HyTrEc

Hydrogen Transport Economy
for the North Sea Region

The Interreg IVB
North Sea Region
Programme

A Joint Hydrogen Strategy Framework for the North Sea Region

Recommendations by the HyTrEc project partnership to support the deployment of hydrogen-fuelled transport

EUROPEAN REGIONAL
DEVELOPMENT FUND

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1 Hydrogen in the North Sea Region

1.1 Introduction

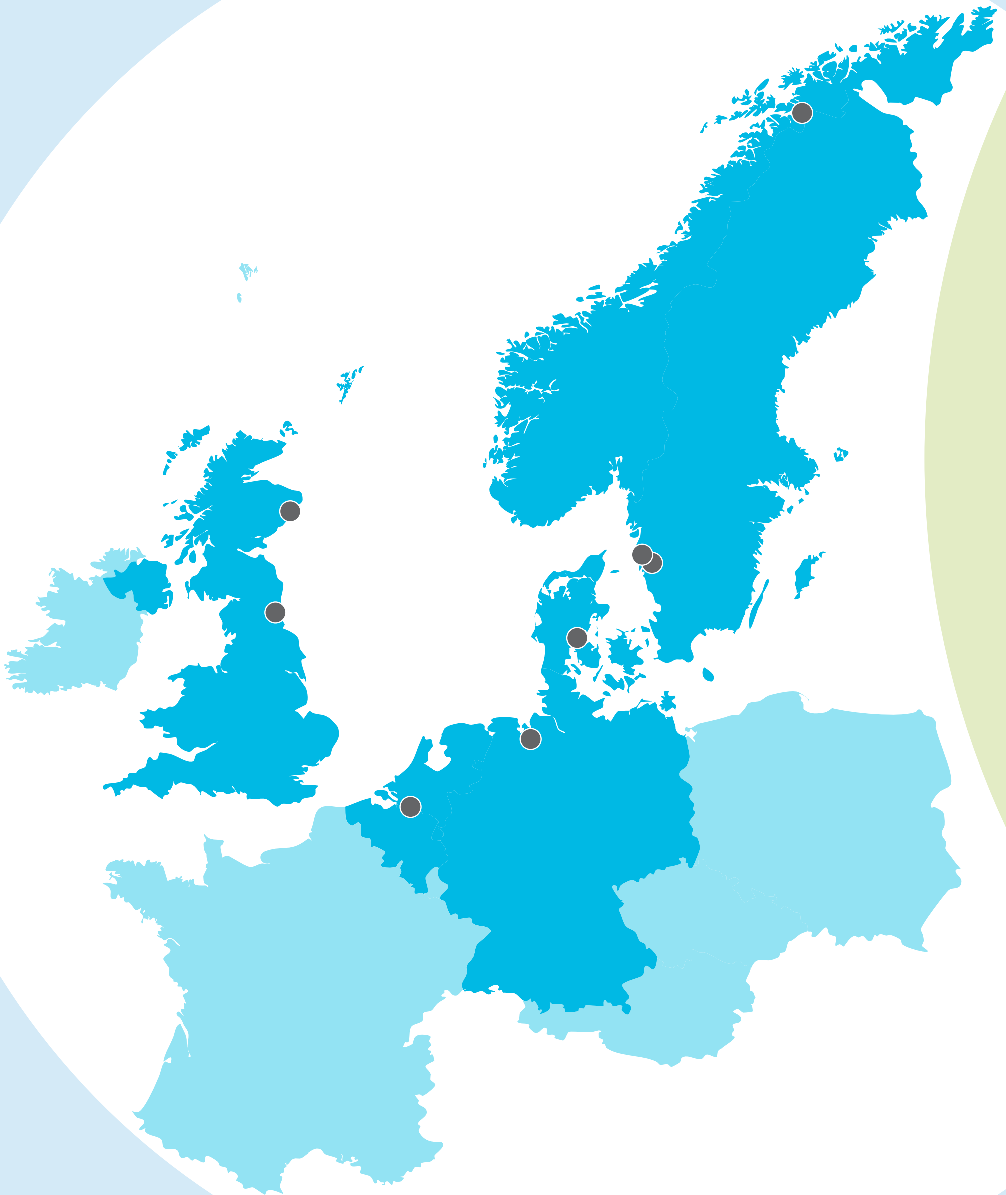
The outputs of the HyTrEc project will improve access to and advance the adoption of hydrogen as an alternative energy vector across the North Sea Region.

