Working the Futures:
Preliminary Results from the Nordic H_2 Energy Foresight

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Abstract
The five Northern European countries have a long tradition of co-operation within research, education, innovation, and energy supply. A technology foresight exercise was launched in 2003 by 16 partner organisations, including R&D institutes, energy companies, and industry, in order to build synergy and critical masses within selected areas of strategic importance to the hydrogen economy, and to position Nordic actions and alliances in a broader international context. The paper describes the background, design, and preliminary results.
Keywords: Foresight, roadmaps, policy and action plans, hydrogen economy

1. Introduction

Hydrogen used as an energy carrier is generally accepted as a promising future replacement of fossil fuels, able to address the issues of environmental degradation and energy supply. The "Forever Fuel" or "Eco-fuel" and the notion of the hydrogen economy have become a hot topic for decision-makers in government and industry all over the World [1, 2, 3]. Visions, proactive actions and investments are paving various pathways to the hydrogen future, from economic world powers such as the USA and Japan to small nation states such as Iceland and Singapore [4, 5, 2]. International collaborative efforts are likewise undertaken in the context of the International Energy Agency and elsewhere [6, 7].

The development of a hydrogen economy, with H_2 produced from renewable energy sources, is a long-term objective of the European research and development agenda and substantial funds have been allocated over the years to pave the way. However, the European investment is much less than the proposed US government investment of 1.7 billion USD over the next five years to develop H_2 fuel cells, infrastructure and advanced automobile technologies. And likewise much less than the Japanese government investment, which for one year – 2002 – was approximately 240 million USD [8]. So, if Europe wants to compete and become a leading world player, it must intensify its efforts.

Generally, 80% of public research in Europe is conducted at national level [9]. This emphasises a need for alignment with national or regional R&D programmes, concerted action by European governments, science communities and industry, and a strategic research agenda. The five Northern European countries (Denmark, Finland, Iceland, Norway, and Sweden) have a long tradition of co-operation within research, education, and innovation as well as within energy supply. This is a solid foundation for concerted action towards sustainable developments, but does not suffice in building strategic intelligence, synergy and critical masses into Nordic R&D-activities to realise the potentials of H_2 energy. The Nordic H_2 Energy Foresight aims at aligning research and development efforts at regional level – between the Nordic countries themselves and between the Nordic countries and the European Research Area. It is, thus, a middle-up contribution of smaller EU states to overcome the fragmentation and duplication of research efforts and to help create the European Research Area [10].

2. The Nordic Knowledge Region

Nordic co-operation rests on a long and shared history, which for has for centuries influenced the political, economic and cultural ties among the Nordic countries. These ties foster shared values — values that are inherent in the Nordic welfare states, with their stable and well-functioning democratic institutions, highly developed economic sectors, and safe communities. Following the foundation of the Nordic Council (1952) and the Nordic Council of Ministers (1971), collaboration has developed in a wide range of areas.

2.1 The Nordic Region in Europe – recent developments

Since 2001, the Nordic countries have been seeking to strengthen co-operation between the Nordic EU members and the two Nordic associated countries, Iceland and Norway, in consultation and knowledge sharing in order to signal a more proactive joint EU-line. The aim is to maintain and develop Nordic influence on European co-operation at a time of EU expansion from 15 to 25 member states [11, 12].

The Nordic countries have large R&D resources. The Nordic countries invest on average over 2.6% of GDP on R&D. Finland and Sweden already today exceed the EU target of 3% by 2010, and all score high on the most important indicators for research and innovation [13]. In the area of H_2 and fuel cells research, the Nordic countries allocate substantial resources at national level (more than 72 mill. EUR to 96 projects in 1998-2002) and are also well represented in EU research projects [14].

