解説

Norwegian Hydrogen Highway — HyNor — Strategy and Realization to Utilize Hydrogen as a Carrier for Clean Energy in One of the Worlds Leading Energy Nations —

執筆者プロフィール

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1. Hydrogen as an energy carrier.

Hydrogen is an energy carrier that can be produced from all types of energy sources, including natural gas and renewable energy, both of which Norway has in abundance. Although the use of hydrogen does not create harmful emissions, the overall effect on the environment will depend on how the hydrogen is produced and transported to the consumer. The greatest environmental benefits of the use of hydrogen as an energy carrier are foreseen in the transportation sector.

In media and sometimes in public forum hydrogen is frequently included among the “new and renewable” energy sources. This is a serious misunderstanding, as hydrogen is not an “free” energy source on the earth such as solar, wind, fossil fuels; uranium etc., but a *secondary* energy source that has to be produced using the abovementioned *primary* energy sources. Commercial scale hydrogen production is typically done through electrolysis; using electricity (from a primary source) to split water molecules into hydrogen and oxygen; or through so-called steam reforming⁽¹⁾ of e.g. natural gas where the end products are hydrogen and carbon dioxide (CO₂). In both cases the hydrogen production can be made CO₂ neutral; if electricity is

generated from renewable energy sources; and if CCS (Carbon capture and Storage) is applied to the process.

The interest for hydrogen in the energy and environment community is thus not as an energy source, but as an effective *carrier* of energy between areas of energy abundance and the consumers. Electricity can for example be produced by large scale solar panel farms in, say, the deserts of Africa and Middle-East; converted to hydrogen through electrolysis of sea water; and transported with ships to consumers in Japan. Another example; electricity produced by offshore wind turbines off the north coast of Norway can be combined with natural gas extracted from the vast gas fields in the Barents Sea to produce hydrogen and CO₂ that is re-injected into the depleted gas fields.

The utilization potential for hydrogen is mainly as a substitute fuel in the transport sector; such as road and sea transport. Hydrogen is then be converted to electricity by fuel-cells or directly to mechanical energy in special combustion engines such as Mazda's rotary engine.

There are some interesting projects in Japan⁽²⁾ and other places utilizing hydrogen as fuel for heating and electricity in households, but this seems as a less attractive concept as buildings can be connected to stationary power plants.

The challenge related to the utilisation of hydrogen as energy carrier is primarily related to its low availability and initial high cost. A recent study carried out in Norway, under the name Nor-Ways, reveals that the investment needed to build a complete hydrogen refuelling infrastructure in Norway, totalling 1100 refuelling stations, is € 1.5 billion. This number complies with similar studies done in the US and Europe. This compares to less than € 1000 per vehicle assuming 1,75 million hydrogen passenger cars within 2050. The cost of hydrogen is in the same study found to fall below € 5/kg and thus be commercially competitive in the 2020-2025-timeframe.

2. Norway — the energy nation

Norway is a unique and considerable energy nation. The coun-

try with a population of just over 4.8 million and land area compared to Japan is a giant in the international petroleum world. Since the first discovery of oil in the North Sea off the coast of Norway on Christmas day 1969, Norway has grown to become the world's 3rd largest exporter of natural gas, and 5th largest exporter of crude oil. The petroleum industry now constitutes half of Norway's exports and one quarter of the GDP.

Nature has been generous to Norway not only by petroleum resources, but also in terms of renewable energy sources. The country's special topology with mountain plains and deep fjords combined with generous precipitation has enabled Norway to develop hydro-power to the extent that covers 98% of the electricity demand⁽³⁾. Finally : the excellent wind conditions off the western and northern coasts of Norway may provide the energy country with yet another significant source of clean energy to be exported to the energy craving European markets. This clean energy requires an efficient storage and transport medium — of which hydrogen is a strong candidate.

