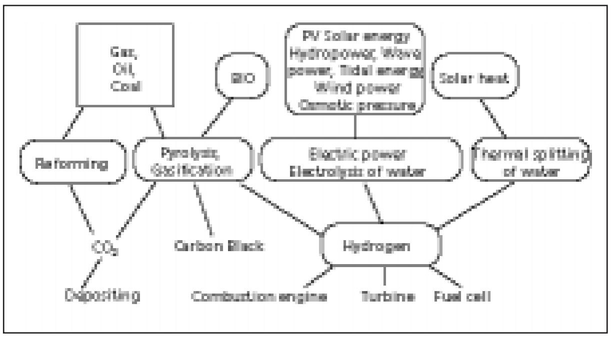


**Figure 5: Hydrogen production**
Hydrogen can be produced from both fossil and renewable energy resources.

### 5.1.

## Regulations and taxes force the development of new technology

The Zero Emission Vehicle (ZEV) regulation, which was adopted by the American states of California, New York, and Massachusetts, goes into effect in 2003. The law requires that at least 4% (approx. 65,000) of all new vehicles be zero-emission cars.

In addition, 6% (approx. 95,000) must be zero-emission cars, or a greater number of extreme-low-emission cars that correspond to the equivalent ZEV credit (car manufacturers get a "credit" for every low-emission-car, and a certain number of these equals one ZEV).

The EU's Auto-oil requirement (EU 30.10.1998) for emission of carbon monoxide, hydrocarbons, and nitrogen oxide from vehicles, will be put into effect from 2000 to 2005, and requirements that also include CO2 (140g CO2/km [Automotive Environment Analyst 1998]) will be put into effect in 2008.

At Majorstua in Oslo, air pollution exceeded the new EU standard 75 days last year, and this area is far from the most polluted in Oslo. In order to meet the requirements which go into force from 2005, drastic measures must be taken. [Aftenposten Jan. 14, 1999]. In The United States, Federal authorities are preparing new regulations which are so strict that diesel vehicles have difficulty passing the tests, even with the most advanced exhaust-purifying technology. [Aftenposten Feb. 22, 1999].

In order to meet these requirements, the car industry is developing new drive trains and looking into new fuels.

The current oil-based combustion engine system, which is more than a century old and pollutes both the local and the global environment, can be abandoned to the advantage of a cleaner energy system based on hydrogen and electricity as energy sources. The combustion engine can be replaced by more advanced technology, not only because of its poor fuel efficiency, or because oil reserves run out, but also because the new alternatives are better and less expensive. There is no reason why the Polluter Pays Principle should not apply to the transportation sector also. The authorities' taxes on fossil fuels must thereby be increased, while cleaner alternatives should become equally less expensive.

Electricity and hydrogen can be incorporated into an energy system based totally on renewable energy and can eventually totally replace fossil fuels. Batteries and fuel cells are two technologies that provide electricity for the electric car, which is the car of the future. It is important that measures are put into effect which will promote the use of these cars, measures such as exemption from fuel taxes and building an infrastructure of hydrogen supply and battery-charging stations.

Bellona proposes that Norwegian authorities should adopt the ZEV regulations and work to get these adopted by the EU—not only as a sign to the car manufacturers, but also to ensure that the best available technology is put into use as soon as possible.

## 5.2.

# Fuel Cell Cars

A Norwegian governmental report from 1998 states that hydrogen-based fuel cell cars are the only known alternative which can combine zero-emissions with the comfort and driving distance we are accustomed to with today's cars. [NOU 1998:II]

Fuel cells generate electricity by converting oxygen and hydrogen into water without combustion.

Fuel cells are quiet, effective and, because they have no movable parts, very dependable. A fuel-cell system in a car will be almost maintenance free.

Fuel cells are superior to combustion engines because of their dependability, energy efficiency, and environmental friendliness.

The modern fuel cell's beginnings started with the space program Apollo, when NASA needed a reliable and simple electrical supply onboard the space capsules. They continued development of the fuel cell, which at that time was looked upon as a curious invention from 1839. On the Apollo lunar mission ,mission, the energy supply on board the space capsule was based on fuel cells with hydrogen, and the "waste product"—water— was drunk by the crew. Fuel cells are quite common in space travel today.

After the successful voyage to the moon, in-depth research into the fuel cell was initiated to develop the fuel cell for use in vehicles. But the cells were quite expensive, especially because of the large amount of platinum needed as a catalyst, and gas prices were also low at the time. But because of increasing environmental awareness and breakthroughs in a technique which reduced the need for platinum, research into development of fuels cells has increased in the last decade.

There are several types of fuel cells with different characteristics and applications. Fuel cells are usually classified by the electrolytes they use. (See the table in Attachment 3.) The fuel cell type which seems best suited for transportation is the solid polymer fuel cell, also called the Proton Exchange Membrane fuel cell (PEM). For a description of how solid polymer fuel cells operate, see Attachment 3.

Development of fuel cells is a billion-dollar industry today, and new developments are continually being made. This development can be compared to the development of the microprocessor where use of raw materials and new technology continuously goes far beyond what was believed possible just a few years ago. One example is DaimlerChrysler's prototype series with the fuel cell car, Necar. The new fuel cell system in Necar 4, which was introduced in 1999, has a 40% higher yield per volume than the fuel cell system in Necar 3, which was introduced in 1997. Ne-

**Photograph 5.2a: A hydrogen station**
Iceland could become the first country in the world to use hydrogen as a major source of energy supply. Norsk Hydro, Shell and DaimlerChrysler have just started a joint company in Iceland to work on this. One of the first projects can be the introduction of hydrogen as fuel for buses in Reykjavik. Other projects are also being considered, with further testing in Iceland.
This picture is from the opening of Europe's first hydrogen station in Hamburg, in February 1999. Another will be opened in Munich in May of 1999. From the year 2000, BMW will start the sale of the first hydrogen cars to the private sector. When can we expect Norway to have its first hydrogen station?

**Photograph 5.2b: DaimlerChrysler's Necar 4**
Necar 4 is a Mercedes A-class where the entire fuel-cell system of 55 kW (enough to supply an entire neighborhood with electricity) is built into the floor pan of the car. This floor pan was originally constructed with the batteries in mind. The car has five seats and the same trunk space as an ordinary A-class. The fuel tank with liquid hydrogen is placed under the trunk and gives the car a distance of 450 km between fill-ups. Maximum speed is 145 km/hr. The car weighs 410 kg. more than the gasoline model, but DaimlerChrysler (DC) expects the weight to drop even more, so that the mass-produced fuel cell will weigh only about 150 kg. more than the gasoline model.

car 1, from 1994, was a large van where all available space, except for the driver's seat, was taken up by the fuel cell system.

Fuel cell technology is now the latest modern technology. DaimlerChrysler will introduce the hydrogen buses to the market in 2002, and DaimlerChrysler, GM and Toyota, Ford, and Honda, have indicated that they will introduce mass-produced fuel-cell cars in 2004 or earlier.

The Canadian company Ballard Power Systems has been a leading company in the development of the PEM fuel cells, and has perhaps come furthest with this type of fuel cell. Other researchers include DeNora, Energy Partners, International FuelCells, Toyota, and Panasonic.

### Fuel cells alone or in combination

There are two main ways to use fuel cells in a car: Fuel cells alone, and a hybrid solution.

When only fuel cells are used, a powerful fuel-cell system is needed. In addition, it is advantageous to use ultra condensators to store braking power for later use in acceleration. DaimlerChrysler's and Ford's prototypes use this method, which indicates that they foresee the fuel cell becoming economically feasible.

The other method is to use fuel cells in combination with batteries. In this case the fuel cells act as battery chargers, while the batteries take the heavy loads and let the fuel cells operate more smoothly. Toyota's prototype car operates on this principle. Even though this is the most inexpensive solution today, it is by no means the only solution for the future. This solution also has a definite advantage: Most people drive less than 30 km a day, which is a distance batteries alone can cover. In this way, a car can be used as a regular electric car for everyday use, and only need be topped off with hydrogen when going on longer trips.

As a natural result of competition with fuel-cell cars, more effective combustion engines will also be developed: Regardless of this, fuel cells will outperform combustion engines because people are moving more and more to urban areas where traffic often goes slowly or at a standstill. When a fuel cell car stands still, just as an electric car, it does not use energy, and even at low speeds it is fuel efficient. A car with a combustion engine is most efficient at 80–90 km/h, but is extremely inefficient at low speeds. On the average, a new medium-sized car with a combustion engine has a fuel efficiency of 12%. A typical PEM fuel cell car with hydrogen probably hasmay have a system efficiency of over 40%, even at low speeds.

Fuel cells can also use hydrogen extracted chemically from natural gas, alcohols, naphtha (coal tar), and other hydrocarbons. This is normally done by a reformer between the fuel tank and the fuel cell that produces hydrogen-rich gas from the fuel, which is then used in the fuel cell, as shown in Attachment 3. Several car manufacturers seem to be opting to use methanol or gasoline as fuel for the fuel cells because of a lack of a hydrogen supply infrastructure. In the meantime, neither methanol nor gasoline will produce hydrogen without also producing emissions. The reformer will demand a lot of energy, require a long start-up time, and give poorer energy output than the use of pure hydrogen. In addition, methanol is also extremely poisonous.

At a production rate of 500,000 fuel-cell systems (in comparison with the sale of new cars worldwide, 36.2 million in 1997) [The Economist Intelligence Unit 1998], the price will drop to 20–30 USD per kW, which is competitive with the combustion engine. [Ford 1998]. Energy density in PEM fuel cells, with today's technology, is about 1 kW/kg, and around 1 g. platinum is used as a catalyst.

## 5.3.

## Hydrogen in Norwegian Transportation

The production of electricity in continental Norway is 99% based on hydropower. A change from fossil fuels to hydrogen produced from renewable energy will mean a changeover to a renewable means of transportation. Local production of hydrogen at fuel stations in Norway will most likely occur by electrolysis of water into hydrogen and oxygen as needed.

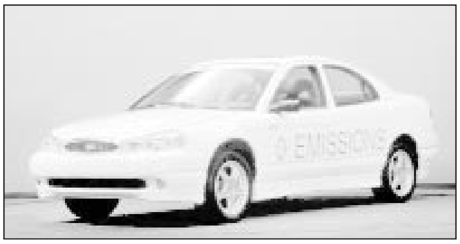
By mass producing electrolytic production systems, tax-free hydrogen from fuel stations, made from electricity at 20 øre/kWh, will be cheaper per driven mile than taxed gasoline. This is stated in research done by Norsk Hydro, and confirmed in another project by Ford. [Ford 1998].

Perhaps the most technically advanced fuel-cell vehicle is the bus, which will soon be on the market, but it may not be able to compete economically because of the bus companies' tax-free diesel. This is a dilemma because diesel buses account for a large amount of pollution in cities. The tax-free exemption for diesel, which was originally put into effect to make public transportation competitive compared to automobiles, can actually hinder the goal of clean technology. Hydrogen buses and hybrid hydrogen-trolley and battery-trolley buses should replace diesel buses. Hydrogen fuel-cell trolley buses are a very good solution in downtown areas, where the buses can utilize the electrical network in central areas where several buses use the same routes, and transfer over to fuel cells on periferal routes. Bergen has had trams on one line since the 1950s and Trondheim is now planning this kind of public transportation system.

**Photograph 5.3: Nebus**
DaimlerChrysler's Nebus will be on the commercial market from year 2002. It stores 24 kg. H2 in pressure tanks on the roof, and has a driving distance of 270–290 km. The fuel cells produce 250 kW and take up no more space than a similar diesel engine does.