Table 1: Population, GDP, and R&D Expenditure in the Nordic Countries [15, 16]

	Inhabitants, 1000 2000	GDP / inhabitants EUR, 2002	Total R&D Exp. % of GDP, 1999	Gov.fin. R&D % of GDP, 1999	Indu.fin. R&D % of GDP, 1999
Denmark	5,432	27,190	2.06	0.67	1.19
Finland	5,171	24,410	3.22	0.94	2.16
Iceland	283	27,284	2.32	0.96	1.01
Norway	4,478	33,410	1.70	0.72	0.84
Sweden	8,883	24,330	3.80	0.93	2.58
Total	24,247	27,325	2.62	0.844	1.698

The Nordic energy systems are quite dissimilar [17]. Finland and Sweden have diverse primary energy sources, including hydropower, nuclear power, oil, natural gas, coal, biomass and peat. In Denmark, most of the energy is produced from natural gas, coal and oil. Renewable energy sources are outspoken in Norway and Iceland due to a high share of hydropower. In the Nordic area, the share of renewable energy sources in electricity production is more than 55% due to hydropower and an increasing share of wind power, especially in Denmark. Furthermore, Denmark and especially Norway are producers and exporters of oil and natural gas. In 2002, Norway produced about 160 million tons of oil and 74 billion m^3 of natural gas. For Denmark, the corresponding figures were 18 million tons and 8 billion m^3. These accounted for 4.9% and 2.9% share of the World's total oil and gas production [18].

3. Objectives and design of the Nordic H_2 Energy Foresight

The Nordic H_2 Energy Foresight exercise was launched in January 2003 by 16 project partners from academia, industry, energy companies, and associations from all five Nordic countries. The Nordic H_2 Energy Foresight has the following objectives:

1) To develop socio-technical visions for a future hydrogen society and explore roadmaps to commercialisation of H_2 production, transport, storage and utilisation;
2) To contribute as decision support for companies, research institutes and public authorities in order to prioritise R&D and to develop effective framework policies;
3) To develop and strengthen scientific and industrial networks.

The foresight process is managed and facilitated by a team of specialists in energy systems and technology foresight from Denmark (Risø National Laboratory), Sweden (FOI Swedish Defence Agency), and Finland (Technical Research Centre of Finland*).* This team has the role as a learning agent that facilitates a creative tension among the foresight participants necessary to build strategic intelligence, take decisions, and mobilise joint action [19, 20].

The Nordic H_2 Energy Foresight puts equal weight on the process itself and the resulting knowledge. The networking and commitment are considered equally important as the end-products [21]. A sequence of four workshops, bringing together project partners and experts from industry, energy companies, research, and governmental authorities form the core of the project. Expert judgements and discussions in these workshops are furthermore assisted and challenged by formal analyses in an iterative process. An important part of the project is to bring the discussions and knowledge on H_2 energy closer to the public. Therefore, a web-site – *www.h2foresight.info* - informs on ongoing H_2 related activities and publishes results generated during the foresight process. Preliminary results are presented and discussed at international conferences, and the Nordic vision and strategy for the hydrogen economy is to be presented to decision-makers from industry, science and governments in the Nordic countries. Evaluation is done simultaneously during the process to adapt and improve the foresight exercise.

4. Main steps of the process

4.1 Developing scenarios and visions

A key activity in the foresight project is the work with *socio-technical visions of Nordic H_2*

energy introduction, *external scenarios* (aka. *context scenarios*) and related *scenario sketches for Nordic H_2 energy introduction* [22]. The methodological approach selected by the core partners is an adaptation of the so-called Shell/GBN approach [23, 24, 25] proceeding through workshops and back office work. In the procedure, a set of 3*3 external scenarios was designed to specifically capture the strong intertemporal interdependencies in the energy sector. On the basis of an interactive Scenario Workshop, a matrix of three *first-period scenarios* set against three *second-period scenarios* was constructed. The first-period scenarios set the socio-economic stage for the second-period scenarios focusing on major energy-related challenges. The three first-period external scenarios can be described as:

- **B – Big Business is Back** is a globalised economy dominated by US multinationals and US big business oriented policy approaches. Major physical investments are not particularly helped by the prevailing quarter-to-quarter capitalism. There is very little interest for global environmental issues. Oil prices are moderate. However, H_2 energy is still believed to be a likely component in future energy systems.
- **E – Energy Entrepreneurs and Smart Policies** is a globalised economy dominated by entrepreneurs and venture capitalists, and with policy actors apt at harnessing the power of innovation for societal purposes. The energy sector is characterised by a tendency towards decentralisation. There is some interest for global environmental issues. Oil prices are moderate.
- **P – Primacy of Politics** is a Europe-centric economy characterised by co-operation between governments and big business and with a great interest in large-scale investment in energy and transport systems. There is some interest for global environmental issues. Oil prices are high due to security-of-supply problems and an important driver for energy sector change.