HyTrEc focuses on:
- Facilitating transnational co-operation and learning
- Enhancing the competitiveness of the North Sea Region
- Providing a platform for joined-up working towards a strategy for supporting the deployment of hydrogen-fuelled transport across the North Sea Region.

Seven European countries have come together to share their variety of experiences in the hydrogen sector and input to the development of this set of strategic recommendations, which will contribute to strengthening and stimulating the hydrogen industry in the North Sea Region. The main activities carried out by the partnership include a Skills Development Programme, Policy Development and Demonstration and Evaluating and Building-In Sustainability.

HyTrEc project partners represent the following regions:

Partner	Region	Member State
Aberdeen City Council,	Northeast Scotland	United Kingdom
Gateshead College	Northeast England	United Kingdom
WaterstofNet	Flanders South-Netherlands	Belgium Netherlands
European Institute for Innovation	Bremen/Lower Saxony	Germany
Green Network	Vejle	Denmark
Hydrogen Sweden SP Technical Research Institute	South-West Sweden	Sweden
Nrvik University College	Narvik	Norway



1.2 Why Hydrogen?

1.2.1 Drivers for the implementation of a hydrogen transport economy
The implementation of hydrogen as an energy carrier for a more sustainable energy system is based on the following key drivers:

- Zero or low emission transport technology - hydrogen fuelled vehicles contribute to air quality targets
- Energy storage - hydrogen will help maximize the share of renewable electricity in the energy system, addressing the problem of intermittent energy production from wind and solar through conversion of excess renewable electricity to hydrogen, for use as a transport fuel - known as 'power to gas'

1.2.2 European Policy Drivers

1.2.2.1 European energy targets for 2020 and 2030
Energy policy objectives in Europe for 2020 are known as the "20-20-20" targets:
- 20% reduction in EU greenhouse gas emissions from 1990 levels;
- Raising the share of EU energy consumption produced from renewable resources to 20%;
- 20% improvement in the EU's energy efficiency.

The 20-20-20 targets represent an integrated approach to climate and energy policy that aims to combat climate change, increase the EU's energy security and strengthen its competitivness.

In October 2014, national governments came together to agree a new EU energy and climate change package which will now include the following three targets for 2030:
- reduce the EU's greenhouse gas emissions by 40% by 2030 from 1990 levels;
- increase the share of renewables in energy consumption by 27%;
- increase energy efficiency by at least 27%;

1.2.2.2 Low-carbon transport within the European energy targets
Low carbon technologies in transport applications will play a crucial role in helping to achieve the overall energy targets. 94% of transport in Europe is oil-based, 84 % of it being imported, at a cost of up to EUR 1 billion per day, with increasing costs to the environment.

The decarbonisation of the transport sector offers a range of benefits, which are in themselves strong drivers for deploying low carbon transport technologies, including:

- **Energy security:**
  - Through reduced demand for fossil fuels, reliance on foreign oil imports is reduced; thereby reducing the geo-political risks associated with often unpredictable parts of the world;

- **Long-term affordability:**
  - By reducing oil imports to fuel the transport sector, significant improvements to the balance of payments can be achieved. This is particularly relevant for alternative fuels produced locally, e.g. renewable electricity, hydrogen and certain biofuels;

- **Expansion of renewables capacity:**
  - Widespread deployment of alternative fuelled vehicles that use electricity as their main feedstock (e.g. electric vehicles, hydrogen fuel cell vehicles), rather than fossil fuels, creates significant additional demand on the electricity grid, which can be used to reduce peaks in grid energy, thereby enabling the deployment of additional renewables - a key policy goal for Europe and the North Sea Region's member states;

- **Energy storage:**
  - With increasing development of intermittent renewable electricity generators to the grid (e.g. wind), unpredictable production patterns can lead to grid balancing issues in supplying electricity at times of low demand, or an inability to supply sufficient electricity at times of high demand. This can restrict the potential share of renewable electricity in the energy mix, and mean that fossil fuels are relied upon to give a reliable base level of power supply. Low carbon transport technologies such as batteries and hydrogen are able to contribute towards grid balancing through offering options for energy storage at times of low demand, and re-generation at times of high demand;

- **Air Quality:**
  - Significant local and national air quality benefits can be derived from the deployment of low and zero carbon vehicles offering zero exhaust emissions, reducing harmful pollutants such as nitrogen oxides (NOx) and particulate matter (PM10).

Hydrogen fuelled vehicles have a key role to play in decarbonising the transport sector since fuel cell electric vehicles can combine high performance (long range) and environmental benefits (low emissions).

