Summary in English NOU 2004: 11

Hydrogen as the Energy Carrier of the Future

Translation from the Norwegian. For information only.

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Chapter 1
Background

By Royal Decree of 20 June 2003 the government appointed a committee to draw up a proposal for further Norwegian efforts to utilise hydrogen as an energy carrier through the development of a national hydrogen programme. The committee was instructed to base its work on, among other things, input from two expert groups – one for the production and stationary use of hydrogen appointed by the Ministry of Petroleum and Energy, and another for the use of hydrogen in the transport sector appointed by the Ministry of Transport and Communications. The committee's terms of reference were as follows:

> «Hydrogen can play an important role in our future energy systems, both as an energy carrier and as a contribution to improving the environment, in that the use of hydrogen involves no harmful emissions to the environment.
>
> Norway has sound experience in the production of hydrogen, from both renewable and fossil energy resources, and has established industries using a variety of hydrogen technologies and applications. At the same time, high-quality research competence is available in important niche areas. Norway also has large natural gas resources, representing a natural resource for large-scale hydrogen production. The conditions are therefore well-suited for increased use of hydrogen in Norway, and for future Norwegian export of hydrogen-related technology and competence.
>
> On this basis, the authorities will aim to facilitate a strengthening of Norwegian efforts to develop hydrogen-related technologies and hydrogen as an energy carrier.
>
> The committee shall formulate national goals and necessary measures for developing hydrogen as an energy carrier and an instrument for domestic value creation and environmental improvement. The committee shall identify the need for public involvement and framework conditions, and put forward proposals for the division of responsibility, organisation, resource requirements and technical content of a national hydrogen programme.
>
> The committee shall explore the economic and administrative consequences of the proposed measures. At least one of the proposals shall be based on an unchanged use of resources.
>
> The committee shall maintain a close dialogue with the Research Council of Norway, and the R&D measures proposed shall be considered in the light of and coordinated with the Research Council's strategies and measures in the field.
>
> The national hydrogen programme shall include the use of hydrogen for both stationary and transportation purposes. Internationally, most progress has been made in the transport sector. The programme must be considered in light of international activities in the hydrogen area and opportunities for Norwegian participation in international research, development and demonstration projects. The nature of the measures proposed for inclusion in the programme must be such that they qualify for government support under the rules of the EEA agreement.
>
> As a starting point for the work on developing a national hydrogen programme, the committee shall identify and assess possibilities and barriers relating to the production, storage, distribution and end use of hydrogen in Norway. The committee shall discuss hydrogen as an energy carrier in relation to alternative options.
>
> The work of the committee shall reflect the results of the work of the expert groups set up to assist the committee and its recommendations shall be based on this work. The expert group for production and stationary use shall base its work on the facts and arguments regarding hydrogen that are already available in the Gas Technology Committee's recommendation (Norwegian Official Report, NOU 2002: 7 Gas Technology, the Environment and Value Creation) and in the Report nr. 9 to the Storting (2002–2003) On domestic use of natural gas, etc. The group shall also conduct such studies as are necessary to support the committee's work so that it can fulfil its terms of reference. The expert group for transport shall base its work on the terms of reference of the expert group under the Ministry of Transport and Communications. The work of the expert groups shall be submitted to the respective ministries by 1 May 2004.
>
> The committee shall submit its report by 1 June 2004, at the latest.»

The committee has consisted of:
Sverre Aam (chair), Managing Director, SINTEF Energy Research
Elisabet Fjermestad Hagen, Head of Section, Norsk Hydro
Hanne Lekva, Director, Statoil
Ole Gjølberg, Professor, Norwegian Agricultural University
Trygve Riis, Head of Section, The Research Council of Norway
Ane Hansdatter Kismul, Head of Nature and Youth

The Ministry of Petroleum and Energy has shared secretariat duties with the Ministry of Transport and Communications. The secretariat has consisted of Senior Adviser Trond Moengen, Energidata AS, who has been in charge of the secretariat's work; Deputy Director General Ann Ingeborg Hjetland, Ministry of Petroleum and Energy; Adviser Tore Grunne, Ministry of Petroleum and Energy; Higher Executive Officer Eirik Midtsundstad, Ministry of Petroleum and Energy; and Adviser Trond Kråkenes, Ministry of Transport and Communications.

Chapter 2
Summary

Chapter 1. The committee's members, terms of reference and work

Chapter 1 describes the background for appointing the committee and the committee's terms of reference and work.

Chapter 3. Norwegian competence and resource base in the energy field

Chapter 3 gives an overview of Norwegian resources and competence in the petroleum and energy field in general, and in the hydrogen field in particular.

Norway is a major producer of hydroelectric power and a considerable producer and exporter of oil and natural gas. Our industries are largely based on this. In step with Norway's emergence as an energy nation, Norwegian industry and research milieus have become competitive in offering products, services and technology to enterprises on the Norwegian Continental Shelf and internationally. This is a favourable starting point for Norway to play an active role in international efforts to utilise hydrogen.

Domestic energy supply. Estimated production in the Norwegian hydroelectric power system in a normal year is around 119 TWh. This puts Norway in sixth place among the world's hydroelectric power producers. Virtually all power plants in Norway are hydroelectric and produce neither greenhouse gases nor other emissions. It has been estimated that the annual Norwegian hydroelectric power production can vary between 90 TWh and 150 TWh as a result of varying precipitation. In recent years electricity consumption and production have largely been in equilibrium. The Norwegian energy supply is vulnerable to reductions in precipitation. This is partly compensated for by the fact that Denmark, Finland, Norway and Sweden have an integrated Nordic energy market.

Hydroelectric power dominates the Norwegian energy supply, but other renewable energy sources also have considerable potential in Norway. The Norwegian wind power output increased from 13 MW in 1999 to over 100 MW in 2002. In 2003 this represented an annual production of 220 GWh. Bio-energy accounts for an annual energy production of around 15 TWh. It is primarily based on the use of wood and residual products from wood processing industries. Norway also has a great potential and extensive research activities in areas such as solar energy, wave power, tidal power and salt power (salt gradients).

The petroleum sector is Norway's largest industry. In 2002 it represented 19.2 per cent of Norway's gross domestic product. This is almost three times the value creation of any other industry. In 2002, 24 per cent of government income came from petroleum activities.

Norway ranks as number seven among the world's oil producers, and is the third largest exporter of crude oil, after Saudi Arabia and Russia. The Norwegian Continental Shelf accounts for approximately 4.3 per cent of the world's total oil production. Oil production is expected to remain at today's level for the next few years, and then gradually decline. Norway is expected to continue producing oil for another 50 years or more.

Norway is the third largest natural gas exporter to the EU, providing approximately 12 per cent of the EU's natural gas consumption. Globally, Norway is the fourth largest exporter of natural gas. Around one third of the natural gas produced is re-injected into the reservoirs to provide pressure support for increased oil production. Some of the natural gas is used for power production on the platforms and at the terminals, and some of it is also used domestically, mainly by the methanol plant at Tjeldbergodden.

The production of natural gas is increasing, and natural gas's share of total petroleum production is expected to rise considerably in years to come, from around 25 per cent in 2002 to around 42 per cent in 2010. A future sales volume of 20 billion Sm^3 is regarded as realistic within 7–12 years. It is estimated that Norway has sufficient natural gas reserves to continue its production for another 100 years.