Norsk Hydro, which has a sizeable share of the world market for electrolysis plants, has developed a compact plant specially designed for fuel stations. The first one, which was opened in May 1999, will supply hydrogen to buses at the airport in Munich. [Teknisk Ukeblad II/2 1999]. If all use of gasoline as fuel in Norway were replaced with hydrogen extracted by electrolysis, a rough estimation would be that the need for electrical power would be about 20 TWh, given today's driving patterns and technology. [Fremtiden i Våre Hender 1996]. This can be seen in context of Norsk Hydro's "hydrogen power plant" (see section 2.3.1.2), which is expected to generate an annual production of 10–11 Twh.

Hydrogen can be produced from natural gas and a by-product of the process is CO2. This CO2 can be reinjected into old oilfields and/or used to increase reservoir pressures. This could be a gold mine for Norway as an export product. Norway has not only large resources of natural gas, but also the capability of depositing CO2 gas. Pipelines will be able to supply vehicles on the continent with clean fuel. Hydrogen can be produced in self-contained production ships offshore, and the CO2 can be pumped down and deposited deep in the seabed.



**Photograph 5.4.1 Ford P2000**
P2000 with fuel cells is designed to have the same fuel efficiency as today's Ford Taurus. It has an acceleration speed of 0–100 km/h in twelve seconds. The hydrogen car has a fuel-cell stack that can generate 90 hp. The hydrogen in the Ford car shown here is stored compressed in a pressure tank. The P2000 is constructed in lightweight materials such as aluminum, magnesium, and plastic in order to achieve the best fuel efficiency. Ford is developing its fuel-cell cars in collaboration with Ballard Power Systems and DaimlerChrysler. The P2000 will be out on the market in 2004.

**Photograph 5.4.2: Hydrogen driven BMW**
BMW is the first car producer who will mass produce-hydrogen-driven cars with fuel cells. The cars will be available from 2000. These cars will be driven by a combustion enginge. The hydrogen is stored liquid in superinsulated tanks. The cars will also have an gasolin tank to use if there is no hydrogen avalible. A fuel cell will run the cars electrical system.

## 5.4.

## Storage

If hydrogen is to be used on a large scale, storage is an important factor. It must be possible to store enough hydrogen in a car to provide the same driving range as today's cars have, and to provide better safety than a gasoline tank of equal size.

### 5.4.1.

### Compressed hydrogen

Storage of hydrogen under high pressure (up to 800 bar), is a well-established technology. The same technology that has been developed for storage of natural gas can also be used for hydrogen.

- These tanks are of the following three types:
- Steel
- Aluminum core encased with composite
- Plastic core encased with composite
- Steel tanks are the least expensive, but also heavier.

Raufoss Composites is a leading supplier of composite tanks, a light pressure-tank type for mobile applications, originally developed for natural gas. For buses, use of compressed hydrogen is an adequate solution, and it is this method which Ballard/DaimlerChrysler uses in their buses. The tanks are placed on the roof and give a range of 270–290 km. These tanks can be filled in a matter of minutes.

### 5.4.2.

### Liquid Hydrogen

Hydrogen can be stored as liquid hydrogen (LH2) in -2530 C in superinsulated vacuum tanks. Use of LH2 for long-distance transportation and in airplanes is quite attractive, and the use, handling and knowledge of LH2 is very advanced.

BMW has researched the use of liquid hydrogen in combustion engines in cars for over 20 years, and considers the use of liquid hydrogen as a good alternative in automobiles also. BMW has developed a tank in which the inner tank is held up by a magnetic field without contact with the outer tank—a concept which supposedly prevents evaporation of hydrogen for four days. [H&FCL 98]

Vaporized hydrogen can pose a risk if the car is parked in a garage. In order to cool the hydrogen down, energy equivalent to approximately 30–40% of the energy in the fuel is needed. Use of LH2 is especially well-suitedwell suited for use in air and space travel, since this type of fuel has qualities which rate it higher than other alternatives. Liquid hydrogen is the most frequently used type of fuel in space travel.

### 5.4.3.

### Metal hydride

Certain metals and alloys have the ability to absorb hydrogen under moderate pressure and temperature, and create hydrides. Hydride is quite simply a compound which contains hydrogen and one or more other elements.

A metal hydride tank contains granular metal, which absorbs hydrogen and releases heat when hydrogen is pressed into the tank under pressure. Hydrogen is released from the metal when heat is applied. This can be excess heat from the fuel cells.

A metal hydride system is compact, but requires a complicated heating system and is expensive and time-consuming to fill. Metal hydride is considered a very safe fuel system in collisions because the loss of pressure if a tank is punctured will cool down the metal hydride, which will then cease to release hydrogen. Metal hydride is considered much safer than a tank of liquid gasoline.

Research is being done to find cheaper metal alloys that have the ability to absorb large amounts of hydrogen, and at the same time, release the hydrogen at a relatively low temperature. IEA's metal hydride program has set a goal of five weight percent absorbed hydrogen and hydrogen release at 1000 C.

The metal hydride NaAlH4 is a new and promising hydride that is both reasonable inexpensive and meets nearly all the requirements set by the IEA standards.

### 5.4.4.

## Hydrogen in carbons

It has long been known that different carbons have the ability to absorb hydrogen—especially nanostructures like nanofibers, nanotubes and fullerenes, which have shown promising results. Certain qualities of Kværner's Carbon Black also have the potential to store hydrogen. The advantage with Carbon Black is that it can be produced inexpensively in large quantities. A system for storage of hydrogen hasn't been fully developed yet, but sources say this technology will be commercially viable with in three years.

And as with metal hydride, this will also be a very safe form of storage.

### 5.4.5.

## Methanol

Methanol has been rated by many as an acceptable compromise for compact cars. The advantage with methanol is that it is liquid and has a high content of hydrogen. Methanol is made by combining hydrogen with CO. In an automobile, the hydrogen will be extracted from the methanol. The energy loss in these processes is high and the effectiveness of the system is therefore very low. This could be improved by constructing a fuel cell which works directly with methanol at high efficiency. Much research is being done on these fuel cells, but so far only a small percentage of the potential efficiency has been achieved. Methanol—or wood spirit—is an extremely poisonous fluid with many similarities to ethanol.

It has often been stated that methanol can be transported and handled in the same way as gasoline, but this is not so. Methanol is very corrosive, and an uncontrolled leak of methanol could cause extreme damage to the environment. Methanol mixes with water and is almost impossible to reclaim once it is spilled.

A fuel-cell car with a methanol reformer emits CO2—probably somewhere between 30 to and 40 percent of that emitted by a similar gasoline car with a combustion engine. [NOU 1998:II Other reports show lower reduction.] There is also emission of hydrocarbons and CO. Increased distribution of methanol can result in poisonous injuries to humans and animals. Because of reduced system efficiency and relatively high emissions compared to hydrogen and electricity, methanol will most likely not measure up to the future fuel requirements for vehicles.

A safe methanol distribution network would most likely be an expensive solution.

### 5.4.6.

## Gasoline and other hydrocarbons

Turning gasoline and naphtha into hydrogen-rich gas for automobiles has also been the object of much research and development. Oil companies, in particular, are interested in this. They have invested enormous sums in a gasoline infrastructure, and are becoming concerned for the future. These solutions, like that for methanol, offer much poorer effectiveness than those based on hydrogen, and is also technically very complicated. The reformer, which turns gasoline into hydrogen gas, needs about 30 minutes to warm up before it can be used, which is why a car would need battery capacity for a half-hour driving time. A very complicated reformer combined with the need for batteries makes this solution very expensive, difficult, and not viable. It is also difficult to remove hydrocarbons and CO, and removing CO can destroy the membranes in the reformer. Such a reformer would have to operate at such a high temperature that it would also create NOx. Chrysler, which has been the most active automobile manufacturer with regard

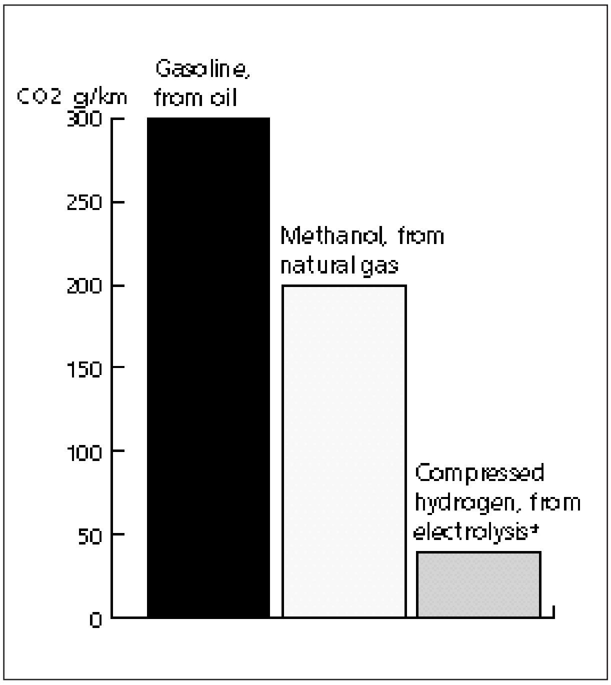


**Figure 5.4.6:**
CO2 emissions at different speeds, for hydrogen, methanol and gasoline: A Swedish comparison CO2 - emissions for USD Federal FTP75 driving speed/pattern with the Volvo 850. Gasoline car with combustion engine, methanol, and hydrogen with fuel cells.

*Average of Swedish electricity production sources. Source: Volvo

**Picture 5.5: Cryoplane**
DaimlerChrysler's hydrogen-driven Cryoplane is based on Airbus 320

to doing research on gasoline reformers, has recently decided to make this a lower priority.

## 5.5.

## Hydrogen in airplanes

Hydrogen can also be used in combustion engines and turbines. In air travel, hydrogen has many advantages over conventional jet fuel. In addition to a cleaner environment, hydrogen as a fuel offers greater performance, increased safety, and lower noise levels.

Liquid hydrogen's high calorific value reduces fuel weight by a factor of 2.8, which means it is possible to use smaller engines with less noise. Even better utilization is achieved by using liquid hydrogen to cool the engines instead of conventional air cooling. It has been determined that the life of jet turbines will be increased by 25%, and the need for maintenance and repairs will be reduced respectively. This is in part due to the purity of the fuel. [Brewer 1991]

The only disadvantage compared with kerosene jet fuel is that hydrogen has a lower density and therefore requires larger fuel tanks.

In 1956, a B57 was flown with LH2, and in June of 1989, a Cheetah was flown using only hydrogen. Airbus is working with Russian Tupolev on building a hydrogen-driven airplane; testing of the plane will begin in the year 2000. Airbus has plans for the commercial sale of hydrogen-driven passenger airplanes from 2005–2007. [Daimler Benz Aerospace/ (Airbus)] Boeing has also indicated that they have designs for building a hydrogen-fueled airplane. [Condit 1997]

Building a hydrogen infrastructure for airplanes is not difficult, and NASA's many years of experience with LH2 for space travel can be drawn upon.

When hydrogen is used instead of kerosene jet fuel, emission of CO, CO2, hydrocarbons, SOx, and particles is avoided. Because of high temperatures in jet turbines, some NOx is emitted (NOx is not generated by the fuel but rather the temperature in the combustion chamber), but otherwise there is just water. But there are several reasons that NOx emissions can be reduced somewhat as compared to conventional airplanes.

Emissions of water from a hydrogen-fueled airplane are 2.6 times greater than from a kerosene-fueled plane. The greenhouse effect on the atmosphere coming from steam at altitudes up to 10 km. is practically nil, but at higher altitudes the steam can produce a greenhouse effect. [Hart 1997] There are varying opinions as to how great this would be, but it must be taken into consideration that, while CO2 remains active in all layers of the atmospheres for over 100 years, water vapor will be in the stratosphere for only 6–12 months, and at lower altitudes, only three to four days. Airbus believes that the water droplets from a hydrogen airplane would be larger, fewer, and more transparent than those from a conventional airplane with jet fuel, and therefore contribute less to the greenhouse effect. Several studies will be made by Airbus to map the greenhouse effect of the water vapor emissions. If this seems to be a problem at high altitudes, restrictions on flying altitude can be put into effect to alleviate the problem. Airbus believes that the first markets for the hydrogen airplanes will be Scandinavia and the west coast of the USA. [Klug 1996] Bellona feels that the Norwegian government should participate actively in the development of the hydrogen airplane by requiring that a certain number of new purchases of airplanes from 2007 should be hydrogen planes.