2.1 Norwegian hydrogen strategy

Norwegian research communities and industrial stakeholders are at the forefront of the development of key technologies that are necessary in order to be able to utilize hydrogen as energy carrier. This work has been closely linked to research and development activities financed by, among others, the Research Council of Norway. Norwegian players are also heavily involved in various hydrogen projects under the EU's Framework Programme for Research, Technological Development and Demonstration Activities. The substantial international activity is a prerequisite for the Norwegian efforts in this field. At the same time, Norway as an energy nation has a special responsibility to take active part in the international efforts to develop hydrogen as an energy carrier, as this will contribute to a more robust transition towards a fully sustainable and non-fossil based energy system.

In 2005 the Ministries of Petroleum and Energy, Transport and Communications launched their strategy which led to the establishment of the Norwegian Hydrogen Platform and the nomination of the Norwegian Hydrogen Council as an advisory body to the Ministries. According to its terms of reference The Hydrogen Council published (December 2006) the first Action Plan 2007-2010 (Footnote 4)⁽⁴⁾, with a set of concrete actions, activities and measures to help solve the challenges and exploit the opportunities that exist in the field of hydrogen.

The Action Plan was met with substantial support across the national stakeholders, and has also received considerable attention abroad. Acknowledging the long term aspects of introducing hydrogen as energy carrier and the challenging global economic situation, the execution of the recommended actions has only partly been successful. Despite this, Norway is still in a leading position internationally, and the national political support is strengthened through the new government's energy Action Plan. The establishment of the governmental body Transnova has been the most important outcome of the current Action Plan. Demon-

stration of the world's first marine supply vessel with fuel cells is another achievement of considerable significance. Totally, the Maritime Fuel Cell project FellowShip has received approximately 50 mill NOK in public support (Footnote 5)⁽⁵⁾.

In the coming period Norwegian engagement in the international efforts is of highest strategic importance, in particular the newly established European public private partnership, the Fuel Cells and Hydrogen Joint Undertaking. This includes participation in R&D and demonstration projects as well as engagement in leading strategic positions for further development of the program. Links to Asian countries and North America will also to be strengthened.

3 HyNor — the Norwegian hydrogen highway

3.1 A key element to demonstrate use of hydrogen in the transport sector is the Norwegian HyNor project.

HyNor is a Norwegian joint industry initiative to implement demonstrations of a hydrogen energy infrastructure along a route of 580 kilometres (360 miles) from Oslo to Stavanger. The project demonstrates the multiple steps required to develop a hydrogen infrastructure and will include demonstrations of various hydrogen production technologies and uses of hydrogen, adapted to local conditions.

HyNor was established as a hydrogen infrastructure project in spring 2003 by a consortium of now about 50 players from industry, transport sector, regional governments and NGOs.

The HyNor project consists of two parts : the hydrogen filling station infrastructure and a fleet of hydrogen fuelled vehicles. As of summer 2010, there are operational filling stations in Stavanger, Porsgrunn, Drammen, and Oslo (see Fig. 1). Three more sites are also planned for the highway : a third near Oslo, another near Oslo, and Lillestrøm, still under discussion, in Bergen to the north, which together would add another 210 km to the network.

The HyNor project is not only a national project to demonstrate the infrastructure, but also a national experiment in large-

Fig. 1 Existing and planned filling stations along the HyNor hydrogen highway

Stavanger : <ul style="list-style-type: none"> Opened August 2006 as an integrated part of a petrol station Hydrogen, Hythane (8% H₂ in Natural Gas) and Natural Gas Start-up with trucked in hydrogen Upgraded to 700 bar technology in 2009
Porsgrunn : <ul style="list-style-type: none"> Opened June in 2007 Next to StatoilHydro research centre at Herøya, Grenland Directly linked to large scale hydrogen by-product, scalable solution Possibility for supply and back-up for other HyNor stations Underground storage, 150kg @ 400 bar, high pressure tanks submerged in liquid Hydrogen delivered at 350 and 700 bar
Oslo and Drammen : <ul style="list-style-type: none"> Both Opened 2009 Filling station concept developed by StatoilHydro — working on commercialization Moveable solution 350 and 700 bar filling, 2-nozzle dispenser Storage : 46 kg @ 900 bar, 34 kg @ 200 bar Room for electrolyser at station
Lillestrøm : <ul style="list-style-type: none"> To be opened 2011 Located 20km north of Oslo Grid-connected PV & PEM-electrolyzer Bio-hydrogen via Sorption Enhanced Steam Methane — Reforming (SE-SMR) Thermal Sorption Metal Hydride Compression
Stavanger II : <ul style="list-style-type: none"> To be opened autumn 2010 Mainly supplying forklifts at the harbour of Risavika, but may also service other vehicles. 	
Oslo : <ul style="list-style-type: none"> Two new stations in 2011 One for cars ; connected to the "H2-moves" project — EU's first lighthouse project for hydrogen infrastructure. One for buses. Oslo's bus company "Ruter" will operate 5 fuel-cell hydrogen-buses for 5 years starting 2011. 	