1.2.2.3 Public-private EU Programme: Fuel Cells and Hydrogen Joint Undertaking

In order to support the development and deployment of fuel cell and hydrogen technologies the Fuel Cells and Hydrogen Joint Undertaking (FCH-JU) was established in 2008. The FCH JU is a public-private partnership between the European Commission, European industry and research organisations. The FCH JU is the result of long-standing cooperation between representatives of industry, the scientific community, public authorities, technology users and the public in the context of the European Hydrogen and Fuel Cell Technology Platform.

In May 2014 the EU formally agreed to continue the Fuel Cells and Hydrogen Joint Undertaking under the EU's new funding programme for research and innovation, Horizon 2020. This second FCH-JU will continue to contribute to the objectives of the Joint Undertaking through the development of a strong, sustainable and globally competitive fuel cells and hydrogen sector in the European Union with an overall budget of more than EUR 1.3 billion, to be invested between 2014 - 2020, with half coming from the European Commission, complemented by at least an equivalent level of investment by industrial and research partners.

The FCH 2 JU programme of research and innovation is structured around two research and innovation pillars dedicated to 'Transportation' and 'Energy Systems'. Complementing these two pillars are overarching projects integrating both transport and energy technologies and a cluster of cross-cutting research activities.

The transportation pillar encompasses all aspects of hydrogen utilisation in transportation including fuel cell electric vehicles (FCEVs) as well as non-road, train, maritime and aviation applications, as well as the hydrogen refuelling infrastructure required to support these vehicles.

The energy pillar will support projects such as hydrogen production for energy storage and grid balancing from renewable electricity. This could include large-scale 'green' hydrogen production, storage and re-electrification systems. The initial focus will be on the role hydrogen can play in supporting the integration of renewable energy into the electricity grid.

Besides these topics the FCH 2 JU will specifically focus on realising large demonstration projects, facilitating a large scale implementation of low-carbon technology in the form of hydrogen fuelled transport applications.

1.2.2.4 EU Clean Power for Transport Directive

The EU's directive 2014/94/EU on the deployment of alternative fuels infrastructure aims to facilitate the development of a single market for alternative fuels for transport for Europe, focussing on electricity, compressed natural gas (CNG), liquid natural gas (LNG) and hydrogen.

The directive:
- requires member states to develop national policy frameworks for the market development of alternative fuels and their infrastructure
- foresees the use or common technical specifications for recharging and refuelling stations
- paves the way for setting up appropriate consumer information on alternative fuels, including a clear price comparison methodology.

Hydrogen infrastructure throughout those member states that choose to develop it is required by 2025.

The member states have two years to submit their national policy frameworks. The Commission will then assess and report on those national policy frameworks in order to ensure coherence at European Union level.

1.2.2.5 EU and national hydrogen-fuelled transport programmes

The Trans European Network for Transport (TEN-T) programme is supporting the development of a European network of hydrogen infrastructure for long distance travel by hydrogen fuel cell car. In addition, most North Sea Region Member States have developed national programmes for the development of hydrogen refuelling infrastructure and deployment of hydrogen vehicles. These are known as H_2 Mobility Programmes.

1.3 Status of hydrogen in the North Sea Region

To establish the status of hydrogen in the North Sea Region the HyTrEc partnership developed:

- A diagram summarising hydrogen activities within the partners' areas using a map of the North Sea Region (Figure 1 and Figure 2)
- A SWOT analysis of a hydrogen transport economy in the North Sea Region, summarising the strengths, weaknesses, opportunities and threats within the area (Figure 3).

These exercises were influenced by the experience that the project partners have in the hydrogen sector or from the introduction of other alternative fuels, renewable energy and low carbon sectors. Other activities undertaken throughout the project period are also taken into account, such as demonstration activities carried out by some partners, as well as the development of the HyTrEc education programmes and a journey by hydrogen car around the North Sea Region. Further information on these can be found on the project website at www.hytrec.eu.