We get the following picture by combining this with second-period developments and assessment results:

Developments 2015-30 / External sce-narios 2003-15	1. Hydrocarbon security-of-supply problems	2. Undisputable CO_2 problems	3. A smooth path to the future
B – Big Business Is Back			B3 Big vision 6%
E – Energy Entrepreneurs and Smart Policies	E1 Big vision 15%		
P – Primacy of Politics		P2 Big vision 18%	

The colour indicates the ease of Nordic H_2 introduction:
green – easy
yellow – intermediate
red – difficult

Figure 1: The 3*3 External Scenarios Constructed

Scenarios B3, E1 and P2 formed the framework for the subsequent Vision Workshop. There potential Nordic market shares of hydrogen 2030 were estimated for these three scenarios.

4.2. Developing roadmaps

The aim of the Nordic H_2 Energy Foresight exercise is to define ambitious but realistic visions and development paths for the introduction of H_2 in the Nordic countries. The challenge is to create roadmaps that link *hydrogen technology visions* and the developments needed on science and education level, technology level, business/industry level, energy market level and government level. In an interactive Roadmap Workshop, three separate roadmaps (hydrogen production and transmission, transport, and hydrogen in stationary use) were constructed on the basis of the sequence of top rank technology-visions.

Table 2: Ranking of Technology Visions

Production	**Transport**	**Stationary use**
Top rank of 23 technical visions	Top rank of 17 technical visions	Top rank of 26 technical visions
* H_2 produced from steam reforming of natural gas * Energy production from renewable energy sources * H_2 produced from wind power * Gasification of biomass	* H_2 driven FC/ electric city buses * H_2 FC/electric drives in new cars * H_2 FC/electric drives for small specialty vehicles * Pressurised tanks for H_2 * H_2 storage as methane or methanol * Methane driven FC/electric engines for ships	* Natural gas driven fuel cells for domestic heat & power * H_2 and FC in decentralized CHP plants * Power sources for mobile communication * Market opportunities for portable electronics

Hydrogen and fuel cell systems in consumer electronics have a strong Nordic interest, as large telecom companies such as Nokia and Ericsson are located here. Nevertheless, it was decided to exclude this area from the roadmapping exercise.

4.3 Model calculations

Nordic H_2 energy scenarios and the roadmaps developed above were further analysed with a linear programming method. The model is a representation of the flows of energy (energy carriers) and technological alternatives in the H_2 energy system (see Figure 2). With the model, the analysis of least-cost strategies for achieving H_2 energy and policy targets can be carried out, including mitigation of emissions.

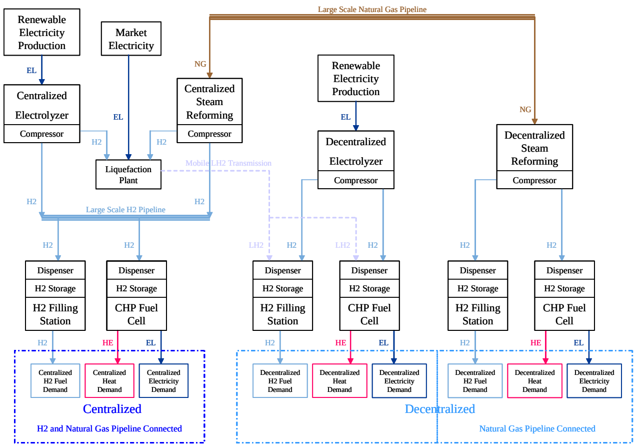

Figure 2: Representation of the Nordic H_2 Energy Model

4.4 Examining the needs for action

The following step of the Nordic H_2 Energy Foresight is an interactive Action Workshop that will discuss the actions needed to overcome the barriers and to realise the visions and roadmaps. The key questions of the workshop are:

- What are the actions needed if the Nordic countries are to introduce hydrogen as a significant energy source by 2030?
- How should hydrogen energy be introduced to the Nordic energy market in order to gain the best benefits?
- How can the Nordic countries utilise the market and business opportunities provided by the introduction of hydrogen energy?