Table. 1 Hydrogen filling stations

15 Toyota Prius Converted to ICE Hydrogen by Quantum (US) Range : 170 km
4 Mazda RX-8 Delivery in 2009/2010 Flexifuel wankel engine Range : 100 km H ₂ , 50 km gasoline
10 Mercedes B-class Part of the "H2-moves" EU lighthouse project.Delivery 2011 PEMFC Range : 400 km
2 Alfa Romeo Mi-To Delivery 2011 Nuvera Fuel Cell Range : 450 km
More cars + buses Other car manufacturers have expressed interest in testing their H ₂ -cars in HyNor 5 FC hydrogen buses from 2011

Table. 2 Projected vehicle fleet form 2011

scale hydrogen production from various sources. In Oslo hydrogen is produced by electrolysis of water ; in Drammen by conversion of methane gas emitted from organic waste ; in Porsgrunn from industrial chemical industry and in Stavanger — the petroleum hub of Norway — from conversion of natural gas.

3.2 The vehicle fleet in HyNor project

In 2007, HyNor began incorporating hydrogen vehicles to the infrastructure. Beginning with the 15 Quantum H₂ Prius vehicles, they added 4 plug-in hybrid H₂ TH!NK cars.

Mazda signed a memorandum of understanding (MoU) with HyNor to participate in the project in November 2007, and started delivering their RX-8 Hydrogen RE cars from 2006.

4. The future of HyNor

HyNor is entering the second phase this year, and for the next

Fig. 2 Building a scandinavian network of hydrogen stations

5 years there will be main focus on developing the market for hydrogen-based traffic : on diversity of vehicles and hydrogen production and on adapting the infrastructure to the hopefully increasing number of vehicles. The infrastructure will be improved by not only making the hydrogen highway longer, but also “thicker” in the sense of widening the accessibility for hydrogen filling to the motorists. The HyNor team will work hard to make Norway and HyNor an attractive market for manufacturers of cars and buses running on hydrogen, and also maintaining HyNor’s attractiveness for large scale testing of vehicles and hydrogen infrastructure. As part of the H2movesOslo one new refuelling station will be built and opened in 2011, plus that one mobile station will be delivered and used during tours in the Oslo area and for other events.

A new initiative called the H2moves Scandinavia is designed to help both promote hydrogen cars and the building of the hydrogen highway system particularly that which connects Scandinavia to the ambitious H2 Mobility plan in Germany and seeks to have hydrogen refueling stations and commercial hydrogen cars in place by 2015.

Part of this plan involves rolling out two Alfa Romeo MiTo fuel cell vehicles, 10 Mercedes B-Class F-Cell vehicles and five H2 Logic electric cars with fuel cell range extenders.

Finally, HyNor constitutes an important part of an Scandina-

vian Hydrogen Highway Partnership as illustrated in the figure below (Fig. 2).

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● References (文献)

- (1) See for example: <http://www.linde.com/international/web/le/us/likelesfus.nsf/docbyalias/reformers>
- (2) The “Fukuoka Hydrogen Town project”; <http://www.japanfnf.org/en/pages/028694.html>
- (3) This number depends on the rain and snowfall for a given year. In “dry-years” Norway import electricity from other Nordic countries; and exports in “wet years”. The deregulated Nordic power market allows for flexible and very efficient utilisation of energy resources across the Nordic countries.
- (4) Footnote 4, <http://www.hydrogenguide.no/hydrogenguide/documents/introduction/plan>
- (5) Footnote 5, http://www.dnv.com/news_events/news/2009/fellowship.asp