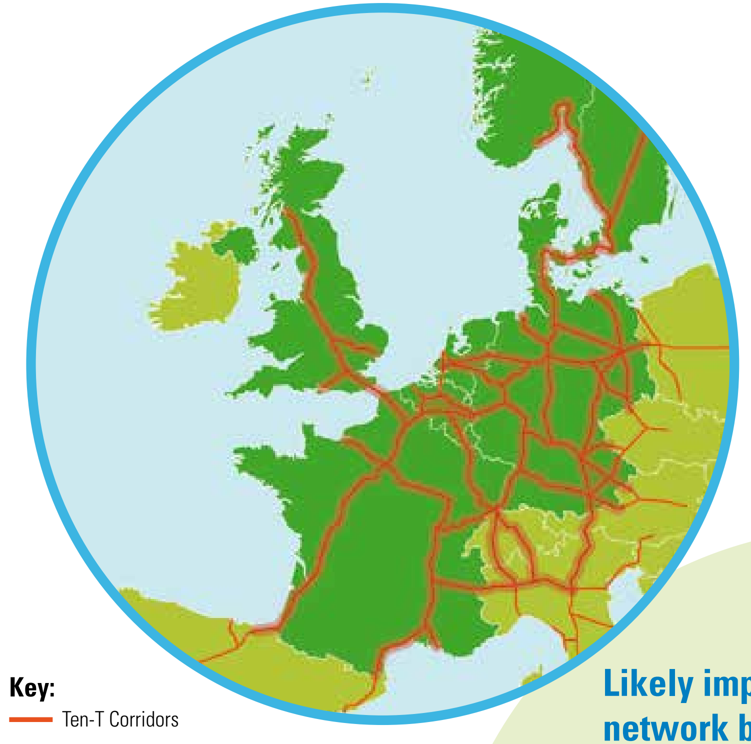
1.3.1 Hydrogen activities of the HyTrEc partners in the North Sea Region

Figure 1 shows that in the North Sea Region hydrogen fuelled transport is demonstrated in terms of:

- Hydrogen refuelling infrastructure (green hydrogen production on-site from electrolysis and also utilising by-product hydrogen)
- Fuel cell electric vehicles (provided directly by OEMs and storing hydrogen on board at 700 bar pressure)
- Electric vehicles with retrofitted fuel cell range extenders, storing hydrogen at 350 bar pressure
- Internal combustion engines converted to burn hydrogen in addition to conventional fuel like petrol or diesel for applications including vans and forklifts, both on 350 bar hydrogen
- Material handling devices running on hydrogen stored at 350 bar pressure.

Figure 1: Hydrogen activities of the HyTrEc partners in the North Sea Region

Figure 2: North Sea Region Member States and National Hydrogen Policies and Programmes



Key:
- Ten-T Corridors
- Ten-T Corridors linked by early HRS
- Nations with H_2 Mobility initiatives
- Nations without H_2 Mobility initiatives

Likely implementation of the network by 2020 (>80 kg/day stations)

Scandinavia
The Scandinavian network will have deployed
35 - 40 Hydrogen Refuelling Stations (HRS) by 2020

UK
The UK will have deployed
60 - 70 HRS by 2020

Germany
The German network will have deployed over
100 HRS by 2020

France
The French network will have deployed
up to 50 HRS by 2020

Hydrogen Vehicle and Refuelling Infrastructure Programmes (2014)

Scandinavia
An initial well distributed network provides coverage across the region for Fuel Cell Electric Vehicles (FCEVs).

UK
A consortium of industry leaders and Government developed a strategy for a network of 65 hydrogen refuelling stations (HRS)

Germany
6H2 Mobility project partners have signed a"termsheet"committing to a nationwide deployment of stations to be ready for OEM mass market sales from 2015

France
A large private consortium has agreed a strategy based on early deployment of captive fleets and associated infrastructure.This will migrate to a nationwide infrastructure for FCEVs

Belgium
Developing H_2 Mobility programme together with industry and government for 2015-2025

Netherlands
Developing H_2 Mobility programme together with industry and government for 2015-2025

1.3.2 SWOT analysis for hydrogen in the North Sea Region

Figure 3: SWOT Analysis for hydrogen in the North Sea Region

The following figure shows the SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis of a hydrogen transport economy in the North Sea Region, undertaken by the HyTrEc partnership.

In summary, the HyTrEc partnership believes the North Sea Region can play a key role in the following main areas:

a) Technology supplier
b) Early market for hydrogen vehicles
c) Exporter of 'green' hydrogen
d) Exporter of skills and hydrogen training expertise
e) Lead for the rest of Europe

1.3.3 Themes of a strategy framework for hydrogen in the North Sea Region

In order to develop a strategy framework for improving access to and advancing the adoption of hydrogen as an alternative energy vector across the North Sea Region, the HyTrEc partnership identified key barriers or challenges to be overcome.

These key challenges and barriers are grouped under the following four themes:

- Infrastructure and applications
- Finance and economics
- Policy and regulation
- Communication and education

These themes then form the basis for this strategy for hydrogen in the North Sea Region.