Hydrogen in Norway. Norway has long-standing traditions in the production of hydrogen. However, almost all the hydrogen produced is used for industrial purposes. The use of hydrogen for energy purposes is currently very limited. Norway has state-of-the art expertise in a number of hydrogen technologies relating to the production, storage and use of hydrogen. Demonstration projects have also been undertaken to test out new hydrogen technologies. In addition to this, Norwegian hydrogen-related products, for example ammonia used in chemical fertilizers, are sold worldwide.

Norway has considerable expertise in the design and operation of plants for hydrogen production. At Norsk Hydro, now Yara, ammonia for the production of chemical fertilizers was produced industrially from hydrogen from water electrolysis, using hydroelectric power for energy, from 1928 up until about 1990. Since then, Yara has based its hydrogen production on steam reformation of natural gas. Today, Yara is a considerable hydrogen producer, but the hydrogen produced is used directly in the production of ammonia and chemical fertilizers. The company has one ammonia plant in Norway (at Herøya near Porsgrunn) and several similar plants in other countries, and a petrochemical plant (in Rafnes), where hydrogen is a by-product.

Since 1997 Statoil has produced hydrogen in connection with the production of methanol at Tjeldbergodden in Møre og Romsdal County. Statoil also produces hydrogen at its refinery at Mongstad. In addition, considerable amounts of hydrogen are produced as by-products by other Norwegian industries.

In 1996, the Norwegian Hydrogen Forum (NHF) was established, with representatives from Norwegian industry, research institutions and universities/colleges. Among other purposes, NHF was set up to contribute to the information flow between Norwegian and foreign milieus and to promote education, research and innovation in the hydrogen technology field.

Chapter 4. Hydrogen as an energy carrier

Chapter 4 discusses the most basic properties of hydrogen and the factors that make hydrogen an attractive energy carrier. These properties are the reason why hydrogen is viewed by many countries as constituting a future solution to the challenges in the energy and transport sector. The chapter starts with a brief historical review of how hydrogen has been used in the past.

The effort to exploit hydrogen is linked in particular to the environmental challenges facing the world, both as regards greenhouse gases and local pollution. The conversion of hydrogen to electricity in a fuel cell has water vapour as its only by-product. However, the environmental properties of hydrogen are no better than those of the energy source from which it is produced. If the hydrogen is produced from fossil fuels, it will still have a negative environmental impact. Given the forecast that fossil fuels will account for 90 per cent of the world's energy consumption in 2030, dealing with CO_2 is a fundamental prerequisite for the realisation of environmentally friendly production and use of hydrogen in the foreseeable future.

Among the countries that are dependent on importing energy, particularly oil, many look to hydrogen as a means of reducing this dependency. Like electricity, hydrogen can be produced from different energy sources, such as coal, natural gas and bio-energy. It can also be derived from the electrolysis of water. This means that domestic energy sources can be exploited and dependence on imports reduced. Hydrogen can be used in both the transport sector and for stationary supply.

A third reason often cited in the countries' targeting of hydrogen and fuel cells is that it will create opportunities for economic development and value creation. Since it is expected that hydrogen can come to play an important role globally, there will be competition to enter this market.

Today, hydrogen is not used as a commercial energy carrier, but it is produced industrially in petroleum refineries, in ammonia production and in methanol production. The amount of energy in this hydrogen would equal 1.5 per cent of the world's total energy consumption if used for energy purposes.

Where do we find hydrogen? Hydrogen (H) is the lightest of all the elements and has the atomic number 1 in the periodic table. It has been estimated that hydrogen constitutes more than 90 per cent of the atoms in the universe and around three quarters of the mass of the universe. In nature, however, free hydrogen is virtually non-existent, and it must therefore be produced from raw materials containing hydrogen. Hydrogen is present in organic materials, in biomass and in fossil fuels, but most of all it is present in water (H_2O). Molecular hydrogen (hydrogen gas – H_2) can be produced from hydrogen compounds in different ways by introducing varying degrees of energy. Reformation of natural gas and electrolysis of water are the most widely used methods of producing hydrogen.

Hydrogen as an energy carrier. Hydrogen is an energy carrier, not an energy source. Hydrogen, like other energy carriers such as petrol, electricity and district heating, must be produced from an energy source. An energy carrier transfers energy from an energy source to an end user with a demand for an energy service, such as heating, transport or lighting. If the hydrogen is to perform an energy service, it must be converted to heat, mechanical work or electricity for end use.

Hydrogen production. About 90 per cent of the world's annual production of hydrogen is based on fossil fuels, mostly natural gas. Conventional reformation of natural gas is currently the most frequently used technology for the production of hydrogen on a medium and large-scale basis. The production process is called steam reformation, and it is roughly identical for natural gas, oil and coal. Cost-effective CO_2 handling is one of the main challenges for this technology in the future.

When an electrical current (energy) is conducted through water, it splits the water (H_2O) into its component hydrogen (H_2) and oxygen (O_2) in their gaseous form. The gases develop where the electrodes come into contact with the water. Whether or not the hydrogen produced in this process is a sound environmental energy carrier, depends on whether or not the electrical energy is produced in an environmentally friendly manner, for example from a renewable source. Commercially, alkaline electrolysers are still the most commonly used technology.

Hydrogen can also be produced from biomass. The most promising method of production from biomass is steam gasification. This method is still at the development stage, however.

A number of other methods of hydrogen production are either still being researched and developed, or they are being demonstrated on a small scale. Some fundamental technological barriers need to be overcome before hydrogen production can take place on any significant scale.

Storage and distribution. Problems relating to the economic, safe and energy-efficient storage of hydrogen are regarded as barriers to the introduction of hydrogen as an energy carrier. Under normal atmospheric conditions, hydrogen is a light gas with low energy density – only 3 kWh/m^3. For the use of hydrogen as an energy carrier to become a realistic alternative, the density of the hydrogen must be increased by compression or other means.

For the vast majority of stationary applications, the volume and weight of the storage system is of minor importance. The storage of hydrogen for the transport sector involves much greater challenges. Hydrogen storage systems for mobile applications and transport purposes are subject to strict operational volume and weight limitations. They must supply sufficient hydrogen for a driving distance of around 500 km, charge and discharge the hydrogen at close to room temperature and supply hydrogen fast enough for the operation of cars, buses and lorries.

Most of the hydrogen produced today is handled and stored as compressed gas (CH_2) under pressure, in gas cylinders or large pressure vessels. Tank size, choice of materials and compression costs are subject to economic considerations. In Norway, hydrogen is most commonly stored and transported in 50-litre steel cylinders at a pressure of 200 bar.

Hydrogen can be cooled to –253 °C, at which temperature it liquifies. The technology to liquify and store liquid hydrogen is highly developed and is used for storage of hydrogen for space applications, among other things. The loss of energy in connection with the liquification process varies with the size of the plant, but around 30 per cent of the energy in the hydrogen gas is generally consumed by the process. This aspect of liquification limits the potential for use of liquid hydrogen.

A number of materials can store hydrogen in fixed compounds. Together with hydrogen, many metals form so-called metal hydrides, which are suitable for hydrogen storage. Metals/alloys that can be used as storage mediums for hydrogen, emit heat when absorbing the hydrogen. Cooling may therefore be required during charging. Likewise, heat must be introduced to release the hydrogen gas. The general advantage of storing hydrogen in metal hydrides is that a very high storage density is attained under normal pressure and temperature conditions. Hydrogen density is higher in many metal hydrides than it is in liquid hydrogen. In addition, metal hydrides have the advantage that they are solid substances that can be handled without any major problems under normal pressure and temperature conditions.