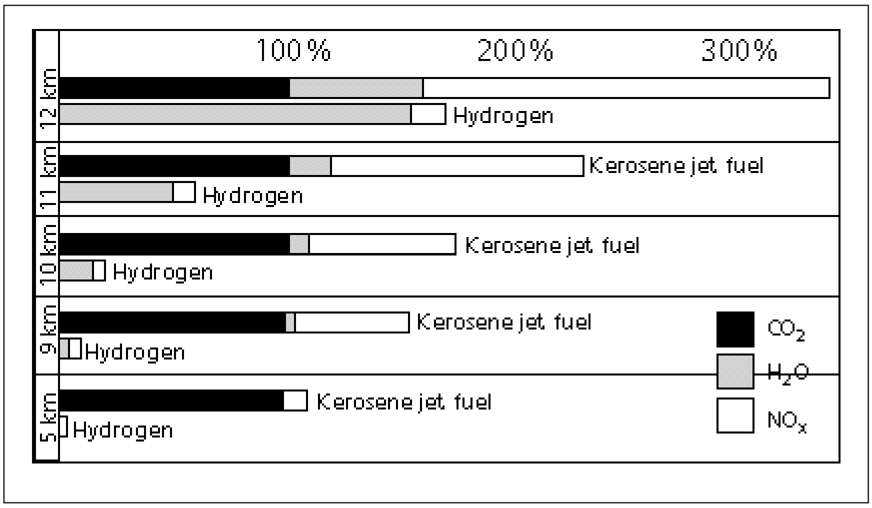


**Figure 5.5**
Relative greenhouse effect at different altitudes using jet fuel (Jet-A) and hydrogen. Source: Daimler Benz Aerospace.

## 5.6.

# Other use of hydrogen in the transport sector

Two passenger ferries—one in Italy and one in Germany—have been converted to fuel cells and will be put into traffic in the summer of 1999. The Italian ferry, with a fuel cell of 40 kW, an electric motor of 120 kW, and a lead battery-based buffer system, has a passenger capacity of 90 and a range of 300 km.

In Iceland, there is a great deal of interest in converting the country's fishing fleet to hydrogen, both to save money and reduce CO2 emissions. Norsk Hydro, Shell and DaimlerChrysler are expected to get involved in this project through the new company Icelandic Hydrogen and Fuel Cell Company Ltd.

There is a definite advantage associated with installing fuel cells as electric power generators in ships, which can supply electricity in port, instead of the extremely polluting diesel generators which are used today. Converting ships to use electrical power while in port should be a general requirement for the shipping industry.

Hydrogen-driven ships will be a very environmentally sound means of transport in the future. Shipping today has practically been allowed a type of amnesty from environmental requirements with respect to emissions. Bellona feels that the time has come to set standards for the shipping industry on the same level as other sectors. This will be discussed in more detail in Chapter 7.

In addition, where rail lines are without electrical supply, fuel-cell–driven trains could be a viable solution.

## 5.7.

# Hydrogen and safety

Hydrogen evaporates very quickly—much quicker than gasoline—and burns almost without radiation heat. All fuel is combustible and can be explosive, which is why it is used as fuel. This means that there is no fuel which is 100% safe: All fuels require careful handling in accordance with their physical properties. The hydrogen industry has over 100 years experience in safe use of hydrogen. NASA, which is the world's largest consumer of hydrogen for transport purposes, such as fuel for space shuttles and the Titan missiles, classifies hydrogen as the safest fuel they use. It is also worth noting that two of the accidents that people most often associate with hydrogen—the Hindenburg and Challenger accidents—were not caused by hydrogen. In the case of a collision causing a ruptured fuel tank, a hydrogen car with metal hydrides would be much safer than a car with a gasoline tank for several reasons. Gasoline, diesel, and the emissions they generate causes allergies and have been found to be a cause of cancer.

## 5.8.

# Battery-driven electric cars

In the course of the next few years, an advanced battery with high storage capacity will be on the market. From 1999, several electric cars will be manufactured with nickel metal-hydride batteries. These batteries are very durable and provide a range of about 150–200 km. With a high-output charger, the battery can be charged to 80% capacity in 20 minutes.

Batteries which seem to have the greatest potential are lithium polymer batteries. These batteries give the electric car a longer range than what is possible with today's batteries, and they take less room and can be molded into practically any shape. This means that the batteries can be put into the car's unused spaces and allow for more room. Lithium polymer batteries are in production for cellular phones and laptop computers, and this technology is expected to be available for use in cars in a few years. This battery type is well-suited for mass production, and can, according to the manufacturers, be made quite inexpensively. It is also much more environmentally friendly than other batteries. See the table below for a comparison between some of the most promising batteries for vehicles.

In 1998, there were about 15,000 battery-driven electric cars in the world. Batteries are still expensive and provide a relatively short range compared to gasoline and diesel cars. On the other hand, they have a lower per kilometer fuel cost. The cost of certain new battery types can eventually be reduced significantly as compared to today's prices.

In California it has become quite common to convert standard cars to electric cars, and there are converter sets available for different car models. It takes approximately 100 to 200 hours for such a conversion on a hobby basis.

The electric car will eventually change how consumers use a car. One example is the Liselec Project in France, where subscribers use an electric car when needed, and then the driver's Smart Card is charged for the car rental when it is returned.

There are seven electric models in Norway, and Pivco's THINK and Kewett's two models are built there. Kewett was previously built in Denmark but production was moved to Norway when Kollega Bil AS bought it. In Norway, this car, with its unique design, is practically synonymous with the electric car. Pivco was bought out by Ford in 1999, and their THINK will be for lease in Scandinavia towards the end of 1999. The PSA group (Peugeot and Citroën) has four models in Norway, and is the only established car manufacturer which actively markets the electric car for reasons other than for meeting ZEV regulations. Prices on electric cars in Norway vary from NOK 120,000 to 230,000 . In all, there were 178 electric cars in Norway as of December 31, 1998—and 1,786,404 cars with combustion engines. [Opplysningsrådet for veitrafikken: The Norwegian Road Federation].

**Photograph 5.8a: Solectria Sunrise**
Solectria's Sunrise is built of composite materials, which makes it light and provides greater collision safety. It has a very aerodynamic design. The standard model, with nickel metal-hydride batteries, has a range of over 200 km.

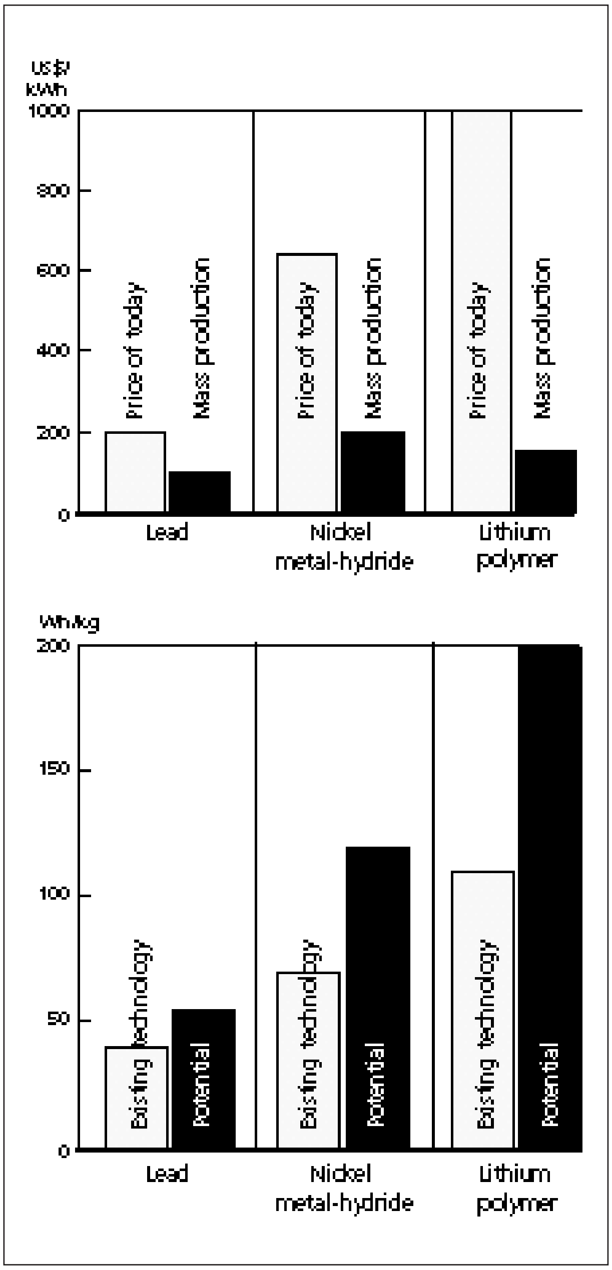


**Figure 5.8b: Different battery types**
Efficiency/price (above) and energy/weight for some battery types.

## 5.9.

# Other electric-powered vehicles

Most urban areas have severe environmental problems, but Asia and Latin America have perhaps the worst. Much of the pollution comes from exhaust from two-stroke engines in light vehicles. Bellona has contributed to the "Butterfly" project, which aimed to develop an electric "Tuk-Tuk" prototype with solar panels on the roof. The developers are architect H. Røstvik and designer P. Opsvik.

The Butterfly was recently tested in Asia, where it had little difficulty keeping up with the two-stroke. Traffic in Asian towns is often at a stand-still, and the electric car is far superior to its predecessors.

Electric motorcycles, scooters, and electric bikes are quite reasonably priced and are sold by several manufacturers abroad. It appears that these ideal, and very energy efficienct, "bikes" will sell in great numbers.

One vehicle which has been treated somewhat unfairly is the electric bus. In Bergen, one bus route has been served by electric buses since the 50s. Gaia Trafikk, who runs the bus line, has 11 electric cable buses; these electric buses have a much longer life span than diesel buses.

Electric buses equipped with batteries can also cover certain distances without the overhead power line, and is the perfect solution. Batteries are then re-charged through the power line. A similar project is in the works in Trondheim.

Bellona would like to see electric buses put into use in Norway to a much greater extent than they are today. In Chapter 7, measures are proposed which can contribute to a large-scale development in the use of zero-emission vehicles.

## Chapter 6 The Energy Industry:

# From supplying raw material to providing technology

In oil and gas production, most of the labor and profit lies in the actual production of the oil and natural gas (including exploration). This is very characteristic of the utilization of non-renewable resources, where property and exploration rights are important. This is where Norway has been very fortunate. Eventually, as the world moves towards renewable energy resources such as bio-, wind-, and solar power, the need to "own" the resource will be less important because these resources are to be found everywhere. Therefore, the "winners" in this market will be those who sell the technology for production of the renewable energy, and not necessarily those who operate the production plants.

Traditionally, countries and companies who have dominated a certain technology in a particular era have not been able to shift their focus quickly enough to be able to dominate newer technologies. Both intellectual and physical capital has been wrapped up in the past they dominated. With this in mind, it is therefore very unlikely that Norway (including Statoil and Norsk Hydro), which is now very strong in oil and gas production, will be able to position itself quickly enough to become one of the major suppliers of renewable energy. As a natural result of this, the Norwegian economy will probably experience the same downturn that the oil industry will experience the world over. Bellona is working intensely to ensure that this does not happen, and feels it is extremely important to stimulate energy efficiency and new renewable energy technology within those areas where Norway can succeed internationally. In the future, the export of such renewable energy technology can mean much more for the global environment and energy situation than just the export of excess energy (which is temporary).