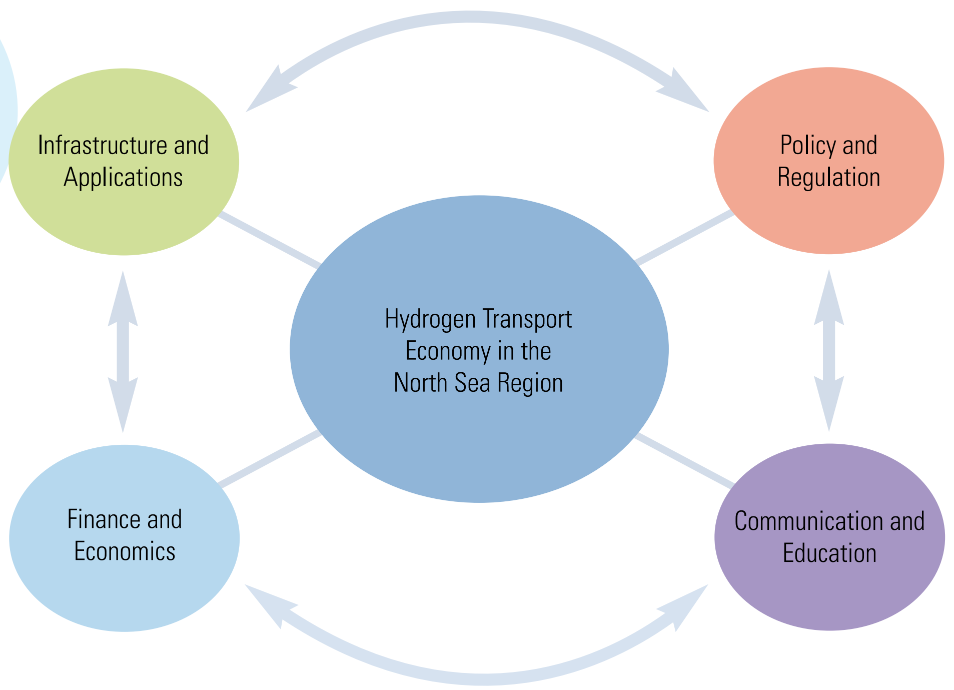


Figure 4: Themes of a joint strategy on hydrogen fuelled transport in the North Sea Region

1.3.4 Challenges to further take-up of hydrogen technologies

The key barriers or challenges identified are listed below, grouped under the relevant theme and explained further on the following page.