Hydrogen can also be stored in chemical compounds, such as methanol, methane or ammonia. These are compounds that give a satisfactory energy density for many applications, but in many cases it is necessary to process the chemical compound to produce pure hydrogen for end use or to allow the fuel cell to handle such compounds directly.

Infrastructure. The type of energy services demanded by end users together with the location of production sites will determine how hydrogen should be transported. In areas with high demand and where the production site is close by, pipeline distribution of hydrogen may be most appropriate. The use of existing pipeline infrastructure for natural gas may be expedient. For transporting large quantities over great distances, the alternative would be to transport liquid hydrogen by road or sea. These two infrastructure alternatives are most applicable in the case of large-scale hydrogen production, for example by natural gas reformation.

One of the advantages of hydrogen as an energy carrier is that it can be produced locally. In future, this may reduce the need to transport hydrogen over long distances. Hydrogen production on a small scale can for instance be done in connection with filling stations for motor vehicles. The production can use one or more energy sources, for example natural gas from a local natural gas net or energy from the electricity grid for electrolysis. However, there are several challenges involved in production from fossil fuels in distributed small-scale plants, including the capture and handling of CO_2.

Safety and standards. Generally speaking, hydrogen is no more dangerous than other fuels, but the risks involved are different, and the use of hydrogen therefore requires that the technology be adapted. Hydrogen gas is colourless and odourless. It is not toxic. Mixtures of hydrogen and air are, however, explosive, with a wide ignition and detonation range. Hydrogen mixes quickly with air, however, and can therefore be quickly thinned to a safer concentration. A prerequisite for a more extensive use of hydrogen is the adoption of international standards and safety criteria for different properties of hydrogen for energy applications and technologies linked to the use of hydrogen.

End use of hydrogen. The chemical energy in hydrogen must be converted to either heat or electric power in order to be used directly or for mechanical work, for example to power a car. This can be done either by combustion or by direct electrochemical conversion in a fuel cell. In a fuel cell the energy is retrieved in the form of electricity. In a combustion engine or turbine, heat and pressure are produced, which in turn creates motion.

Fuel cells. In principle, a fuel cell operates in the same manner as a battery, except that the hydrogen is not stored in the cell but is supplied from a storage facility near by, and oxygen is taken from the air.

A number of fuel cells have been tested in the laboratory and some have been commercialised. Fuel cells are often named after the type of electrolyte that is used. All fuel cells can run on hydrogen.

Before fuel cells can have a commercial breakthrough in transport and stationary combined heat and power production, there are several technological challenges that need to be tackled. The most important are:

– Reducing the use of expensive materials and precious metals
– Improving the performance and life span of the components
– Reducing weight and size. This applies primarily to fuel cells used for transport purposes and portable applications.

Chapter 5. International efforts with respect to hydrogen

Chapter 5 gives an overview of the efforts and role played by the authorities in those countries that lead the field in hydrogen. It also contains a short summary of Norway's participation in this work.

International efforts with respect to hydrogen and fuel cells have been considerably intensified in the last few years.

More resources are being spent on research and development, and international initiatives to increase cooperation between countries have been established. In a global economy with increasing energy demands, uncertainty regarding oil and natural gas deliveries from unstable areas and international conventions on climate change, hydrogen will be considered a future solution. The car industry is one of the most important driving forces for change.

Common to these countries' efforts is the close cooperation between the authorities, industry and the academic community. There is also a common belief that hydrogen in time will make an environmentally friendly contribution to power and transport even though it may have to be produced from fossil fuels in a transitional phase. An important justification for investing more heavily in hydrogen, particularly in the USA and Japan but also in the EU, is the concern about security of supply and an increasing dependency on energy imports. With hydrogen as an energy carrier, national energy sources could be used to a greater degree thus reducing this dependency.

Since the oil crisis in 1973, Japan has invested considerably in energy research including fuel cells and hydrogen. The car industry is one of the strongest driving forces behind fuel cell research. It is a declared goal to have 50,000 fuel cell vehicles on the Japanese market by 2010, and 5 million by 2020.

In the last few years, the Bush administration in the USA has joined the hydrogen and fuel cell efforts with force, both nationally and internationally. Public funding for hydrogen related research and development increased by 60 per cent from 2003 to 2004. The hydrogen programme is governed by a combination of cost and performance demands. These primarily relate to hydrogen in the transport sector and must be fulfilled before the market can be expected to make commercial decisions. In addition, many American states have their own hydrogen programme. The California Fuel Cell Partnership is well known. In spring 2003, the USA took the initiative for the International Partnership for the Hydrogen Economy (IPHE).

Canada's efforts were originally tied to the development of fuel cells. Today, it has one of the world's biggest producers of fuel cells. Today, Canada is investing in a broad range of hydrogen-related technologies as an answer to the challenges relating to climatic change and in order to position itself in relation to the potential international market.

The EU's hydrogen and fuel cell efforts have until now been linked to framework programmes for research. With the EU Commission's initiative in January 2004 to establish a separate network for the coordination of research, development and demonstrations relating to hydrogen and fuel cells, its efforts have become more visible. The member countries have to varying degrees made their own efforts. Germany has made the most significant efforts. Iceland has set itself the goal of becoming the world's first hydrogen economy.

Hydrogen and fuel cell efforts are characterised by extensive international cooperation. In this way efforts can be coordinated, costs reduced and the transition to a hydrogen society hastened. Norway is active in many international collaborations, through its participation in the EU's framework programme, the EU's Hydrogen and Fuel Cell Technology Platform, the International Partnership for the Hydrogen Economy (IPHE), the Carbon Sequestration Leadership Forum (CSLF) and the International Energy Agency (IEA). In addition, Norway has signed bilateral cooperation agreements with the USA and Japan that include hydrogen and fuel cells. This gives Norwegian industry and research milieus the opportunity to participate in important international projects.

Chapter 6. Why invest in hydrogen In Norway?

In Chapter 6 the committee looks more closely at what makes Norway unique as regards hydrogen and which considerations the committee feels should be the basis for Norway's efforts.

The energy situation in Norway is in many ways different from that in the oil-importing countries, which are now at the forefront of hydrogen efforts. Norway has an energy production which, including the production of oil and natural gas, is ten times greater than its total domestic consumption, including the transport sector. The security of supply is therefore less of an issue than it is in many other countries.

In the committee's view, it is not rational to look to hydrogen as an energy carrier for stationary use in Norway. Norway has a well-developed electricity grid covering almost all stationary users, and nearly all electricity production is renewable. A conversion from electricity as energy carrier to hydrogen as energy carrier would result in an energy loss of 25 per cent. By additionally converting the hydrogen to electricity, for example in a fuel cell, an additional 40 per cent of the energy would be lost. However, some of the properties of hydrogen make it appropriate for use in decentralised energy supply.

The committee points out that the strong international efforts are a prerequisite, but not *per se* a justification for the Norwegian efforts. Increased use of hydrogen and demand for hydrogen technology in the international market will, however, open possibilities for the Norwegian business community.