The workshop is intended to provide well-grounded suggestions and ingredients for a Nordic action plan. Attention is paid to the development of science and technology, R&D programmes, markets and business opportunities, as well as supportive financing, regulations, standardisation, taxation and other policy measures. The Nordic viewpoints are also reflected against the national and EU-level developments.

5. Preliminary results, conclusions and reflections

We will conclude this paper with some preliminary results of the project.

From scenarios & visions: An ambitious Nordic policy strategy to champion wide H_2 energy introduction was developed. It consists of four mutually supporting parts, viz. niche markets and entrepreneurship; RTD centres of excellence; demonstrations, pilots and large-scale socio-technical experimentation; and technology foresight and other co-ordination activities. The testing of this strategy across scenarios indicates that it should be possible to devise reasonably robust Nordic policy strategies to help H_2 energy realise its potential relative to other energy technologies. On the other hand, the broad policy strategies outlined apply to a broader set of emerging energy technologies than H_2. It seems advisable that policies are not too H_2 specific and oriented towards picking winners before the contest has begun.

From roadmaps: A preliminary conclusion from the roadmap workshop is that reforming of natural gas in 2030 will produce 50% to 70% of H_2 and the rest will be produced from renewable energy and nuclear power.

The key issues in the resulting 'production and transmission roadmap' are depicted in Figure 3.

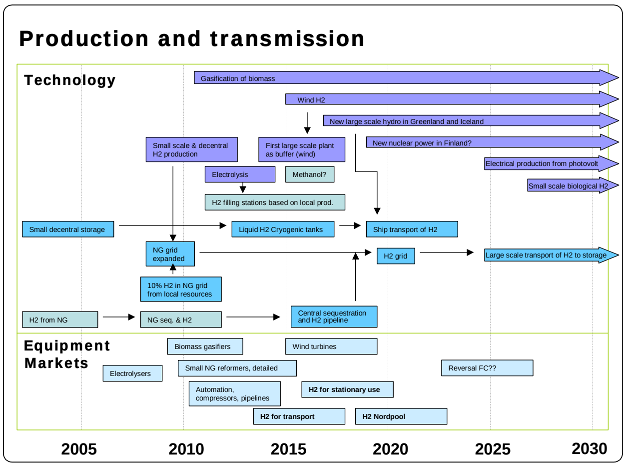

Figure 3: Draft Production and Transmission Roadmap

The considerations for hydrogen used in transport, in turn, suggest that it is quite clear that Nordic industry will play a minor global role in the design and manufacturing of H_2 FC driven cars, busses, trains, etc. But the project has pointed at two opportunities for Nordic industry and research: 1) Marine use of H_2 and fuel cells, and 2) Infrastructure equipment for H_2 in the transport sector.

The preliminary roadmap for stationary use of hydrogen suggests: Now and shortly after 2005, niche markets for fuel cells in power back up systems are established. Between 2005 and 2010, the natural gas driven fuel cells are introduced on niche markets. Around 2010, the first semi-commercial demonstrations of H_2 / fuel cell systems are introduced in summer cottages and private homes. This will also be niche markets and early commercial market penetration. Around 2015, decentralised H_2 and fuel cell driven CHP plants are introduced to the market/energy system on a larger scale.

From model calculations: The total energy demand in the Nordic region is estimated to grow approximately 7% from 2002 until 2030 in the Nordic region [26, 27]. The highest increases are assumed in consumption of electricity (18%) and transportation fuels (12%). The projected evolution of hydrogen energy markets is calculated for different Nordic hydrogen energy scenarios described below.