In this chapter we will discuss Norway's greatest potential in cleaner energy technology.

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### 6.1.

## Hydrogen in transportation based on Norwegian electrolysis and gas expertise

Norway is a large producer of energy and energy technology, with a great deal of experience in the production of hydrogen. There are several world-leading producers and suppliers of equipment for storage, transportation, and production of hydrogen.

Norsk Hydro Electrolyzers has 70 years of tradition in the production and construction of effective electrolyzers and hydrogen systems, and holds a leading position in this field. The new electrolyzers that are under development will reach 90% effectiveness, which is far better than the competitors' results. These electrolyzers will therefore become an important export product from Norway when the hydrogen infrastructure for vehicles is built up on a large scale.

Raufoss Composites currently supplies light-weight pressure tanks for storage of pressurized hydrogen in vehicles. Composites will be used to a greater degree in electric and fuel-cell vehicles than they are today.

Kværner's Carbon Black & Hydrogen Process is a newly developed technology which changes natural gas or oil to hydrogen and Carbon Black, without emissions. Carbon Black is used in making tires, among other things, but it can also be used inexpensively and very effectively to store hydrogen. Kværner's process replaces the earlier, very polluting methods for producing Carbon Black. The first plant based on this technology was started in Canada in May/June of 1999.

Transportation of liquid hydrogen is basically comparable to transportation of liquid natural gas. The Norwegian shipping industry should be able to take a leading position, similar to that with LNG.

As chapters 5 and 7 indicate, Bellona is working very actively in promoting the changeover to a hydrogen-using society.

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### 6.2.

## From Norwegian silicon to international solar power.

Norway is among the world's leading producers of metallurgic silicon, and the purest form of it (99.8%) is made here today. The price is somewhat under 2 USD/kg. After further purification in Germany, Japan, or the United States, the purity factor reaches up to 99.999999–99.9999999 %, and at a price up to 50–70 USD/kg. This highly pure form is used in electronics and computers, and the surplus from that goes into solar cells. The growth in the solar-cell industry has increased so tremendously (40% growth in 1997), that there is a lack of this excess, and the prices are now up to over 20 USD/kg.

Production of solar cells does not require as pure a form of silicon as the computer industry does; purity in the area of 99.999 % is sufficient. Since Norway is the foremost in the world, producing a 99.999% pure product, the Norwegian silicon manufacturers have a unique chance to break into the world's fastest growing energy market. The Norwegian producer of silicon wafers for the solar-cell industry, Scanwafer, and Elkem have established Silicon Solar AS in order to develop a new production process for extraction of solar quality silicon.

Bellona is working on research funding for this key process in the world's solar energy market, and one result was that ABB has started an internal pre-engineering project on solar energy in 1999. We have also worked actively through the business community's scholarship fund for NTNU (Norwegian Technological University). The first breakthrough came on June 2, 1999, with a donation of approximately NOK 500,000 per year from them for the project "From sand to solar cells." This was enough to start the project, and will hopefully generate a matching amount from the Norwegian Research Council, or EU's Fifth Framework Program.

The founders of Scanwafer in Glomfjord have also begun work on establishing a solar-cell production facility in Narvik, and if all goes according to plan, the first solar cells will be made in Norway in the first half of year 2000.

## 6.3.

## Energy from waste

Since the beginning of the 90s, SINTEF in Trondheim has worked to develop a clean incineration technology for medium-sized incinerators. In the period 1996–1997, the first pilot plant was built in Trondheim, and the measurements taken from the plant in 1998 showed that the emissions so far are the lowest in Europe. The emissions are also lower than the new EU requirements for waste incineration plants, see figures 6.1 and 6.2.

Norway has 1.5 million metric tons of waste refuse (after recycling) which can be recycled as energy. This would save burning 400,000 metric tons of crude oil. The energy efficiency of this alone can reduce CO2 emissions by 1.4 million metric tons. And in addition, an even greater advantage is that waste is not left to rot, releasing methane gas. The plant's moderate size makes it possible to reduce the need for transportation in the waste industry by building several local facilities instead of one large plant. Such decentralized incineration will increase profitability and the potential for recyclable energy. The energy and environmental potentials for Norway are described further in Chapter 3.2.1. In this connection, it is the potential for export which is most important.

This technology is now being made commercially viable by Energos ASA, which is based in Trondheim and Stavanger. They are planning to build over 20 energy recycling plants in cooperation with local partners in Europe. For example, in Germany, they have entered into a contract for building and a shared operation of seven local energy-recycling plants worth NOK 750 million. In other words, in a rather short period, Norwegian technology has been introduced commercially, and in the future will help to solve environmental and energy problems throughout Europe.

Bellona places great emphasis on finding and working for the best solutions in the waste sector so that the most productive environmental solutions will be chosen. Bellona and Energos are cooperating on a long-term basis through the B7 Program.

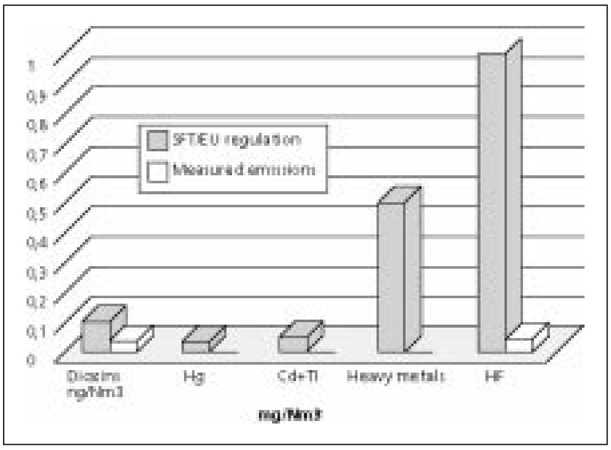

**Figure 6.3a**
The levels of emissions from SINTEF/Energos's new waste energy plant are clearly under the maximum allowed (Chart: Energos, December 1998).

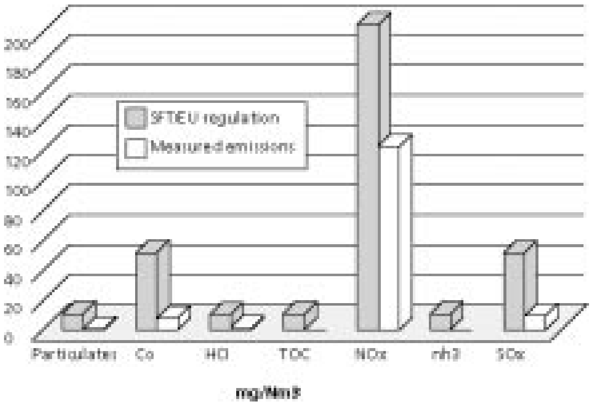

**Figure 6.3b**
The levels of emissions from SINTE/Energos's new waste energy plant are clearly under the maximum allowed (Chart: Energos, December 1998).

## 6.4.

## Concrete with 50% CO2 emission

At Luleå University in Sweden, a Russian guest researcher has been the spearhead for the development of an entirely new grinding process for cement and sand. This new process makes cracks in the finely ground grains so that a greater portion of the grain adds to the strength of the concrete. By grinding cement and sand in this new process, the quantity of cement in concrete can be reduced to half the amount.

About 6% of the world's CO2 emissions are connected to the production and use of concrete. Extremely large amounts of energy are required for the blast furnaces which make the cement, and this energy comes most often from burning coal. Energy efficiency and a reduction in CO2 in the cement industry has therefore been, up to now, concentrated on smaller improvements in furnace technology as well as replacing coal with waste oil and other refuse where possible and/or profitable. Concrete releases great amounts of $CO_2$, also during the drying process. This degassing is a result of the key reaction in the hardening curing of concrete, so it has often been assumed that there is no possibility for improvements in this area. The new cement-grinding technology developed in Sweden reduces emissions radically, both on the production side and during curing, by reducing the amount of cement by 50%, without compromising the strength of the concrete. Since this solution is also profitable, there is a good possibility of decreasing the world's $CO_2$ emission by approx. 3% just by use of this new technology.

The Norwegian Atle Lygren, is working with the Russian researcher to patent, develop quality control, and commercialize this new technology through the company EMC 50. They have already proven that concrete produced with EMC 50 cement has sufficient strength to be approved on the Norwegian market, and thus the European market as well. They will hopefully, in the course of this summer, get approval for the quality of the production process.

If, and when, EMC 50 technology is finally approved, Bellona will be very active in stimulating the demand for this cement, contribute to the industrialization and financing of the company, and influence the BAT requirements in the EU to also include the amount of cement used in the concrete.

## 6.5.

## Light materials for cleaner transportation

The aluminum industry in Norway is big internationally and supplies light metals for use in the transportation sector, among others. Light materials reduce vehicle energy consumption during use. The actual production of aluminum requires a great deal of valuable energy in the form of electricity, and is effective use of Norwegian hydropower. Aluminum is also a material which is not degradable by recycling, and even there, recycling uses only 5% of the energy required for production of new metal. Export of aluminum, such as in the form of auto parts, is therefore an important contribution by Norway in the quest for more environmentally safe transportation worldwide. Bellona will therefore work toward the availability of electricity for the aluminum industry, but wishes the same incentives for energy-effective operation in this industry as in the rest of society. Bellona has therefore proposed a tax on the energy losses in the power industry, but no taxes on the energy which is exported in its natural state. Light metal must be seen as a pure form of export of Norwegian energy, a type of "frozen power".

The aluminumaluminum industry is actually a very good example of a niche where unique Norwegian pollution requirements have lead to the development of world-leading Norwegian purification technology. This purification technology was developed by ABB in cooperation with Norsk Hydro, and dominates the world market today. It has contributed both to creating jobs in Norway, and also to greater environmental improvements worldwide.

## Chapter 7

# A total energy policy

In the chapter on energy and environmental challenges, we pointed out three main areas of concern when considering the special qualities of the different fossil fuels:

Physical properties, energy content, and environmental impact.

Traditionally, the energy sector has been based on fossil energy sources, with supplementation from some nuclear power and hydropower. Production has therefore been very centralized and the major companies have become production specialists. Their products have been counted in barrels of oil, liters of gasoline or diesel, cubic meters of gas, and kilowatt hours of electricity, etc., and commercial divisions have mainly been divided into stationary production and use, and transportation.

We have pointed out that the primary reason for producing energy is to satisfy the need for three types of energy services: *Mechanical operations, heating, and cooling.*

As consumers of power, our needs will not always necessarily comprise a liter of gasoline or a kilowatt of hydropower. In the future, the power companies will not be able to concentrate only on traditional methods of optimal production of one source, but must evaluate how they can supply the whole scope of basic energy services which are needed.

Since there is no basic characteristic that makes energy a pollutant, the only logical energy and environmental goal must be that all production and use of energy must take place without generating emissions or encroaching harmfully on the environment. An environmentally effective energy policy must focus on the following principle: Use the highest quality, cleanest energy as efficiently as possible.

## 7.1

## Developments in the energy market

In this report we have shown that there are several non-traditional methods, sources, and forms which can meet our needs for energy, and at a fraction of the cost to the environment. New renewable sources of energy will mean a decentralization of energy production, effective local solutions, and more “small is beautiful” operators will appear in the market. In order to remove CO2 and benefit from economy of scale advantages, the sources of fossil fuel emissions will need to be concentrated in central discharge stations. Even though this may seem to be a paradox, there will be both centralization and decentralization of energy products at the same time.

Several oil companies are redefining themselves as energy companies, entering into alliances and integrating themselves downline in the value chain. Likewise, the industrial companies are engaging themselves more and more in the production of energy.

In 1991, Norway became one of the first countries to deregulate the power market. Sweden, Finland, and several EU countries have since followed suit. In the next decade, a large portion of the market in Western Europe will be deregulated, which will lead to several smaller operators merging into larger entities. Good consumer relations will be important, and companies with these relations will be able to break into the market as suppliers of energy—which will in turn mean that energy can be offered as a multi-product package that only a larger supplier can offer.