The committee highlights three main reasons for Norway to invest in hydrogen:

- The use of Norwegian natural gas for environmentally friendly production of hydrogen
- Environmental benefits of the use of hydrogen in Norway
- Economic development relating to hydrogen

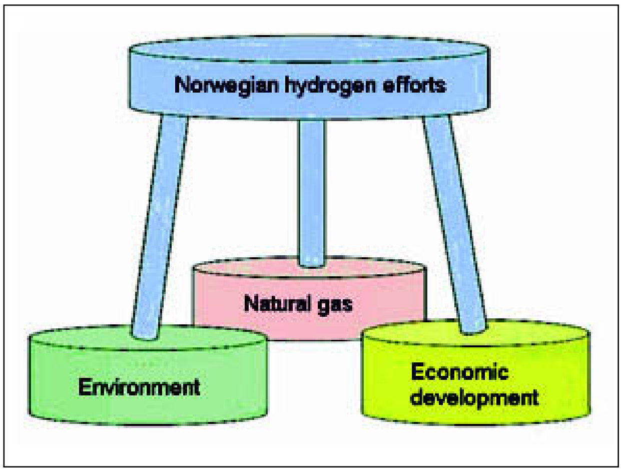

Figure 2.1 Norwegian hydrogen efforts are justified by environmental considerations, the country's natural gas resources and opportunities for economic development

Environmentally friendly production of hydrogen from Norwegian natural gas. Norwegian natural gas has a potential for environmentally friendly production of hydrogen in the future. In addition, this may be the right direction to take in order to safeguard Norwegian petroleum values in the long term. It will be important to find solutions where CO_2 can be separated during the production process and disposed of or stored in a satisfactory manner. In recent years, Norway has been one of the most active countries in researching solutions for handling CO_2 from gas-powered electricity production. Many of the problems, challenges and possible solutions will be the same for handling CO_2 from hydrogen production using natural gas. For example, the pre-combustion technology (hydrogen-powered turbine) could be used as the basis for large-scale electricity production where hydrogen would be a natural intermediate product. The opportunities and challenges involved in the further handling of CO_2 will be the same.

In a few years time, Norwegian oil fields may require considerable amounts of CO_2 in order to increase oil production. In addition to the possibility of re-injecting CO_2 into producing fields, CO_2 could also be stored in water-filled aquifers or empty reservoirs on the Norwegian Continental Shelf. This type of storage would affect costs, since the CO_2 in this case would have no value, unlike the option whereby it is re-injected to increase oil production.

Environmental benefits of using hydrogen in Norway. Environmental effects are an important reason to expend resources on hydrogen. The committee concludes that hydrogen cannot play a real role in meeting the Kyoto commitments for the period 2008–2012, but that it could present a good climate-friendly solution in the long term.

This applies especially to the use of hydrogen in the transport sector. The transport sector currently produces 25 per cent of Norway's CO_2 emissions. Hydrogen utilised in fuel cell vehicles only emits water. Hydrogen produced from renewable energy or natural gas with CO_2 handling will constitute a zero emission fuel. Local production of hydrogen by water-electrolysis for use in the transport sector is the most likely option for early use in Norway. With regard to local pollution problems and NO_X emissions in the transport sector, hydrogen may also be a good solution. It is expected, however, that improvements in traditional fuels and future developments in automotive technology will minimise environmentally hazardous emissions in the future. Hydrogen will therefore primarily be an element in the long-term solution to the climate problem.

Large-scale natural gas reformation will be an option where natural gas is available. One of the advantages of centralised large-scale generation of hydrogen from natural gas is that the CO_2 can be handled in one place. The expert group for production and stationary use believes that energy chains based on natural gas reformation without CO_2 handling will have no environmental advantages compared with direct conversion of natural gas for final use. The large-scale production of hydrogen from natural gas without CO_2 handling for use in stationary applications is not, therefore, regarded as a realistic alternative.

Economic development. Possible future growth in the international market for hydrogen will create opportunities for economic development and value creation for Norwegian players who are able to position themselves and be competitive. The committee believes the opportunities primarily lie in:

- Production and transport of hydrogen
- Supplying technology
- Supplying expertise, including research.

The committee believes that Norway as a whole has advantages that make hydrogen from the Norwegian Continental Shelf an interesting long-term prospect. The committee bases this belief on the opportunities for large-scale production of hydrogen near natural gas reserves, where CO_2 is re-injected in order to increase oil production in producing oil and natural gas fields or where it is compressed and disposed of in aquifers on the Norwegian Continental Shelf. The hydrogen can be transported by pipeline, or compressed or liquified for transport by, for example, ship.

International investment in hydrogen could entail opportunities for Norwegian suppliers of technology and solutions regardless of how or to what extent hydrogen is taken into use in the Norwegian energy and transport systems. The committee points in particular to the opportunities to be found for sub-suppliers of, for example, constituent components. Even before the technology becomes competitive in the ordinary market, a situation can be envisaged in which early markets stimulated by subsidy schemes will be of interest. These markets would focus on demonstration projects and research environments.

Norwegian research and competence milieus will have an opportunity to supply top expertise in Norway and internationally. Norway is already at the forefront of many hydrogen-related areas. Participation in international collaborations will also provide good opportunities for bringing knowledge to Norway, and for international financing of Norwegian competence development.

Chapter 7. A norwegian hydrogen effort

In Chapter 7 the committee presents an overall vision for the Norwegian hydrogen efforts. The committee discusses in some detail the individual elements in the overall effort. At the end of the chapter it defines different types of demonstration projects (prototype development, pilot projects and market introduction projects).

The committee's vision for the Norwegian hydrogen efforts is:

> «Norway shall be a driving force for the use of energy and fuels based on pollution free energy technologies – in which hydrogen plays an important role as an energy carrier.»

The committee emphasises that efforts must be based on those areas in which we have advantages. In many areas we will be dependent on international developments. We must therefore stay informed about international developments, in the technology as well as the political field.

The following goals have been set:

Goal for production of hydrogen from natural gas:

- The production of hydrogen from natural gas with satisfactory CO_2 handling shall take place at a price that is competitive with its per-energy equivalent in petrol or diesel.

Goals for early users of hydrogen vehicles:

- Norwegian players shall be early users of hydrogen vehicles in the transport sector.
- Norwegian authorities shall be as ambitious as the EU in promoting the use of hydrogen vehicles. Norway should target fleet vehicles in particular.

Goals for storage:

- Norwegian competence milieus shall be at the forefront internationally in the storage of hydrogen.
- Norwegian industrial players shall be internationally competitive in the delivery of products and services relating to hydrogen storage.

Goals for the development of the hydrogen technology industry:

- Norwegian industrial players shall participate in the growing international hydrogen market as suppliers of components and sub-systems relating to the production and use of hydrogen.
- Norwegian players shall be internationally competitive suppliers of filling stations based on electrolysis technology.
- Norwegian maritime milieus shall lead the field in terms of competence in the use of fuel cells in ships and be among the first to demonstrate such use.
- Norwegian academic milieus shall be expert in a number of areas – both in order to serve Norwegian industry and in order to compete on the international knowledge market in the hydrogen field.

The committee also examines more closely the different opportunities and barriers, as well the measures and instruments linked to each of the above goals.

Chapter 8. A national hydrogen programme

In Chapter 8, the committee presents its proposal for a national hydrogen programme. See chapter 3 for a complete presentation.