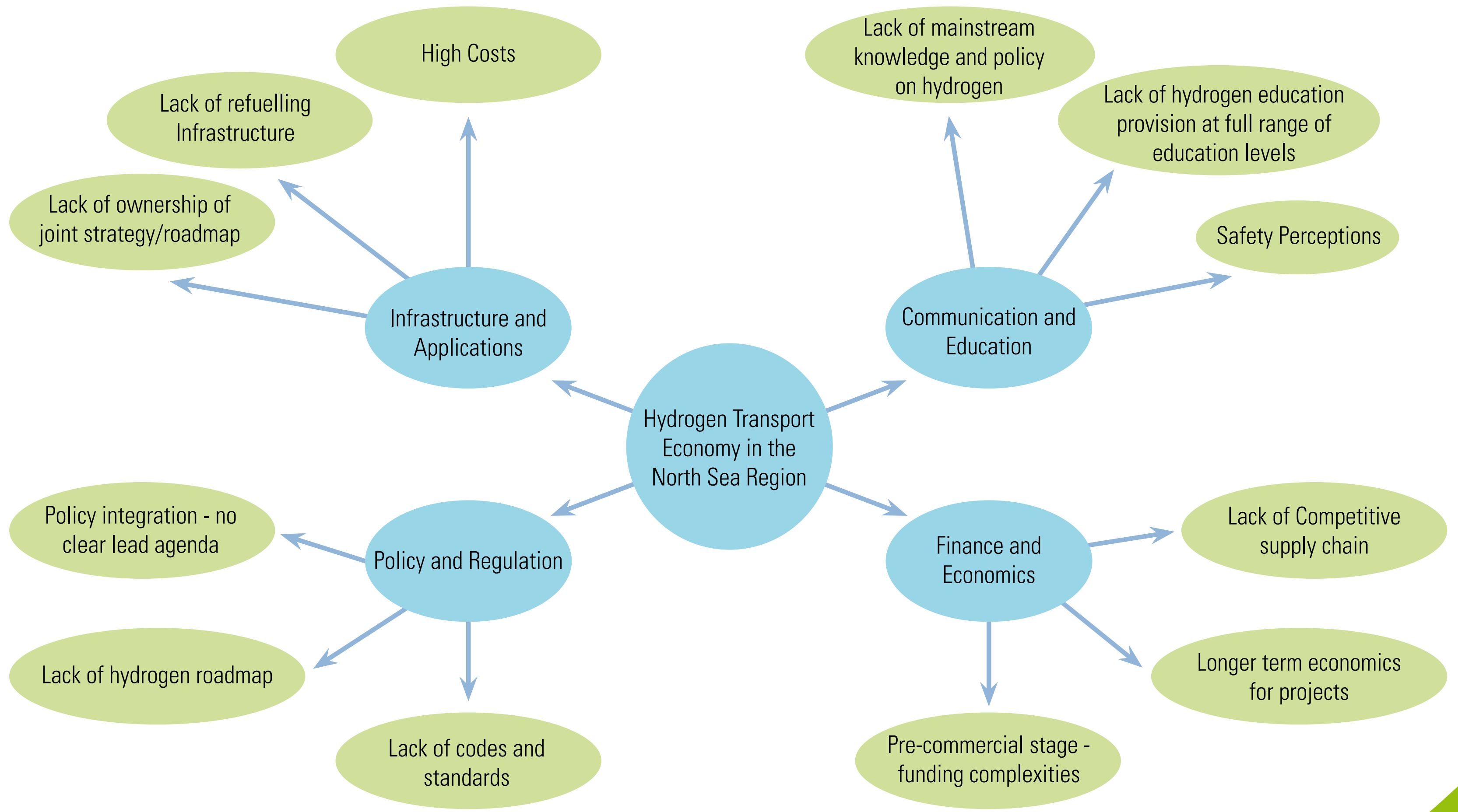


Figure 5: Key challenges for hydrogen transport roll-out in the North Sea Region

Infrastructure and Applications

Although a number of regions have introduced hydrogen vehicles, which have a driving range comparable to conventional fuelled vehicles, the use of these vehicles for longer distance trips is still limited due to a lack of refuelling infrastructure throughout the North Sea Region. Costs are a barrier at this point in time as they are still well above those of incumbent technologies. A lack of clear ownership for joint strategies and roadmaps is a challenge in some areas because hydrogen transport hits several key policy agendas and government departments, for example energy and transport, with often no one department taking a lead. The development of infrastructure and the deployment of vehicles need to be implemented in parallel and based on realistic expectations.

Finance and economics

With the sector still being in a demonstration stage and pre-commercial, the need for public funding matched with industry and local funds can be a barrier, not least because of the complex nature of setting up and managing funding partnerships. The lack of a competitive supply chain is another challenge, which also impacts on costs. With projects having high start-up costs and time-limited grant funding, the longer term economics can be a challenge. Local circumstances around potential for use of residual heat and oxygen from electrolysis, as well as electricity grid balancing should be considered in order to enhance the business case for refuelling facilities.

Policy and regulation

In some areas a lack of one clear lead policy driver can be a challenge, when the topic cuts across many agendas. Where this should be an advantage, it can be restrictive where no one department takes a clear lead in driving a roll-out strategy forward. The Hydrogen Journey undertaken by the HyTrEc partnership identified disparities in regulations and knowledge of regulations throughout different member states. Having clear policies will support investment and encourage well planned and co-ordinated deployment, maximising potential benefits. HyTrEc's Hypothetical Journey exercise concluded that the EU policy / regulatory framework tends to be translated differently by member states, making it difficult to coordinate a joined up, cross border hydrogen refuelling infrastructure network. This challenge is reinforced by the fact that although most North Sea Region member states have H_2 Mobility programmes, there is little or no mechanism to ensure the national programmes are co-ordinated with each other and to ensure cross-border issues are tackled.

Communication and education

A lack of mainstream knowledge and understanding of hydrogen in transport and the opportunities it presents can restrict the buy-in of decision makers and policy makers. There is also a lack of hydrogen education opportunities at certain levels within the education system, such as in further education and in some cases schools.

2 A Joint Strategy Framework for advancing the adoption of hydrogen as an alternative energy carrier in the North Sea Region

Following consideration of the SWOT analysis for hydrogen transport in the North Sea Region, the HyTrEc partnership proposes the following vision for 2020. This Strategy Framework then goes on to explain how the key barriers standing in the way of achieving this vision can be overcome.

2.1 Vision
In 2020 the North Sea Region is leading Europe on the production and use of green hydrogen as an energy carrier, using excess renewable electricity for zero emission transport. Hydrogen is a widely accepted, commonly used low emission transport fuel helping to maximise the sustainable use of the North Sea Region's natural resources.