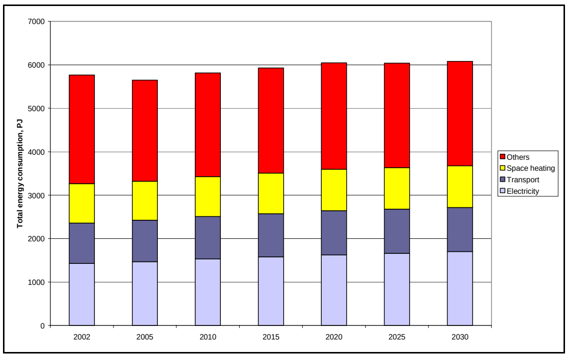

Figure 5: Estimated Energy Consumption in the Nordic Area until 2030

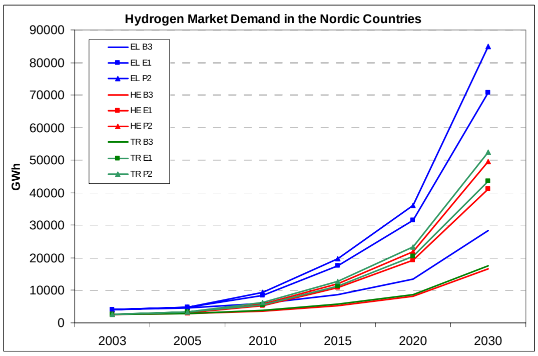

Figure 6: Projected Hydrogen Energy Demands in Different Scenarios

The total costs including investment and operating costs for H_2 production plants and storage, costs for H_2 infrastructure as well as costs for fuel cells for heat and power production appear in Figure 6. Assumed investment costs are presented in Table 3. Thermal efficiencies, availability and lifetimes are also taken into account, as in normal cash flow analysis. The data is collected from the industrial partners of the project and literature sources [28] and will due to the uncertainty of such future estimations constantly be updated, refined and validated throughout the project. A base scenario for natural gas prices is estimated based on IEA price forecasts, implying different gas prices in the three scenarios.

Table 3: Investment Costs used in the Scenario Calculations, €/kWh

Size	CHP fuel cell[1)]		Steam reformer		Electrolyzers		H_2 pipel.	Mobile[2)] transp.	Fuelling station
	0,7 MW	1,9 MW	150 MW	460 MW	1 MW	5 MW	all	All	all
2003	12000	10000	600	140	2700	1170	700	1000	700

2015	5000	2500	560	140	1800	700	500	900	650
2030	1000	800	550	140	1100	470	440	850	650

1) Total thermal energy; 2) Includes liquefaction plant

The total costs for H_2 production, storage, transportation, and H_2 energy conversion are highest in the E1 and P2 scenarios because of the high share of H_2 demand.

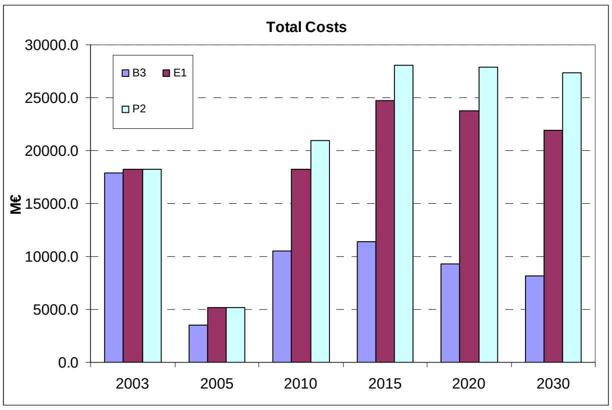

Figure 6: Total Costs

To conclude, we do not know the future, but the foresight project partners have embarked on a process, which is intended to help create the future, to strengthen the shared knowledge creation and strategic intelligence, and to find the best options and pathways for Nordic stakeholders to the hydrogen economy. With the words of the "Mr. Hydrogen" of the Nordic countries, Dr. Bragi Arnason, University of Iceland, "Many people ask me how soon this will happen. I tell them, 'we are living at the beginning of the transition. You will see the end of it. And your children, they will live with this World'" (quoted by Dunn [2]).

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