Chapter 9. Economic and administrative consequences

Chapter 9 considers the socio-economic consequences of the committee's proposal for targeting the hydrogen field.

The committee has identified a need for state funding and framework conditions, and presents proposals relating to the division of responsibility, organisation and resource requirements involved in a national hydrogen program.

The committee recommends the establishment of a national hydrogen programme that uses the whole spectre of public funding instruments. The programme should be managed by a separate programme board responsible for designing and running the programme. The committee expects that the programme can be based on the use of existing institutions and bodies, rather than establishing new ones. The committee believes the programme should be attached to the Research Council of Norway.

The committee regards the establishment of a hydrogen programme on the basis of present funding and activity levels as inexpedient. Instead, the committee recommends that a hydrogen programme be established within a more generous financial framework. The committee recommends a gradual increase in the total public funding of the hydrogen programme, from approximately NOK 50 million in 2005 to between NOK 100 and 150 million in 2014. The total financial framework for the period would thus be around NOK 825–975 million. How much of the funds are allocated each years, will depend on when demonstration projects have reached sufficient maturity for implementation.

The committee has based the funding of the programme on the sector principle and recommends co-funding by the Ministry of Petroleum and Energy, the Ministry of Transport and Communications and the Ministry of Trade and Industry. The committee emphasises in particular the need for both stable and long-term funding of the hydrogen efforts. The recommendations of the committee are based on the assumption that any subsidy schemes must be in accordance with the EEA Agreement's guidelines on state aid.

The socio-economic impact of the committee's proposal is expected to be positive. The proposal will help stimulate long-term technological and economic development in Norway and will also provide opportunities for Norwegian industrial players internationally. Furthermore, such efforts may increase the value of our gas resources and facilitate environmentally friendly energy use in Norway and internationally.

Chapter 3
Proposal for a national hydrogen programme

3.1 Introduction

The committee's terms of reference were to draw up a proposal for a national hydrogen programme. The programme presented here has been developed on the basis of the technological, financial, institutional and psychological challenges represented by the efforts to utilise hydrogen. The goals and instruments proposed by the committee in chapter 7 of the NOU 2004: 11 are the backbone of the programme. International developments in this area have also been taken into account. Norwegian involvement in hydrogen as an energy carrier will be dependent on technological developments in the international car industry, among other things. In general, Norway is dependent on the technological standards that are set and choices that are made globally in this area. At the same time, Norwegian industry and expert milieus should aim to contribute to develop this technology and influence the regulations and standards that are chosen. It is important to bear in mind, however, that any extensive use of hydrogen in the Norwegian transport sector will depend on international developments.

A national hydrogen programme should have a strategy for both the short and the long-term. The short-term perspective (5–10 years) should include measures directed at trying out known technologies on a small scale. Demonstration projects or other measures may lead to improvements in current technology. The long-term part of the programme (10–25 years) consists of basic research and investments in technology and potential applications, which we cannot yet fully conceive. These long-term efforts must be initiated right from the outset of the programme.

The national hydrogen programme should be directed at production as well as transport, storage and utilisation of hydrogen as an energy carrier. At the same time, it is necessary to set some key priorities with respect to on which areas the programme should focus its main efforts.

The committee has focused on defining some key priorities relating to which main areas should be targeted. The committee has also identified instruments, measures and framework conditions. It has indicated how a hydrogen programme can be organised and managed. The committee has also raised the issue of the funding of Norwegian hydrogen efforts, as well as other factors that do not necessarily belong in a national hydrogen programme but which are nevertheless important in relation to efforts in the hydrogen field.

Summary of the goals

The committee's proposed goals for the Norwegian hydrogen effort, as presented in chapter 7 of the NOU 2004: 11, can be summarised as follows:

- The production of hydrogen from natural gas with satisfactory CO_2 handling shall take place at a price that is competitive with its per-energy equivalent in petrol or diesel.
- Norwegian players shall be early users of hydrogen vehicles in the transport sector.
- Norwegian authorities shall be as ambitious as the EU in promoting the use of hydrogen vehicles. Norway should target fleet vehicles in particular.
- Norwegian competence milieus shall be at the forefront internationally in the storage of hydrogen.
- Norwegian industrial players shall be internationally competitive in the delivery of products and services relating to hydrogen storage.
- Norwegian industrial players shall participate in the growing international hydrogen market as suppliers of components and sub-systems relating to the production and use of hydrogen.
- Norwegian players shall be internationally competitive suppliers of filling stations based on electrolysis technology.
- Norwegian maritime milieus shall lead the field in terms of competence in the use of fuel cells in ships and be among the first to demonstrate such use.
- Norwegian academic milieus shall be expert in a number of areas – both in order to serve Norwegian industry and in order to compete on the international knowledge market in the hydrogen field.

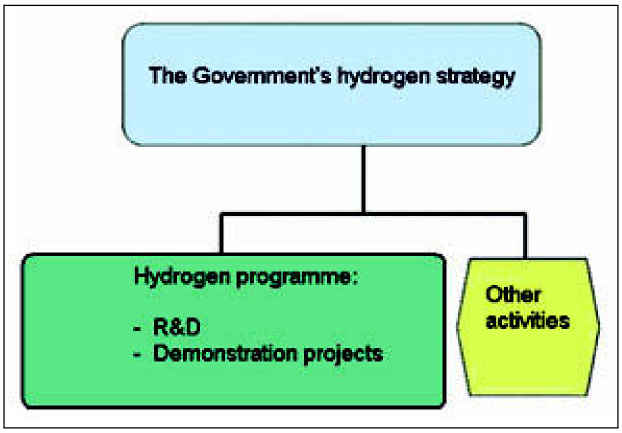

Figure 3.1 The government's hydrogen strategy as seen by the committee. The detailed organisation is described in section 3.3.1 and illustrated in figure 3.2

The committee believes that a joint, overriding hydrogen strategy should be developed on the basis of the hydrogen programme. The strategy should, in addition to the programme, cover other framework conditions that could contribute to increased and more coordinated efforts in the hydrogen field, see figure 3.1. This should include instruments such as tax incentives, safety regulations, standards and certification, and other measures as required.

3.2 Activities in a Norwegian hydrogen programme

The hydrogen programme's main emphasis is on resources and activities relating to research and development and various types of demonstration projects that go beyond what can be accomplished in a research laboratory. Some of these efforts should have a relatively short-term time scale (5–10 years). At the same time, the time scale should also be in step with the time scale pursued by the international car industry among others. This industry aims to develop fuel cells and distribution technology which will lead to a large-scale introduction of hydrogen as an energy carrier in the transport sector in 10 to 15 years.

3.2.1 Research, development and demonstration

3.2.1.1 Research and development

Through its work, the committee has identified specific target areas and associated opportunities and barriers. These target areas have varying time scales, represent different ambition levels and involve different degrees of technological challenges. The committee has not attempted to draw up a complete research strategy, but acknowledges that research must account for a large portion of the hydrogen efforts. The development of a more detailed research strategy will be a key task for those in charge of implementing the hydrogen programme, see section 3.3. In the following, the committee outlines what should be the main elements of the hydrogen programme.