Looking at the big picture, society has so far evolved from an agricultural society to an industrial society, and we are now on the threshold of a new millenium, which many call the “knowledge society.” It is very clear that this will open up the possibilities for a more intelligent control of energy use, where waste is minimized without compromising comfort.

Here again we will see two presumably opposite effects

**Table 7.1a**
**Energy policies and examples**

| Energy and environmental goals | Examples |
|---|---|
| Clean energy | New energy forms |
| Good quality | Reduced electricity for normal heat |
| Efficiency | Fuel cells |
| Other political goals | |
| Reasonably priced | Deregulation,<br>bigger companies |
| Other areas of involvement | Industrial power ? |

**Table 7.1b**
**Developments in the energy market**

| Energy market | Traditional | Future |
|---|---|---|
| Sources | Fossile energy (atom/hydro) | Many sources |
| Production | Centralized | Centralized and decentralized |
| Branches/ companies | Production specialist | Supply specialist |
| Product | Barrels of oil,<br>liter/gallon of gasoline/diesel,<br>cubic meter of gas,<br>kilowatt of electricity, osv. | Combination of energy carriers,<br>energy solutions (light and heat) |
| Commercial side | Separation between stationary production and use vs. transport | A market that encompasses both areas |

happening at the same time: both a diversification and a specialization of operators on the energy market.

Norway's energy policy has always been closely connected to other political goals, such as promotion of industry. Development in recent years, including deregulation, would seem to indicate that the time is past when energy production "subsidizes" industrial production. However, as shown in chapter 6, a considerable amount of the energy-intensive industrial production can be justified purely in terms of energy use, with respect to general energy consumption. Even though the basic cost is the same, it is not unlikely that taxation of the various energy products will be determined in a way that takes this into consideration.

The energy producing companies will be forced to consider both a more environmentally aware market in the struggle for customers, and an increasing environmental awareness in the workforce, which will affect the companies' ability to retain the best personnel in the field. This is important because human resources will be of greater importance as a competition factor, as employees will no longer be tied to the operation of heavy machinery in the workplace.

The common factor is that we, in many ways, will go from a production-based to a customer-based energy sector.

## 7.2

# Norway, the land of energy

Production of hydrogen and electricity, with the extraction of CO2, makes it possible to supply satisfy our energy needs with fossil energy sources practically pollution free. Hydrogen can be used not only for production of power, but also as fuel in transportation, as a raw material in industry, and in other areas. Certain industries which are currently heavy polluters will be able to avoid these problems because the pollutants from their emissions will be removed at the point of production. In the case of CO2, this means that instead of there being millions of individual plants creating emissions, the problem will much more controllable.

Hydrogen will be considered by many to be the energy supply of the future and "the ultimate fuel," and this will have great influence on the structure of many branches. In the near future, the fuel cell's breakthrough in the transportation branch will effectively cause the hydrogen market to explode.

When we know that many hundreds of thousands of people in Norway alone suffer from noise and air pollution from traffic, it is obvious that quiet and pollution-free fuel-cell vehicles will be in great demand. It should also not be forgotten that carbon is often a carrier of other polluting elements. Fuel cells will also play an important role in future power generation within a relatively short time span

The oil and natural gas industry will be forced to reduce its environmentally destructive effects dramatically if it wants to compete with renewable energy sources and technology. As long as oil and gas have such a negative impact on the environment, compared to renewable energy, fossil energy will become even less attractive. We are currently experiencing the same reduction in cost for renewable energy as when oil attained its leading position as a source of energy in the 1950s.

One interesting aspect is that Ford has carried out studies which prove that supply of decentralized hydrogen for fuel-cell cars is economically competitive with gasoline. Generally speaking, it has been proven that, where there is a need, the likelihood of a breakthrough in new technology is very strong, even if a relatively complex infrastructure is required.

This is a factor that the oil and gas industry must take into account. This branch requires heavy capital investment on a long-term basis, and it would be very unwise to invest in energy and environmental relics. In addition, the severe problems must be resolved on a long-term basis, such as that proposed in this report. The companies who wish to operate on the continental shelf will be challenged to find profitable technological solutions for pollution problems and it is not likely that all will succeed.

The more an energy company's diversification contributes to environmentally efficient energy use, the greater the chance of success and security for the investments in that energy source. If the power companies' real reason for existence is taken into consideration, and knowing how pollution is very critically viewed, then the natural conclusion is this: If your type of "business" pollutes, you are "out of business."

This report has looked at the possibilities of finding cleaner energy sources; optimizing electricity use, that is, using it for lighting and electrical equipment, while using other energy sources for heating; and using available energy as efficiently as possible.

We have shown how Norway, simply and inexpensively, can save 20 TWh of electrical power, cut the emissions of carbon dioxide by more than half, and at the same time produce 50 TWh of renewable energy. In this way, during a normal year, we will be able to export an additional 10–15 TWh pure electrical power, either in the form of refined metals (bauxite refined into aluminum) or as a direct export of electricity. We can also export large quantities of "clean" fossil energy in the form of electricity or hydrogen.

The environmental factors apply whether or not there is a balance of "power" at all times. Even though Norway can produce considerable amounts of energy with and without CO2 extraction, the emissions will not be reduced if we don't use the power in a sensible way. It will be equally senseless to increase the use of valuable energy for winter heating when this could be exported. Norway has been a large producer of energy for a long time, and every kilowatt that is wasted is potential income from its export. We are not an isolated island in a Europe which is overflowing with clean energy; on the contrary, it is quite the opposite! The energy we waste results in continued pollution from our neighbors, and it would be a total waste to not utilize some of the best conditions for wind power in Europe. We also need to utilize bioenergy, heat pumps, district heating, and solar power, and in this way put an end to the burning of oil.

Effective environmental protection is dependent upon the most cost-efficient solutions. It is therefore important to find the methods which will lead to meeting environmental goals in a socially acceptable and economically feasible way. The solutions that are cost-effective for reducing emissions by 10% could turn out to be quite costly if we later discover that the emissions must be reduced by an additional 30%. In such a situation, many of the improvements that were made to achieve relatively little gains will have probably been in vain because a greater reduction in emissions requires the development of a totally different technology or structure. A cost-efficient method for a reduction of greenhouse emissions is therefore not cost-efficient on a long-term basis—unless it opens the way for additional reduction of emissions at the same time.

In previous chapters, we pointed out possible methods for achieving solutions and what possibilities exist. There is presently a great need for an overall strategy in developing energy policy, and we are therefore presenting a combination of methods. In order to make the presentation more clear, the methods are grouped according to three main categories:

- Improved efficiency in existing energy use
- Development of new renewable energy
- Direct reduction of emissions from energy production and use

One method will often have several consequences, and will thus be discussed more thoroughly in the main category where it has the greatest effect, and only be mentioned in the other cases where it is a lesser contributing factor.

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## 7.3
## Effective use of existing energy consumption

### 7.3.1
### Less expensive food and clothing, higher price for electricity

Denmark and Sweden have consumer taxes of approximately 53.5 and 12.8 øre/kWh, respectively, for normal electricity usage outside of industry (1997). In Norway, on the other hand, it has been difficult to get consumers to accept a tax increase on electricity above the current rate of 5.6 øre/kWh. In the business sector it is the Federation of Norwegian Commercial and Service Enterprises which is most sceptical to an increase, and the political parties are also extremely concerned. An increase in taxes is a common worry for both parties, whether because of the measures to be taken, or concern over voters' viewpoints. Bellona has therefore explored ways to redirect the taxes back into the business sector, as well as to benefit the voting consumers, as easily and fair as possible. Bellona proposes the following:

#### Measures

Reduce value-added tax by one percent, and at the same time establish an electricity tax of 5 øre per kWh on all consumption, except that which goes towards production of materials in the power industry.

This means that all other goods will be cheaper, while electricity will be more expensive. Combined, we pay the same amount of taxes as before. The exception for materials produced in the power industry is mainly based on the fact that these are, to a great degree, export items, which is just another means of exporting power. This is also energy which can be used by many generations to come because it is stored in materials which are suitable for recycling. Bellona nevertheless proposes the following:

#### Measures

- Energy which is lost in power-demanding industry must be taxed at the same rate as general consumption.
- This will result in giving power-demanding industries an incentive to use energy more efficiently, which reflects the incentives given to the rest of society. The extra burden these costs put on this sector will be compensated by the fact that power-consuming industries will save through the reduction of value-added tax.

### 7.3.2
### Technological efficiency to avoid energy waste

Technological development opens up the possibility for large cuts in the use of electricity without any reduction in the living comforts many Norwegians are accustomed to. For heating purposes, technology for exploitation of geothermal energy has provided heating at prices down to less than 11 øre/kWh for larger new projects. In addition, the methods for burning waste have become so clean that district heating based on waste incineration appears to be more and more attractive. Blast furnace technology for incineration of biological fuel is also continually being improved, and there is still a great deal of TWh waste heat from industry available in urban areas. It is therefore not necessary to use electrical wall heaters, which create heat by simply using obstructing electric powercurrent, as primary heating in Norwegian homes. As shown in Chapter 5, Bellona encourages Norway to follow Denmark's and Sweden's examples of banning electrical wall heaters in new buildings, with the exception of single-family residences. The developers will then will be able to choose between heat pumps, district heating, geothermal heat, solar power, bioenergy fueled boilers, and in an introductory phase, electrically heated boilers for heating new buildings, without having to write special ordinances for every alternative.

There has been a tremendous development of technology in both incandescent and fluorescent lighting. While the worst light bulbs have an energy efficiency of 3%, now there are lamps/bulbs which are up to 10 times more efficient, and which havewith an energy efficiency of 30%. In the same way that there are certain requirements for buildings, electrical wiring, water supplies and drainage, it is now time to set certain minimum requirements for lighting. The light quality (color balance) of the most effective technology is presently not quite the same as for conventional incandescent bulbs, so it could be best to set the requirements somewhere between the best and the least efficient available technology.

Just the stand-by function on Norwegian TVs consumes more than 0.3 TWh today. If we include PCs, stereos and other electrical equipment, consumption is closer to 0.7 TWh. With the growth that we are seeing in this market today, it is important to stop this unnecessary use, which is due merely to indifference on the part of the manufacturers.

#### Measures

- Restrictions on electrical wall heaters as a primary source of heat in new buildings, with the exception of single-residence and "unattached" homes, as well as commercial buildings under 200 kvm2
- A requirement that the minimum energy efficiency for

- lighting sold or installed in Norway after January 1, 2001, be approx. 12%, or 40 lumens/Watt. At the same time, similar requirements for installation and/or renovation in industrial buildings should be 70 lumens/watt
- A requirement that the stand-by function on electronic equipment use no more than 10% of the energy needed under normal use

### 7.3.3

### Free environmental process heat must be treated the same as renewable energy

It is Bellona's opinion that the surplus heat from industrial processes has environmental qualities which are at least as good as renewable energy resources. First, this energy has already been produced and concentrated without additional physical impact on the local environment; second, using it will not create any environmentally dangerous emissions. It is, in fact, environmentally "free." Using this source of energy should therefore be given the same advantages as renewable energy in Norway.

#### Measures

- Exemption from investment tax where this tax is not already removed
- Exemption from value-added tax for consumers the first five years

The accumulated effect of these two measures will indirectly contribute approx. 10 øre/ kWh the first five years, and thereafter an indirect contribution of about 1.5 øre/kWh, using a base price of less than 40 øre/kWh and excluding value-added tax. In terms of competition, process heat will enjoy the positive effects of an eventual change in direction of the government's income from value-added tax to tax on electricity.