2.2 Recommended actions 2015 - 2020
Actions that could overcome the key barriers (1.3.4) to achieving this vision for 2020 were identified by the partnership. Although this produced a wide range and high number of actions, many could be grouped together and the most important five actions are explained below. These broadly fit under the four themes explained in section 1.3.3.

2.2.1 International demonstration / lighthouse projects
Aim: Enlarging existing and realising new DEMONSTRATION PROJECTS highlighting and supporting the critical steps towards large-scale implementation of hydrogen as a sustainable energy carrier.

Based upon the experiences and strengths of the North Sea Region the demonstration projects should be focussed on:

- Hydrogen refuelling stations utilising green hydrogen
  - hydrogen produced from (excess) renewable electricity (especially wind)
  - hydrogen produced as a by-product from chemical industries

- Zero-emission transport applications (cars, buses, vans, forklifts, refuse trucks, water-based vessels,…)
  - upscaling existing fleets in order to have optimal utilisation of fuelling stations
  - transferring existing knowledge and experience to other areas within the North Sea Region

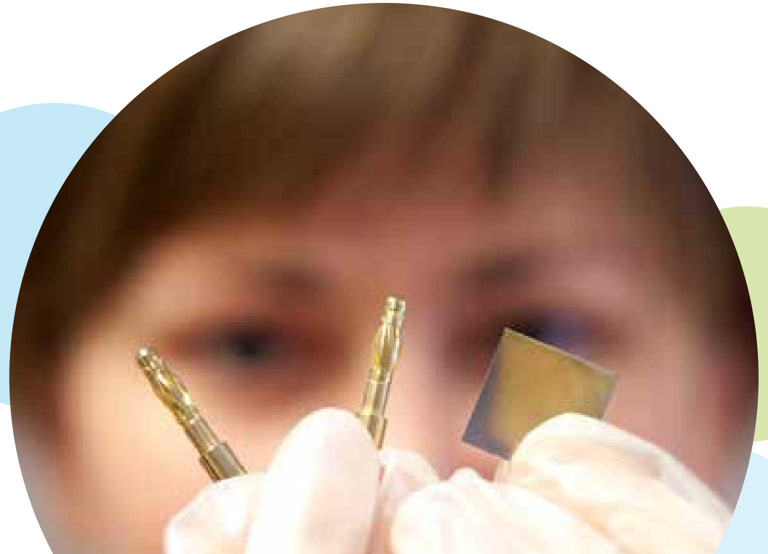
With the strong and ambitious renewable energy targets of the North Sea Region, large scale demonstration projects should take place with hydrogen used as an energy storage medium.

These regional large scale demonstration projects should be in line with the European vision, as stated in the second Fuel Cells and Hydrogen Joint Undertaking (FCH 2 JU) and will be coherently funded by industry, by FCH 2 JU and by structural funds.

Exchanging applications (buses, cars, forklifts,…) between regions will be a cost-efficient way of learning best practice.

2.2.2 Policy Support measures for early implementation
Aim: Transnational ANALYSIS OF INCENTIVES that can compensate in a sustainable way for the additional costs of zero emission hydrogen technologies

The aim of this action is to inventory and analyse incentives (their definition, advantages and disadvantages and lessons learnt) regarding the implementation of hydrogen (fuelling stations, transport and energy storage) in all North Sea Region member states and beyond. With the involvement of governments, industry and other key stakeholders, this will provide recommendations on the most effective incentives for each member state, within current legislation. It is also important to learn from experiences of other clean transport fuels.



2.2.3 Education programmes
Aim: Developing a well-coordinated, transnational EDUCATION PROGRAMME on hydrogen for transport and energy storage, based upon the knowledge and experience gained in demonstration projects. This will support large-scale demonstration of hydrogen technology by the education sector and government.

Different target audiences for training have to be distinguished:

- Young professionals and technical students (technician and bachelor levels) seeking an understanding of hydrogen technology
- Scientists and engineers working in or entering the hydrogen industry
- Employees of industries that will be active in hydrogen technology
- System developers and integrators
- End users and system operators

Two primary targets are defined:

- Teaching the teachers
- Vocational training centres

2.2.4 Communication
Aim: Active, structured and regular transnational COMMUNICATION of the status of hydrogen's implementation as an energy carrier throughout the North Sea Region. This should be based upon results, experiences, barriers encountered and overcome, opportunities identified, publications issued.

Tasks within this action include:

- Formalising a transnational 'North Sea Hydrogen Stakeholder Platform', with representatives from industry, research, education and government covering the North Sea Region
- Annual conference presenting results achieved and discussing future transnational actions needed
- Dedicated workshops on specific key issues that will help further the implementation of hydrogen in transport and energy storage
- Cooperation and aligning of activities with other North Sea Region organisations, including the North Sea Commission Thematic Group and North Sea Power to Gas Platform.