Basic and strategic research

Technological breakthroughs and new fundamental knowledge are prerequisites for any broad-scale introduction of hydrogen as an energy carrier. In addition, any future growth of new technologies and systems will require new expertise and competent personnel. Up until now, a significant part of the Norwegian research activities in the hydrogen field has been basic research. This has contributed to the good results achieved so far. The following are some of the areas of basic, strategic research of particular importance to hydrogen:

- Membranes and absorbents for CO_2 separation
- Fuel cells (PEMFC, SOFC) and electrolysis
- Solids materials for storage in vehicles
- Compression and liquification (cryogenic technology)
- Combination of compression, cryogenic technology and storage in solid materials
- Combustion of hydrogen in general and related to turbines in particular.
- New catalysts relating to the production of hydrogen

These topics relate to what currently appear to be the most promising solutions and in which Norwegian expertise has reached a high level. The committee would like to emphasise that many of the challenges in the hydrogen field are of a fundamental nature. It is difficult to predict where fundamental breakthroughs will be made. Hence, thematic priorities must be balanced against the search for solutions on a somewhat broader basis. The committee would like to emphasise the importance of securing adequate resources for universities and research milieus as a part of such a strategy.

Applied research

Applied research is largely influenced by industry's expectations and initiatives. Research projects could include the following topics:

- CO_2 capture, transport and storage
- Hydrogen storage systems
- Fuel cell systems for maritime applications
- System development
- Process technology
- Gas turbines with high efficiency and low NO_X emissions

Other areas may also emerge, depending on the initiatives taken by industry.

3.2.1.2 Demonstration projects

Relevant demonstration projects

Demonstration projects require major investments. The committee would therefore like to point out that it is necessary to give careful consideration to what one seeks to accomplish by supporting demonstration projects, especially in relation to the definitions and criteria described in section 7.2 of the NOU 2004: 11.

Hydrogen technology is not yet mature enough to undertake large demonstration projects with a view to broad market introduction. In the period leading up to 2010, the focus should be on pilot and test systems aimed at technology development. Since demonstration projects are costly, it is important to plan Norwegian activities in cooperation with international players with a view to coordinated implementation. It may be relevant to target selected niche markets.

The committee has reviewed in detail some demonstration projects that may be relevant and some examples are cited below. These projects cannot be implemented without state funding. The public funding of projects is estimated at NOK 120–200 million during the period until 2010 and at NOK 50–100 million between 2010 and 2014. It is expected that the public and private sector will contribute 50 per cent each. The funding must be designed to satisfy the EEA Agreement's guidelines on state aid.

Establishment of a national research-oriented test laboratory (test lab)

In the phase between research and demonstration projects it can often be worthwhile to test out solutions on a small scale. Consideration should therefore be given to establishing a research-oriented test laboratory which could be accessible to the key national research players in this field. This could for example be done by having some of the key national research institutions share responsibility for the facility. Such a test lab could undertake prequalification of major pilot projects in order to shed light on the challenges associated with for example scaling-up, operation and maintenance. System analyses are another important function that could be attended to. Such a project could be established within a short time.

Pilot project relating to the production of hydrogen and electricity from natural gas with CO_2 handling

During the past three to four years it has been an acknowledged strategy of the Norwegian authorities to conduct research into the development of technologies for the production of electricity from natural gas that include CO_2 handling. Some of the concepts are already beginning to take form as potential candidates for trials on a larger scale. After a thorough evaluation of the alternatives, a pilot project based on the most promising technology may soon be implemented. Such a pilot project is conditional on choosing a location where the surrounding infrastructure is, or can be made, satisfactory in terms of power, hydrogen, waste heat and CO_2, as well as access to natural gas and qualified personnel. Such a pilot project will, as the committee sees it, lie within the terms of reference of the new state innovation enterprise in Grenland. The funding must be considered in the context of the government's special targeting of natural gas-powered electricity production with CO_2 handling. Such a project could be implemented before 2010.

A Nordic «hydrogen corridor»: Stavanger – Oslo – Malmö – Copenhagen

Norway could take the initiative for a Nordic project to use hydrogen and fuel cell technology in buses, fleet vehicles and ships in a large area, which would allow for both local and inter-city traffic. This would be an expansion of the HyNor project which is already being planned[1]. A hydrogen corridor could run between cities in western Norway via Kristiansand and Oslo through Sweden to Copenhagen. It would require filling stations in the cities along the corridor and the procurement of a certain number of buses and fleet vehicles. It would be natural to begin with the cities, since this would enable servicing of the greatest number of vehicles per filling station, and also enable the servicing of fleet vehicles. Such a project should include thorough preliminary work, including the drawing up of regulations and standards, competence-building in approval bodies, garage person-

1. http://www.hynor.no

nel etc. The project should have a minimum time scale of five years. Such a Nordic project would be in step with the increased focus on hydrogen in the Nordic Council and the Nordic Council of Ministers. It should be possible to start such a project before 2010.

A pilot project to introduce hydrogen/natural gas mixtures that would not require special end user technology

The use of natural gas mixed with different fractions of hydrogen (HCNG) is seen by many as an expedient way of phasing in use of hydrogen. The advantage of such a phase-in is that it requires little change in end user technology or transport and storage technology. The technology could be based on the existing infrastructure for natural gas. An HCNG pilot project could be a first step towards a larger demonstration project for the use of hydrogen, for example in the transport sector. Such a project should be possible to implement before 2010.

Fuel cells in ferries

Smaller demonstration projects employing fuel cells in small passenger boats, yachts and submarines have been carried out in Europe during the last five years. They were based on fuel cell technology developed for land-based use. In Norway, many studies have been done on fuel cell operation of the ferries that form part of the national road network, and draft concepts for demonstration have been developed.

Many ideas are under development. A prototype project for fuel cells in ships could provide valuable experience and have great value in directing the Norwegian maritime industry towards this market. Safety and certification are also important and these alone could represent an international market. In this manner, knowledge could be combined in several areas where Norwegians are at the forefront and in which international niche markets may emerge. Fuel cells in ships can cover a ship's energy needs in different ways. The first applications could be to cover the ship's power needs excluding propulsion. Such a solution could be interesting for international shipping, as many large ports have strict emission requirements. Emissions can be a problem when ships alongside quay have to run their engines to maintain their power supply.

On ferries, this type of fuel cell project could eventually become part of a Nordic hydrogen corridor. It will not be possible to implement such a project until after 2010.

3.2.2 Early user of hydrogen vehicles

Early use of hydrogen vehicles is one of the main ambitions for the investment in hydrogen in Norway. This is described in detail in section 7.1.2 of the NOU 2004: 11. By being early users, Norwegian players can gain experience at an early stage. When fuel cell vehicles become available commercially, the technology should be sufficiently familiar and accepted among the Norwegian public for user knowledge not to constitute a barrier. In addition, early use in Norway could facilitate involvement by Norwegian industrial players in the development of hydrogen technology, thus strengthening their position in a situation of international competition. The long-term potential for the reduction of CO_2 emissions can be realised sooner through the early phasing in of hydrogen technology.

One important activity associated with early use of hydrogen vehicles would be market introduction projects.

3.2.3 Innovation and economic development

The potential for technology-based economic development aimed at international markets was described in detail earlier, for example in section 6.5.2 of the NOU 2004: 11. Active participation as a supplier of expertise, technological components and solutions must be at the top of the agenda for the national hydrogen programme. The hydrogen programme should stimulate cooperation between research environments and industrial players with a view to commercialising Norwegian hydrogen expertise. Here, a framework should be created that allows for close cooperation with Innovation Norway[2] which has top expertise in this area.