In comparison, Norway currently imports coal-based power from Denmark. When sold for normal consumption in Denmark, there is a tax of 53 øre/kWh . As long as Norway does not tax electricity in the same manner, an indirect contribution of 10 øre/kWh towards renewable energy and development of the use of industrial process heat will only be moderate, but nevertheless, important. A tax of 150 NOK/metric ton on $CO_2$ created from import of coal power from Denmark would mean an increase of 15 øre /kWh.

### 7.3.4

### Power grid companies must opt for a district heating network when this is least expensive.

Paragraph 3 of the Norwegian Energy Act requires the power companies to supply electricity or district heating to its customers. The regulations are presently interpreted (by NVE ) in such a way that the power companies do not actually have the real option of offering district heating instead of electricity, even when it is the cheaper alternative.

The main problem is that building a new district heating network requires the participation of all the new units in order to lower the price. Only the local authorities can require owners to hook-up through zoning regulations. They would then effectively be giving concession to one district heating company. Redesigning building plans is a very time-consuming and resource-demanding process, and in reality, the building contractor has often come too far in the design of the buildings before local planning committees and commercial interests can get involved so that hook-up is required.

#### Measures

- Bellona recommends that the Ministry of Petroleum and Energy (OED) and the Norwegian Water Resources and Energy Directorate (NVE) change the interpretation of Paragraph 3 of the EnergyAct, so that it is the power company which decides if hook-up should be required for the district heat network in an area, based on what is economically feasible.
- Bellona recommends that the greater portion of fees for power grid subscription be transferred to net use per kWh. This will result in a beneficial social effect and increase the incentives for using electricity more effectively without electrical bills increasing on the whole. For those who use the least amount of electricity, the costs will be considerably less.

## 7.4

## Development of new renewable energy

Today's framework for development of new renewable energy in Norway (sun, wind, geothermal, micro hydropower and biomass) is not sufficient. Long-term goals are also weakened by the economic "horse trading" in the budget process every year. Initially, Bellona wants additional funds to be appropriated, i.e., funds other than direct donations and investment support, in addition to those allocated in the annual national budget.

### 7.4.1

### Required sale of at least 5% renewable energy

**Table 7.4.1: Increase in required percentage of renewable energy**

| Year | Required percentage of new renewable energy sold in Norway | Amount of TWH created |
|---|---|---|
| 2002 | 2 % | 2 |
| 2003 | 3 % | 3 |
| 2004 | 4 % | 4 |
| 2005 | 5 % | 5 |

In several American states, a requirement is going into effect that all power grid companies which sell electric power for normal usage must ensure that a certain percentage of the power they sell is produced from renewable energy sources, such as wind, sun or biomass. This is one simple and fast way to increase the demand for renewable energy, and the companies in the market will try to produce the required amount as inexpensively as possible.

Measure

- Bellona proposes a system where all companies which sell power for normal use in Norway are required to provide a certain percentage from renewable energy sources.

Table 7.4.1 shows a suggested gradual increase of the system. Such a system will also stimulate cooperation between net companies and local producers of new renewable energy.

### 7.4.2

### Tax-exemption the first five years

Since Norway has not managed to incorporate the external environmental costs of importing Danish coal power into the price of electricity, as Sweden and Denmark have, the Norwegian renewable energy sources do not enjoy the same advantages. Imported Danish coal power would, as mentioned previously, cost 15 øre more per kWh if the power plants were required to pay 150 NOK per metric ton in CO2 tax. This price increase would be enough to make renewable energy such as wind power and biomass very attractive in Norway. In order to reduce the imbalance in the energy market, Bellona proposes the following:

Measures

- All research and development of renewable energy should be exempt from existing investment tax.
- All development of new renewable energy should be exempt from value-added tax (VAT) for sales to private consumers for the first five years.

The combined effect of these two measures would be an indirect savings of 10 øre/kWh the first five years, and thereafter an indirect savings of 1.5 øre/kWh, based on a sales price of 40 øre/kWh, excluding VAT. It should be pointed out that this is not savings which will lead to private operators engaging in non-profitable activities; on the contrary, this will be economically beneficial for society as well as private operators.

## 7.5

## Direct emissions reduction from energy production and use

In the parliamentary report on Norway's follow-up of the Kyoto Protocol, it was stated that

Political strategies must take into consideration long-term suitability where we must be prepared for increasingly stricter standards.

Investments must be long-term but not bind us to unnecessary high pollution in the long run.

This would offer Norwegian industry competitive advantages in keeping up with the inevitable changes.

In this perspective, the main challenge in Norway is related to CO2 emissions from the petroleum industry, the transportation sector, and oil combustion for heating. In addition, landfills are the greatest source of methane gases, which can also be reduced by a simple matter of sorting, collecting, and energy recycling. There are actually a relatively small number of companies who are responsible for a large portion of these emissions.

### 7.5.1

### The petroleum industry and oil heating

In order to reduce CO2 emissions from the oil industry, we have mentioned the following measures:

- Electrification: use of land-based power and cogeneration
- Power production with CO2 extraction and increased energy efficiency
- Moving power use onto the mainland
- Reduced production of water and seawater injection
- Increasing the size of the gas lines
- Combined, these measures will reduce emissions from the oil industry by about 95%. ABB says it is possible to reach 80% total energy efficiency with only half the amount of CO2 through:
- Connected platforms
- Optimizing production
- Combined-cycle power plants
- Underwater processing
- Cogeneration in power production

When we know that we can also extract CO2 and use some power from land, a 50% reduction of emissions by 2010 should be a minimum, and 90% reduction for 2020.

Oil heating can, as previously mentioned, be replaced by other energy sources.

Bellona therefore proposes the following steps for reducing CO2 emissions from the oil industry and from oil heating:

Measures

- A carbon fund to replace today's carbon tax system.
- A system for "Environmental Performance Evaluation" to be established and used as a basis for all central decisions concerning oil field activities (i.e., gas allocation, combination of portfolios, etc.)
- The principle of Best Available Technology (BAT) applicable applied for operation and permits.
- Emission permits issued according to pollution laws must be applied to before other permits.
- A technology strategy requiring removal of CO2 from all fossil fuel-based power, heating, and fuel production.
- Closing the Barents Sea and Skagerrak for the production of oil.
- Ban on oil heating from 2003.

### 7.5.2

### Transportation and energy technology, and energy carriers

Hydrogen cars will be on the market in a few years. Electric cars with a range of over 200 km and which can be quick-charged to 80% in 20 minutes are already on the market in some countries. The lack of a hydrogen infrastructure and battery charging stations are used as arguments against these new technologies. New technology is also blocked from entering the market because of its high costs until a mass market develops which makes the production less expensive.

Hydrogen and electric buses, ideally with combined fuel types, as well as trams, represent an emission-free alternative to today's diesel buses. Hydrogen buses will be sold commercially by 2002, while trams already use well-proven technology. Continuing the policy of tax-free diesel can hinder the introduction of environmentally friendly technology.

Requirements for health and quality of life have high priority in northern Europe, Japan, and on the west coast of the USA. Germany, USA, and Japan have initiated extensive programs which support the development of this type of technology.

Approximately 200–300 people die each year of cancer due to emissions from diesel-fueled vehicles in Norway. As many as 750,000 Norwegians suffer from air and noise pollution caused by traffic. Moving towards a pollution-free transportation system will be a big step towards improving the quality of life for many.

Norway has profited considerably from the source of the climate problems we are experiencing today. The future cannot be based on today's energy carriers, and it would be in our own interest to lead the development and implementation of zero-emission technology, goods, and services, which will be sought after in the future.

Bellona proposes the following standards for the transportation sector:

### Measures

- Norway should follow California's Clean Air Act, which means that all car manufacturers must have zero-emission cars on the market by 2003, and at least 10% of all cars sold from then on must be zero-emission vehicles. Norway must take the initiative for implementing these standards in the EU.
- All new busses for use in cities must have zero emmission from2005. By 2010, all new busses must have zero emmission.
- All diesel from 2003 should have a 5% blend of biodiesel. The tax-free exemption for sale of pure biodiesel must also apply for mixed biodiesel.
- Twenty percent of all new ocean vessels (fishing boats, ferries and ships) sold in Norway must be emission-free from 2005. Likewise, all existing vessels must be re-built to reduce their emissions of CO2, SO2, and NOx by at least 40% by 2010. At least 10% of all international vessels with ports of call in Norway must be zero-emission ships from 2007. Starting in 2010, the standards would increase to 20% and also require that all ships with port calls in Norway have emissions of NOx , CO2 and SO2, that are 40% lower than today's average for that particular ship specification, calculated as emissions in metric ton/km. Norway must take the initiative to encourage the EU to implement the same standards. These standards would help create a demand for freight on these types of ships, and environmental restrictions would be placed on one of the most polluting industries in the world.
- At least 50% of all new ships from year 2005 must be zero-emission, and 50% of all existing ships must be rebuilt in order to reduce their emissions of CO2 and NOx by at least 40%.
- At least 50% of all new trucks must be zero-emission from 2007, and all new trucks by 2010. Norway should take the initiative to implement these regulations in the EU.
- Twenty percent of all new aircraft from year 2007 must have the technology to reduce NOx by 70% and CO2 by 100%; this should be increased to 50% of all new aircraft from 2010.

### Other options:

- Exemptions from investment taxes, import taxes, road taxes, and highway tolls for hydrogen vehicles should be comparable to those for electric cars. All resources and funds which are dedicated to nuclear power research today should be redirected to research and development within hydrogen and solar power research. These technologies will create many more jobs in Norway than nuclear power.▸
- Norway should initiate a long-term hydrogen program to continue through 2020, at NOK 200 million annually.

## 7.5.3

## Energy recycling of solid waste

Landfills are responsible for 67% of methane emissions, which make up 11–12% of the total emissions of greenhouse gases. Waste reduction, and in many cases recycling, is a practical way to reduce emissions. For solid waste, energy recycling is a reasonable way to reduce emissions of climatic gasses. Bellona proposes the following standards (exemptions can possibly be given under certain circumstances):

### Measures

- Existing landfills with emission of methane over 10,000 metric tons CO2 equivalent should be required to collect and recycle deposit gas.
- From year 2005, all counties with a population over 10,000 should be required to recycle the energy from waste.

## 7.5.4

## Other significant stationary point sources of CO2

Generally, it is quite costly to remove CO2 from small facilities, whether they are stationary or mobile. Bellona's approach to these small facilities is mainly to prevent them from being built. There are currently 28 companies in Norway that together release 9.1 million metric tons of CO2, or 17% of Norway's total emissions. As these plants are very large, they will be the cheapest facilities for future CO2 removal and depositing. Many of them also have great potential for development of technology which can prevent the creation of emissions instead of having to remove them later. The large investments tied up in these companies necessitate optimal stability and long-term regulations for operational requirements. Bellona therefore proposes:

### Measure

- Mandatory CO2 extraction and depositing for all point sources of over 100,000 metric tons CO2 equivalents starting from the year 2010.

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## Attachment 1

# Gasturbines on norwegian shelf

In 1996 the use of natural gas based energy on the Norwegian shelf represented 10 TWh alone. It is expected to reach ca 14 TWh during 2002- 2003. Due to the low efficiency of the turbines the emission of CO2 may be compared to the average emission from the European powerplants based on coal.

Per may 1998. The stated efficiency is nominal. In average the load of the turbines is only 70 percent, thus the real efficiency is somewhere below.