In new technology areas the key is to communicate results and expectations as clear as possible and avoid 'overpromising / underperforming'. It is important to communicate results rather than expectations.

2.2.5 Structural cooperation
Aim: Create a structural cooperation platform 'Hydrogen in the North Sea Region' for continuous knowledge exchange and taking forward the steps necessary to realise the vision.

Tasks within this action include:

- Forming a Working Group "Hydrogen in the North Sea Region" with clear terms of reference
- Meeting and reporting every six months to discuss:
  - Technical / economic results from existing projects- Fuelling stations and vehicle applications - closing the infrastructure gaps around the North Sea Region (taking forward recommendations from HyTrEc's Hydrogen Journey)
- Discussion of policy measures
- Regulations and codes - raising awareness of key disparities around member states
- Incentives - identifying and recommending the most effective approaches
- Defining further joint actions and projects that will assist in the delivery of the previously identified four key actions around Demonstration, Policy Support Measures, Education and Communication.

3 A Hydrogen Transport Energy Economy in 2020

In 2020 the North Sea Region is leading Europe on the production and use of green hydrogen as an energy carrier, using excess renewable electricity for zero emission transport. Hydrogen is a widely accepted, commonly used low emission transport fuel helping to maximise the sustainable use of the North Sea Region's natural resources.

In order to be a leader in the sector in Europe, the Interreg North Sea Region, with about 60 million inhabitants and an area of about 664,000 km², will focus on applications that are closest to commercial production so as to support existing refuelling infrastructure and the development of new facilities that will close current gaps. This increased volume will lower costs through targeting supply chain development. While other, currently more niche and innovative applications will also be important, the highest priority applications for large scale roll-out are:

- Hydrogen Fuel Cell Cars (refuelling at 700 bar)
  - In 2015 hundreds of cars are running on hydrogen around the world and major OEM's have clear ambitions for further roll out. Based on current plans and programmes, in 2020 it is realistic to expect that there will be 5,000 hydrogen fuel cell cars operating in the North Sea Region.
- Hydrogen Fuel Cell Buses (refuelling at 350 bar)
  - In 2015 about 100 buses are running on hydrogen around the world and European OEM's have defined a target of 500 - 1,000 buses in Europe in the short term. Based on current plans and programmes it is realistic to expect that in 2020 there will be 500 hydrogen fuel cell buses in the region.
- Hydrogen Fuel Cell Forklifts (refuelling at 350 bar)
  - In 2015 around 5,000 forklifts are running on hydrogen around the world and in Europe some major end-users are starting demonstration projects. The North Sea Region is a major logistics centre for Europe. Based on current plans and programmes, it is realistic to expect that in 2020 there will be 3,000 hydrogen fuel cell forklifts operating in the region.
- Based on current plans it is expected that in 2020 these vehicles will be supported by 145 hydrogen refuelling stations (100 at 700 bar and 45 at 350 bar).

The North Sea Region, with the largest installed wind capacity in Europe, will focus hydrogen production on renewable electricity. By estimating the annual total hydrogen use of the vehicles expected to be operating in the North Sea Region in 2020, the HyTrEc partnership conclude that 185MW of electricity is required per year to produce this fuel (appendix 1). Total wind energy capacity in the HyTrEc partners' countries totalled almost 69,000MW in 2014 (Source: European Wind Energy Association), and most of these countries are in need of a method for storing energy, to assist with the difficulties of matching supply and demand.

It is therefore concluded that by working together as one region, it is possible to achieve the vision for 2020 and be a leader in Europe on the production and use of green hydrogen as an energy carrier, using excess renewable electricity for zero emission transport.

Appendix 1

Application	# Hydrogen Refuelling stations	# Vehicles per station	# Total vehicles	Annual Hydrogen use [tonne/year]	Equivalent Wind capacity [MW]
Cars	100	50[2]	5000	1500	36[1]
Buses	25	20[3]	500	3500	84
Forklifts	20	150[4]	3000	2700	65

1 Average hydrogen production efficiency: 60 kWh/kg, average wind turbine: 2500 equivalent full load hours

2 Annual range 30.000 km/year, specific hydrogen consumption 1 kg/100 km

3 Annual range 70.000 km/year, specific hydrogen consumption 10 kg/100 km

4 3 shifts/day, 300 days/year, specific hydrogen consumption 1 kg/shift

For further information

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