3.2.4 Public acceptance, education and information

If hydrogen over time is to become a significant energy carrier in Norway, it will require considerable efforts with regard to information and the development of technical standards and safety regulations. A systematic review of Norwegian

2. Innovation Norway – Merger on 1 January 2004 of the former Norwegian Industrial and Regional Development Fund (SND), Norwegian Export Council, Norwegian Government Consultative Office for Inventors (SVO) and the Norwegian Tourist Board.

regulations should be initiated in order to identify any changes needed. This should be done by a group with expertise about hydrogen as an energy carrier. Relevant administrative authorities such as the Directorate for Civil Defence and Emergency Planning (DSB), the Norwegian Labour Inspection Authority and the State Pollution Control Authority (SFT) are among those that should be represented.

Demonstration projects and individually selected research projects will also be important in terms of getting information across to the general public.

3.2.5 International cooperation

The most likely arenas for international cooperation are briefly described in section 5.5 of the NOU 2004: 11. International cooperation should be a central element in a national hydrogen strategy, and those responsible for the hydrogen programme must be fully aware of its international aspects. The most important arenas for Norwegian participation will be:

- EU's framework programme
- EU's «Technology Platform» for hydrogen and fuel cells
- The International Energy Agency – IEA
- Nordic Energy Research
- International Partnership for a Hydrogen Economy – IPHE
- Carbon Sequestration Leadership Forum – CSLF
- Bilateral collaboration with the USA
- Bilateral collaboration with Japan

The committee recommends that as part of the national hydrogen programme resources are earmarked for facilitating participation in these and other relevant collaborative arenas.

3.3 Organisation and financing of the hydrogen programme

According to its terms of reference, the committee should consider the organising and financing of a national hydrogen programme. The committee has based its work on the assumption that the hydrogen programme will make use of existing institutions and bodies as far as possible. A national hydrogen programme, as described in the committee's terms of reference, must cover a wide spectrum of activities. Hence, it should be organised in such a manner as to promote coordination and cooperation among the responsible authorities in terms of both funding and implementation of activities.

3.3.1 Organisation of a hydrogen programme

The committee believes that a programme board should be appointed, which would be responsible for the strategy and for the operational part of the hydrogen programme. The members of the board should be appointed by the hydrogen programme's stakeholders, i.e. funders and users.

The committee believes it is important that the Research Council of Norway play a central role, as research and development will constitute a major part of the programme. It will also be natural to involve institutions engaged in innovation and more market-oriented activities. The most relevant would be the new state innovation enterprise in Grenland, the Directorate of Public Roads and Innovation Norway.

The new state innovation enterprise should be involved, given that the hydrogen effort has such a clear interface with natural gas power-powered electricity production with CO_2 handling. Among other things, the committee recommends a pilot project that would be a part of the innovation enterprise's expected area of responsibility. This is described in section 8.2.1 of the NOU 2004: 11. The Directorate of Public Roads could also be involved in demonstration activities directed at the transport sector. Innovation Norway will be an interesting participant from an economic development perspective. In this way, Innovation Norway could be a useful tool for the Ministry of Trade and Industry in its hydrogen efforts. Enova, with its commitment to the environmentally friendly use and production of energy, could be a relevant player in a more long-term perspective. Norway's Water Resource and Energy Directorate (NVE) could also play a role in the authorities' efforts in the hydrogen field.

The whole idea behind establishing a common, national hydrogen programme, is that while hydrogen has a broad spectrum of potential uses, many of its applications involve the same challenges. Therefore there may be synergies in that results and progress in one area can be applied to and benefit another area. With an overall and well-coordinated programme, it will be easier to see the interconnectedness of the whole value chain.

The hydrogen effort could have consequences for the Norwegian energy system, the transport sector and climate policies, and could represent major value creation and innovation. It is therefore

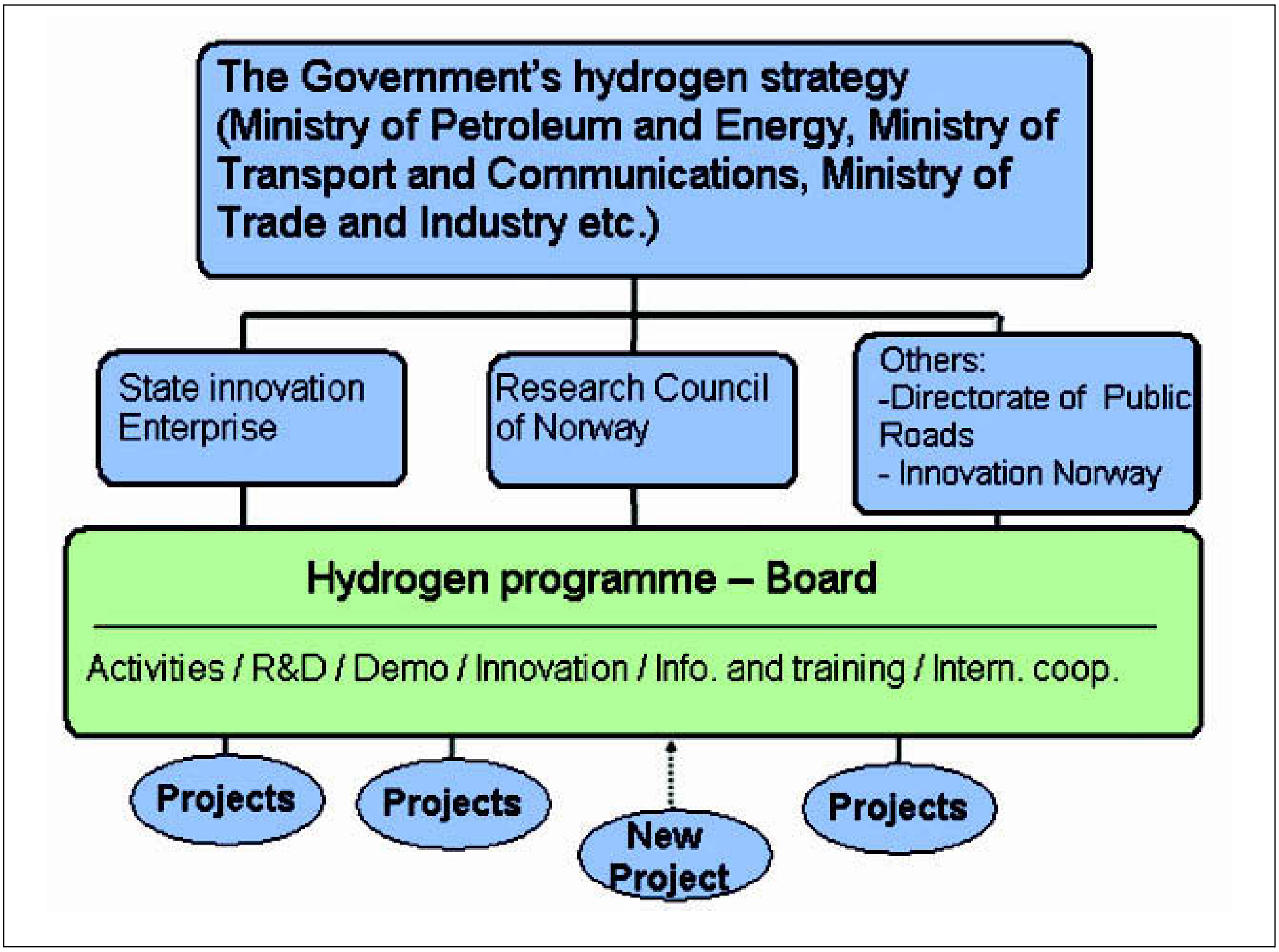

Figure 3.2 Organisation of a national hydrogen programme

natural that overall responsibility for the programme be shared by the Ministry of Petroleum and Energy, the Ministry of Transport and Communications and the Ministry of Trade and Industry.