Gener. = generator, Compr. = compressor, Emerg. = emergency power, Waterinj.= water injection

| Operator | Turbine/engine | Field | Function | Total | Running | Efficiency | Installed | Output/unit. (MW) |
|---|---|---|---|---|---|---|---|---|
| Amoco | Allison 501KB | Valhall | Gener. | 5 | 3 | 22.00 | 1982 | 2.80 |
| Amoco | Coop/Rolls Avon | Valhall | Compr. | 4 | 2 | 22.00 | 1982 | 15.00 |
| Amoco | MTU | Hod | Gener. | 4 | | | | 0.20 |
| BP | EGT Tornado | Gyda | Gener.. | 4 | 4 | 30.70 | 1989 | 6.07 |
| BP | MTU | Gyda | Gener. | 2 | | | 1989 | 1.00 |
| BP | ABB Stal GT35 | Ula | Gener. | 3 | 3 | 29.40 | 1985 | 13.40 |
| BP | Mercedes | Ula | Gener. | 2 | | | 1985 | 0.36 |
| Elf | ABB Stal GT35 | Frigg | Gener. | 2 | 2 | 29.00 | 1981 | 16.00 |
| Elf | UTI GG4C-3F/FT | Frigg TCP2 | Compr. | 3 | 0 | 25.00 | 1981 | 27.00 |
| Elf | KG5 | Heimdal | Gener. | 5 | 5 | 20.00 | 1985 | 3.00 |
| Elf | LM-2500 | Heimdal | Compr. | 2 | 2 | 36.00 | 1985 | 12.00 |
| Esso | Wärtsilla (V16) | Balder | Emerg. | 1 | | | 1997 | 1.50 |
| Esso | Wärtsilla (V16) | Balder | Gener. | 4 | | | 1997 | 5.70 |
| Esso | Gasturbin | Jotun | | 2 | | | | 50.00 |
| Hydro | LM-2500 PE | Brage | Compr. | 1 | 1 | 30.80 | 1993 | 14.50 |
| Hydro | LM-2500 PE | Brage | Gener. | 2 | 1 | 35.50 | 1993 | 21.20 |
| Hydro | LM-2500 GE | Njord | Gener. | 2 | | 37.00 | 1998 | 22.00 |
| Hydro | LM-2500 GE | Njord | Compr. | 1 | | 37.00 | 1998 | 23.00 |
| Hydro | Coop/Rolls RB 211 | Oseberg A | Gener. | 3 | 3 | 33.00 | 1988 | 23.00 |
| Hydro | Coop/Rolls RB 211 | Oseberg A | Compr. | 1 | 1 | 34.70 | 1991 | 25.18 |
| Hydro | KG2-3C | Oseberg A | Emerg. | 3 | | 16.40 | 1988 | 1.61 |
| Hydro | Coop/Rolls RB 211 | Oseberg A | Compr. | 2 | 2 | 34.70 | 1989 | 25.18 |
| Hydro | Coop/Rolls RB 211 | Oseberg C | Gener. | 2 | 2 | 33.90 | 1991 | 24.80 |
| Hydro | KG2-3 | Oseberg C | Emerg. | 3 | | 16.40 | 1991 | 1.61 |
| Hydro | LM-2500PE | Troll Oil | Gener. | 2 | 1 | 35.50 | 1996 | 21.20 |
| Hydro | LM-2500PE | Troll Oil | Compr. | 2 | 1 | 35.50 | 1996 | 21.20 |
| Hydro | LM-2500GE | Visund | Gener. | 2 | | 37.00 | 1998 | 22.90 |
| Hydro | LM-2500GE | Visund | Compr. | 1 | | 37.00 | 1998 | 22.90 |
| Saga | LM-2500PE | Snorre | Gener. | 3 | 3 | 35.00 | 1992 | 22.00 |
| Saga | MTU | Snorre | Gener. | 2 | 2 | | 1992 | 2.00 |
| Saga | Wärtsila | Varg | Gener. | 4 | 4 | | 1998 | 6.75 |
| Saga | Wärtsila | Varg | Gener. | 1 | 1 | | 1998 | 6.75 |
| Saga | Wärtsila | Varg | Gener. | 1 | | | 1998 | 2.10 |
| Saga | LM-2500 | Vigdis | Compr. | 1 | 1 | 35.00 | 1996 | 19.50 |
| Shell | ABB Stal GT35C | Draugen | Gener. | 3 | 3 | 30.00 | 1993 | 16.80 |
| Shell | EGT 2sh Tornado | Draugen | Waterinj.. | 2 | 2 | 28.80 | 1996 | 4.60 |
| Statoil | Typhoon | Troll Gas | Emerg. | 1 | 0 | 30.00 | 1996 | 4.64 |
| Statoil | KG2-3C | 16/11-S/E | | | | | | |
| Statoil | LM-2500 PE | Gullfaks A | Gener. | 4 | 3 | 33.00 | 1984 | 22.00 |
| Statoil | LM-2500 PE | Gullfaks A | Compr. | 2 | 2 | | 1998 | 22.00 |
| Statoil | LM-2500 PE | Gullfaks C | Gener. | 3 | 3 | 33.00 | 1988 | 22.00 |
| Statoil | LM-2500 PE | Gullfaks C | Compr. | 2 | 2 | 33.00 | 1988 | 22.00 |
| Statoil | Coop/Rolls RB 211 | Heidrun | Gener. | 3 | 2 | 35.50 | 1994 | 25.50 |
| Statoil | Coop/Rolls RB 211 | Heidrun | Compr. | 1 | 1 | 37.20 | 1994 | 26.60 |
| Statoil | LM-2500 PE | Norne | Compr. | 2 | | 37.00 | 1998 | 21.20 |
| Statoil | LM-2500 PE | Norne | Gener. | 2 | | 37.00 | 1998 | 21.20 |
| Statoil | LM-2500 PE | Sleipner A | Compr. | 5 | | 30.00 | 1993 | 22.00 |
| Statoil | LM-2500 PE | Sleipner A | Gener. | 3 | | 30.00 | 1993 | 22.00 |
| | LM2500 PE | Sleipner T | Compr. | 3 | | | | 22.00 |
| | Kværner pelton | Sleipner T | Gener. | 2 | | | | 3.00 |
| Statoil | KG2 | Statfjord A | Emerg. | 3 | 2 | ? | 1979 | 1.50 |

| Operator | Turbine/ engine | Field | Function | Total | Running | Efficiency | Installed | Output/unit. (MW) | |
|---|---|---|---|---|---|---|---|---|---|
| Statoil | LM-2500 PC | Statfjord A | Compr. | 3 | 2 | 30.00 | 1979 | 19.00 | |
| Statoil | LM-2500 PC | Statfjord A | Gener. | 3 | 3 | 30.00 | 1979 | 19.00 | |
| Statoil | LM-2500 PC | Statfjord B | 2G+3K | 5 | 5 | 30.00 | 1981 | 19.00 | |
| Statoil | LM-2500 PC | Statfjord C | 2G+3K | 5 | 5 | 30.00 | 1985 | 19.00 | |
| | LM-2500+ | Statfjord C | | 1 | 1 | | | 29.00 | |
| Statoil | Wärtsilä | Veslefrikk | Gener. | 8 | | | | 4.00 | |
| Statoil | LM-2500 PE | Veslefrikk | Gener. | 1 | | 33.00 | 1989 | 20.00 | |
| Statoil | MTU | Veslefrikk | Emerg. | 1 | | | | | |
| Statoil | Solar Mars | Veslefrikk | Waterinj. | 1 | 1 | 31.00 | 1989 | 8.80 | |
| Statoil | | Yme | | | | | | | |
| Statoil | LM-2500+ | Åsgard B | Compr. | 2 | | | 1998 | 28.00 | |
| Statoil | LM-2500 PR | Åsgard B | Gener. | 3 | | | 1998 | | |
| Statoil | LM-2500+ | Åsgard A | Compr. | 2 | 2 | | 2000 | 28.00 | |
| Statoil | LM-6000 DLE | Åsgard A | Gener. | 2 | 1 | 40.00 | 2000 | 42.00 | |
| | KG2 | Statpipe 16/11 | | 4 | | | 1.50 | | |
| PPCoN | Caterpillar D399 | Albuskjell 1/6-A | Gener. | 3 | 1 | 35 | 1978 | 0.9 | Out 1998 |
| PPCoN | Caterpillar D399 | Albuskjell 2/4-F | Gener. | 3 | 1 | 35 | 1978 | 0.9 | Out 1998 |
| PPCoN | Caterpillar D399 | Cod 7/11-A | Gener. | 3 | 1 | 35 | 1977 | 0.9 | Out 1998 |
| PPCoN | Waukesha | Edda 2/7-C | Compr. | 1 | 1 | 35 | 1995 | 0.5 | |
| PPCoN | KG2-3C | Edda 2/7-C | Gener. | 2 | 1 | 12 | 1976 | 1.3 | |
| PPCoN | MTU 16V 396TC | Ekofisk 2/4-FTP | Pump. | 1 | 0 | 45 | 1993 | 1.9 | Out 1998 |
| PPCoN | MTU 12V 396TC | Ekofisk 2/4-J | Pump. | 4 | 0 | 45 | 1998 | 1.5 | |
| PPCoN | D-R GT610 | Ekofisk 2/4-K | Pump. | 3 | 3 | 32 | 1985 | 14.9 | |
| PPCoN | Allison 570 | Ekofisk 2/4-K | Gener. | 3 | 2 | 30 | 1985 | 4.7 | |
| PPCoN | Caterpillar D399 | Ekofisk 2/4-K | Gener. | 5 | 4 | 35 | 1976 | 0.9 | |
| PPCoN | Mitsubishi 16V NPTA | Ekofisk 2/4-T | Gener. | 1 | 0 | 43 | 1985 | 1.2 | Out 1998 |
| PPCoN | MTU 16V 396TC | Ekofisk 2/4-X | Gener. | 1 | 0 | 45 | 1997 | 1.9 | |
| PPCoN | LM-2500 GJ | Ekofisk 2/4-J | Compr. | 5 | 5 | 37 | 1998 | 23.2 | |
| PPCoN | LM-2500 PJ | Ekofisk 2/4-J | Gener. | 2 | 2 | 37 | 1998 | 23.2 | |
| PPCoN | Hedemora diesel | Eldfisk 2/7-A | Gener. | 1 | | | | 1.4 | |
| | Er. KG2 ila | | | | | | | | |
| | PPCoN KG2-3C | Eldfisk 2/7-A | Gener. | 2 | 12 | 1979 | 1.34 | | |
| PPCoN | Hedemora diesel | Eldfisk 2/7-B | Gener. | 1 | | | 1.4 | | |
| PPCoN | KG2-3C | Eldfisk 2/7-B | Gener. | 2 | 2 | 12 | 1979 | 1.34 | |
| PPCoN | Frame MS-3002 | Eldfisk 2/7-B | Compr.. | 2 | 1 | 25 | 1979 | 10.9 | Out 1998 |
| PPCoN | Frame MS-5002 | Eldfisk 2/7-FTP | Compr.. | 2 | 1 | 26 | 1979 | 24.3 | Out 1998 |
| PPCoN | Solar Centaur H | Tor 2/4-E | Compr.. | 1 | 1 | 29 | 1988 | 4.1 | |
| PPCoN | Caterpillar D399 | Tor 2/4-E | Gener. | 2 | 1 | 35 | 1988 | 0.9 | |
| PPCoN | KG2-3C | Tor 2/4-E | Gener. | 2 | 0 | 12 | 1976 | 1.34 | |
| PPCoN | Caterpillar D399 | W.Ekofisk | 2/4-D | Gener. | 2 | 1 | 35 | 1977 | 0.9 |
| PPCoN | Wärtsilä 18V32D | West Omicron | Pump. | 4 | 4 | 44 | 1993 | 6.6 | |
| PPCoN | MS-5001 | Ekofisk 2/4-C | Compr. | 4 | 2 | 26.00 | 1976 | 17.90 | |
| PPCoN | Solar Saturn | Ekofisk 2/4-H | Emerg. | 3 | 0 | 29.00 | 1978 | 0.90 | |
| PPCoN | MS-3002 | Ekofisk 2/4-P | Pump. | 3 | 2 | 25.00 | 1977 | 10.44 | Out 1998 |
| PPCoN | MS-5001 | Ekofisk 2/4-R | Gener. | 2 | 1 | 27.00 | 1983 | 22.40 | Out 1998 |
| PPCoN | MS-3002 | Ekofisk 2/4-T | Compr. | 2 | 1 | 25.00 | 1977 | 10.44 | Out 1998 |
| PPCoN | MS-3002 | Ekofisk 2/4-T | Compr. | 2 | 1 | 25.00 | 1979 | 10.44 | Out 1998 |
| PPCoN | MS-5002 | Ekofisk 2/4-T | Compr. | 4 | 3 | 27.00 | 1978 | 22.40 | Out 1998 |
| PPCoN | MS-5002 | Ekofisk 2/4-T | Compr. | 3 | 2 | 27.00 | 1978 | 22.40 | Out 1998 |
| PPCoN | MS-5002 | Ekofisk 2/4-T | Cooling | 2 | 1 | 27.00 | 1977 | 27.59 | Out 1998 |
| PPCoN | LM1600 2/7-E | (eldf WI) | Pump. | 4 | | | 2000 | 16.00 | Out 1998 |
| PPCoN | LM 2500 GJ 2/7-E | (eldf WI) | 1 | | | | 2000 | 23.20 | |
| PPCoN | Steamturbin 2/7-E | (eldf WI) | Gener. | 1 | | | 2000 | 10.30 | |
| PPCoN | Hedemora diesel 2/7-E | (eldf WI) | Gener. | 1 | | | 2000 | 2.15 | |
| PPCoN | KG2-3C | Ekofisk-field | Gener. | 33 | 16 | 12.00 | 1978 | 1.30 | |
| PPCoN | KG2-3C | Norpipe B11 | Gener. | 3 | 1 | | | 1.34 | |
| PPCoN | Frame 500 | Norpipe B11 | Compr. | 3 | 1 | | | 27.6 | |
| PPCoN | KG2-3C | Norpipe H7 | Gener. | 3 | 1 | | | 1.34 | |
| PPCoN | Frame 500 | Norpipe H7 | Compr. | 3 | 1 | | | 27.6 | |
| Esso | Coop/Rolls Avon | Odin | | 2 | 0 | | 1990 | 14.00 | Removed |
| Esso | KG2-C | Odin | | 3 | 0 | 12.00 | 1985 | 1.20 | Removed |