The committee proposes an organisational model for a hydrogen programme as shown in figure 3.2

The basic idea behind the programme is to put all efforts into a context and to give users one point of contact. The hydrogen programme should be based within one of the existing organisations, so that it can effectively use an established infrastructure and administrative system. As the main emphasis of the programme will be on research, the committee recommends that the programme be based in the Research Council of Norway.

The responsible board, or programme board, should be appointed by the programme's stakeholders, and possibly include representatives of relevant interest groups. The board should be balanced, competent and not exceed 7–10 persons.

3.3.2 Financing of a hydrogen programme

Principles for financing

The public component of funding should be in accordance with the sector funding principle. This means that research in each sector should be funded by the applicable Ministry for that sector. For a national hydrogen programme, this would mean public funding by the Ministry of Petroleum and Energy, the Ministry of Transport and Communications and the Ministry of Trade and Industry. The committee will not comment on the distribution of funding between these ministries, but naturally the weight given to different activities should be reflected in the funding. Up to now, research activities relating to hydrogen have primarily been financed by the Ministry of Petroleum and Energy, regardless of applications. Demonstration projects have been financed by the Ministry of Petroleum and Energy and the Ministry of Transport and Communications.

In addition to public funding, industry must be required to contribute. Such contributions will be project-specific. This means that the individual players participating in the different projects also contribute financially. It is also important that public funding complies with the EEA Agreement's guidelines on state aid.

Currently, most of the hydrogen effort is linked to research and development, supported by the Ministry of Petroleum and Energy through the Research Council of Norway's RENERGI programme[3]. The Ministry of Transport and Communications supports pilot projects in the transport sector, which may or may not include hydrogen. In addition to direct subsidies for research and development, the *Skattefunn* tax deduction scheme is another potential means of supporting hydrogen projects. This scheme is only available to enterprises and it is therefore most relevant for business-related research in the hydrogen field. Under this tax deduction scheme, enterprises can deduct up to 20 per cent from their taxable income for costs relating to accepted research and development projects. For enterprises that are not in a taxable position, an estimated deduction can be given as a direct grant. The measure is controlled by regulation and therefore not limited by public budgetary constraints.

Funding levels

A financing plan should be directed at research and demonstration projects. Research efforts must be built up gradually. The current financing level could be used as a starting point. The level of support for hydrogen research under the Research Council of Norway's clean energy programme (*RENERGI*) is approximately NOK 34 million in 2004. This includes support for hydrogen-related purification technology in gas-fired power plants. If this part is excluded, then the funding totals approximately NOK 20 million. Figure 3.3 shows the distribution of the Research Council's funds for hydrogen-related research in 2004. The committee's proposal for the hydrogen programme means that support for research must be gradually increased to a significantly higher level.

In addition, funding for demonstration projects will be needed. Examples of relevant demonstration projects could include:

Before 2010:

– Establishment of a national research-oriented test laboratory

3. RENERGI – Clean energy system for the future.

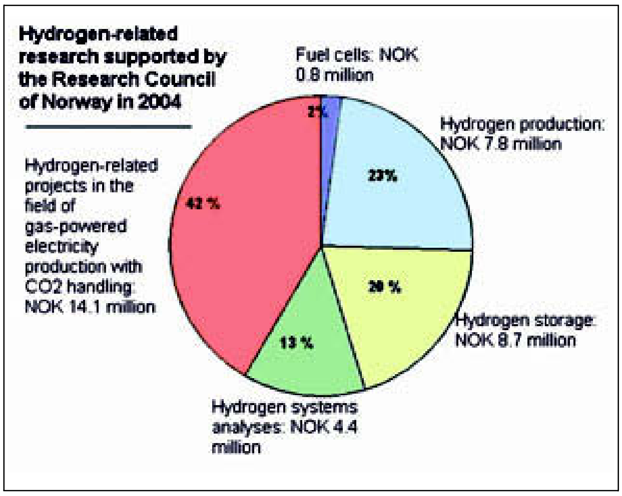

Figure 3.3 Thematic distribution of the Research Council of Norway's Support for hydrogen-related research in 2004 – totalling approx. NOK 34 million

– Pilot project linked to the production of hydrogen and electric power from natural gas with CO_2 handling
– A Nordic hydrogen corridor.
– Establishment of a project to test hydrogen/natural gas mixtures (HCNG)

2010 – 2014:

– Fuel cells in ferries

These projects are discussed in detail in section 3.2.1.2

Support for demonstration, as described in the above, could represent public funding of NOK 120–200 million for the period until 2010, and NOK 50–100 million for the period 2010–2014. This would constitute a total allocation of NOK 170–300 million for demonstration projects for the whole period. The estimates are based on a 50/50 sharing of costs between the public and private sectors.

Support for research and development should be gradually increased from NOK 40 million in 2005 to approximately NOK 100 million annually in 2014. This would mean a total of around NOK 625 million over the 10-year period.

Information and training will entail annual activity of between NOK 3 and 5 million, totalling NOK 30–50 million over the ten-year period.

The combined share of public funding of a national hydrogen programme will thus total approximately NOK 825–975 million over a 10-year period, see table 3.1.

Table 3.1 Level of public funding for the hydrogen programme. All figures are in NOK million.

Period	Research	Demonstration	Information and training	Total
2005 – 2009	250	120 – 200	15 – 25	385 – 475
2010 – 2014	375	50 – 100	15 – 25	440 – 500
Total	625	170 – 300	30 – 50	825 – 975

3.4 Other measures in a hydrogen strategy

If the authorities wish to initiate other measures for the development and use of hydrogen technology in Norway, there are many areas over and above those discussed that should be considered. In addition to straightforward programme activities such as support for research and demonstration projects, it is important to work concurrently on the implementation of other measures as described below. A review of such measures should also form part of a broad-based national hydrogen strategy.

General framework conditions for the use of hydrogen

To stimulate the introduction of hydrogen in Norway, the committee has proposed that tax and duty incentives be introduced for fuel cell vehicles along the same lines as for electric vehicles. Consideration should also be given to granting tax exemptions and other incentives for hydrogen vehicles with combustion engines in an introductory phase. This should be a part of the Government's hydrogen strategy. Other incentives should also be considered. Examples of such incentives are market-based stimulated demand mechanisms in the form of certificate schemes.

Safety and standards.

Standards for the use, storage and transport of hydrogen are partially lacking and must be drawn up and implemented. The authorities can initiate standardisation work, training work and safety studies.

Certification and approval

An important element relating to safety and standards is the initiation of necessary measures to identify what certification and approval schemes the use of hydrogen requires. Implementation of these processes will be an important contribution to a national hydrogen strategy.