# Attachment 2

# A closer look at fossil oil, well pressure, and produced water

[This attachment is based on research done by Palm and Rostock, Bellona 1996]

Petroleum, or crude oil, is created by large amounts of plankton and other organic material which has fallen as mud into shallow bays, lagoons, rivers, or lakes. Over time, the extremely high pressure and temperature changes the organic material from a solid to a liquid state: oil. Since the raw material that crude oil is made from is under constant pressure, the oil is forced to ooze through porous stone formations. This oozing will continue until it is stopped by a type of rock it cannot seep through. At this stage the oil is trapped, often with a high-pressure blanket of gas above and a layer of water below.

Since oil has a lower density than water, the oil forms in the uppermost stratum, and a certain amount of water will also be found in the oil. In the areas between the strata there is a mixture of oil and water. When the oil is pumped out of the reservoir, or when rate of production is too high, some of this mixed oil and water will come up with the oil. It is this water which is called “produced water.”

Under optimal operation, the product which is pumped directly out of the well will be about nine parts oil and one part water. Before the oil is transported and treated further, the produced water is separated out. The separation takes places in mechanical devices which utilize the density of the oil and water in the process. The produced water will naturally contain some oil and soluble oil products.

Oil found in the well is under extremely high pressure. It is this pressure which enables the oil to be pumped up to the surface. At the same time, the pressure in the well falls drastically when the oil is pumped out, and this leads to a lesser yield than what is actually found in the well. Reduced pressure can also cause a lower pump rate than desired.

In order to increase the amount of oil that can be pumped out of the well, it is important to maintain pressure. This is often accomplished by pumping more water down into the layer of water that lies under the oil, thus increasing the pressure and forcing more oil up. Up to now, the operators have preferred using seawater instead of re-injecting the produced water for this added pressure.

Sooner or later the well will be drained and a defined layer of oil will be difficult to locate. Some of it will be mixed with water and some will remain on the surface of the rock; leftover pockets of pure oil are also common. The operator has to pump down relatively large amounts of water to push the last of the oil up. This water is always treated with chemicals to prevent corrosion, growth of bacteria, etc., but also to enhance its ability to press the oil upward. When a well is operated in this manner, the amount of produced water increases dramatically. In 1990, the average content of water in the oil was 20%. The prognosis for year 2000 is around 55%.

Produced water contains chemicals which have been added and substances which appear naturally. The concentration of these chemicals is steadily increasing. The most prominent are the “BTX compounds” (benzen, toluene, and xylene), ethyl bezene, and naphtalene. These are also relatively water soluble and considerably more poisonous than the other components in the oil. Produced water also contains smaller amounts of alkylphenol compounds. Several of these have been shown to cause fertility problems because they resemble the female hormone, estrogen. The effects on the environment depend on both the amount and rate of break-down.

Until now traces of alkylphenoles in the North Sea have not been found, the presence of which would cause the likelihood of reproductive disturbances in fish. The effect on other species is more uncertain, but there is no evidence of any toxicity near the discharge pipes on the platforms, and because of the large amounts of water this discharge is diluted in, no severe effects are expected either. The BTX compounds and certain alkylphenoles are less degradable and can build-up as they move up the food chain. This could lead to unexpected side effects over time.

Use of chemicals in the oil industry in the Norwegian oilfields is steadily increasing. In the course of the last ten years, use has increased 10% annually. Total use is over 300,000 metric tons per year, and over half this amount is released into the environment. There are a total of 1,800 different products which are used as additives to drilling mud or injected water, and the majority could be released into the ocean. A large portion of this use is relatively harmless minerals, but discharge of stronger compounds is increasing.

Knowledge of the effects from chemicals on the environment is still somewhat lacking. Testing chemicals for approval is largely limited to determining toxicity. Since these chemicals are highly diluted, toxicity is not a relevant measure, and the test organisms are also of little relevance for the conditions in the North Sea.

In later years, a data program called CHARM (chemical hazard risk management) has been developed, which will be used instead of the toxicity tests in determining levels of toxicity when chemical compound systems are to be chosen. This computer (model) program factors in dilution and, to a certain degree, different species’ susceptibility in different stages of life.

The calculations do not take into account either the fact that the chemicals are mixed with relatively large quantities of poisonous elements from the oil or the fact that these chemicals can have gone through chemical processes or changed while inside the well itself, where there are extremely high shear forces, pressure and temperatures.

Even though the CHARM model is better than the options previously available when it comes to the risks, there is still some doubt regarding the actual risk that the use and discharge of the different elements represent.

The effects of the discharges of oil, oil compounds, and chemicals is not known, but there is reason to believe that a certain degree of negative effects as a result of long-term exposure will take its toll on plankton, bottom-dwellers, and fish. It is therefore critical that the discharges of oil and chemicals from produced water are reduced as much as possible.

# Attachment 3
# **Fuel Cells:** From fuel to electricity and clean water

We have chosen a proton exchange membrane or PEM fuel cell (Figure a3) to explain how fuel cells work.

Energy comes from the process where the hydrogen ion combines with oxygen to become water. The gases are separated by an electrolyte, and in a PEM fuel cell this is a polymer membrane which is covered with a catalyzer containing platinum. The gases are lead through finely distributed ducts to the catalyzer surfaces so that it builds up a positive charge on the oxygen side and a negative charge on the hydrogen side. The fuel is oxidized by the anode (-), and the freed electrons flow through an electric circuit to the cathode (+). The circuit is closed when H+ ions are moved through the electrolyte (proton exchange membrane which separates fuel and oxygen) and combines to form water from the oxygen.

The effect from a single fuel cell is minimal, so the cells are linked together to achieve the desired capacity. Several fuel cells connected together is called a fuel cell stack.

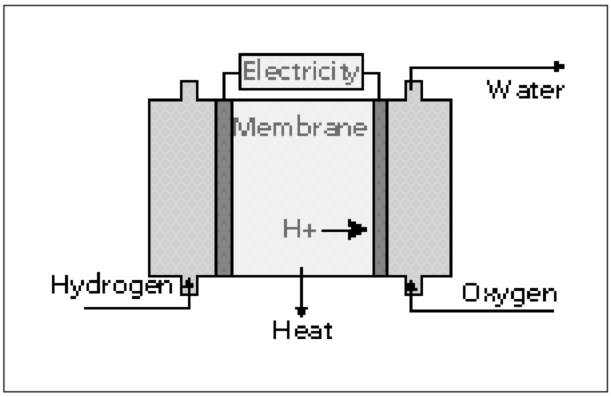

**Figure a3: Fuel Cell**
This figure shows how a fuel cell generates current and some heat from hydrogen and oxygen. The process is galvanic and without combustion. The waste product is pure water.

**Table a3.1: The most important fuel-cell types**

| Type | Electrolyte | Required temp. (° C) | Area of use |
|---|---|---|---|
| Alkaline (AFC) | Alkaline | 50-200 | Aeronautics and transport |
| Direct methanol (DMFC) | Polymer | 80-200 | Transport |
| Phosforic acid (PAFC) | Phosphoric acid | 190-210 | CHP, Power plant |
| Proton exchange - membrane (PEM) | Solid polymer | 50-80 | Transport, CHP |
| Molten carbonate (mcfc) | Molten carbonate | 630-650 | Power plant |
| Solid oxide (SOFC) | Solid oxide | 850-1000 | CHP, Power plant |

# Attachment 4

Index of organization names

Abbreviations:

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|---|---|
| DN | Direktoratet for naturforvaltning, a branch of MD, Miljøverndept. Norway's Ministry of the Environment (www.naturforvaltning.no) |
| EPA | Environmental Protection Agency – in the USA. (www.epa.gov) |
| Habiol as | Oil company which bases its products, mainly diesel, on botanic material |
| MD | Miljøverndepartementet - Norway's Ministry of the Environment (www.odin.dep.no/md) |
| MILFOR | "Virkemidler i miljøvernforvaltningen", i.e., "Political instruments in environmental management" is a research program under Norway's Research Council (NFR) focal area "Environmentally sound production and consumption," financed by the Ministry of the Environment |
| MILJØSOK | A working forum for the oil industry and government. Initiated by the Ministry of Industry and Energy in 1995 with the slogan "A clean oilfield is a profitable oilfield" (www.miljosok.org) |
| NIVA | Norsk Institutte for Vannforskning – Norwegian Institute for Water Research, an independent organization whose Board is nominated by the MD, Norwegian Research Council (NFR), and its employees (www.niva.no) |
| NREL | National Renewable Energy Laboratory, a branch of the US Dept. of Energy |
| NVE | Norges vassdrags-. og energidirektorat, the Norwegian Water Resources and Energy Directorate, a branch of the Ministry of Petroleum and Energy (OED). |
| OD | The Norwegian Petroleum Directorate exercises supervisory control of petroleum activities on the Norwegian continental shelf and on Spitsbergen. The directorate functions as adviser to the Ministry of Petroleum and Energy and to the Ministry of Local Government and Regional Development, and is responsible for providing all participants in the petroleum industry, as well as the general public, with guidance and information. (www.npd.no/norsk/home/homeno.htm) |
| OED | Olje- og energidepartementet – The Ministry of Petroleum and Energy (www.odin.dep.no/oed) |
| SFT | Statens forurensningstilsyn, the Norwegian Pollution Control Authority, a directorate under the Ministry of the Environment. (www.sft.no) |
| Statnett | Statnett SF, the Norwegian Power Grid Company, supervises and coordinates operation of the entire Norwegian power system. This state-owned company also owns and operates more than 8,500 km of high-voltage power transmission lines and subsea cables, in addition to 74 sub stations and switching stations. (www.statnett.no) |
| VOC | Volatile Organic Compounds, an umbrella term for organic materials (such as hydrocarbon compounds) which evaporate at low temperatures. |