Europäisches Institut für Innovation

HyTrEc
Hydrogen Transport Economy
for the North Sea Region

A Hypothetical Hydrogen Journey through the North Sea Region

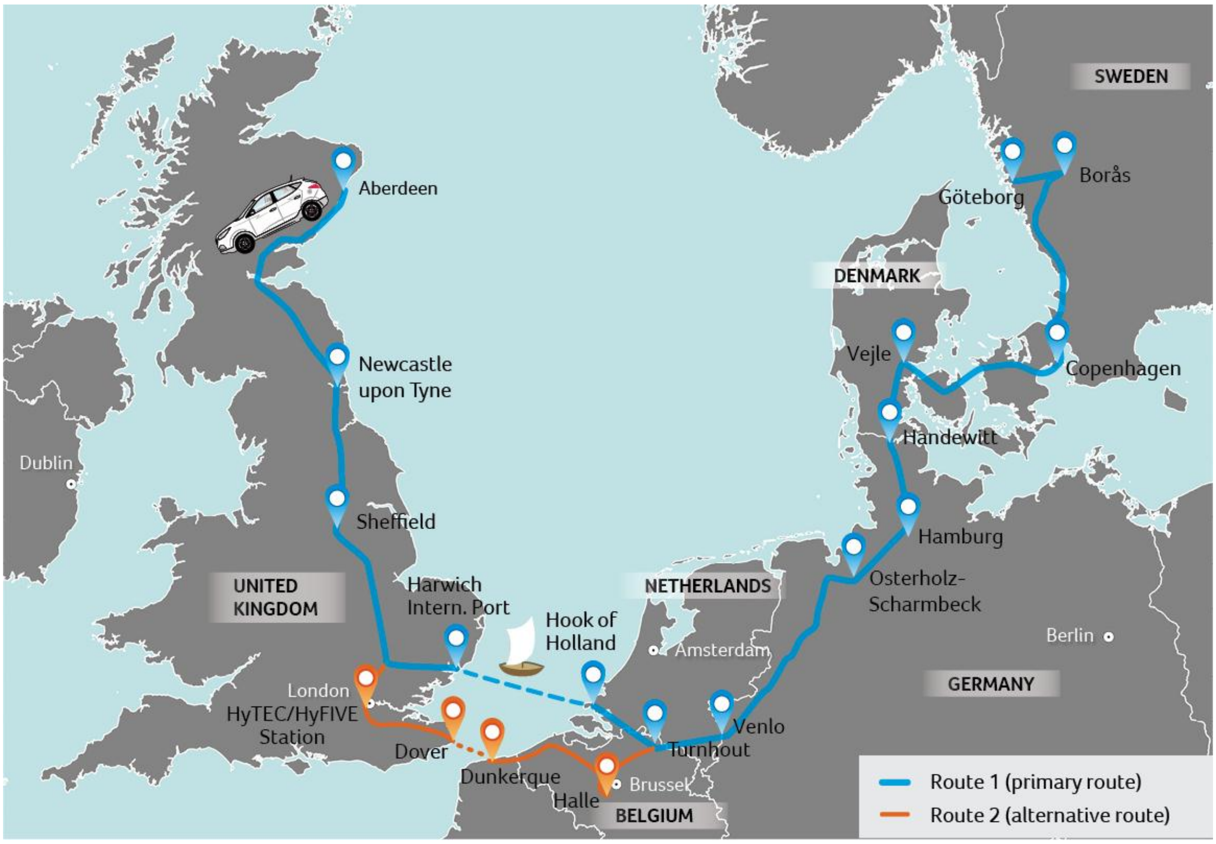

Figure 1: The journey through the NSR
(Source: European Institute for Innovation)

European Union The European Regional Development Fund

The Interreg IVB North Sea Region Programme

Investing in the future by working together for a sustainable and competitive region

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Executive Summary

Sustainable, secure and competitive energy supply and transport services are at the heart of the EU2020 strategy for a low carbon economy. Innovation and deployment of new clean technologies are essential for a successful transition to a new sustainable economy as there is no silver bullet technology available to progressively replace fossil energy sources. In addition to creating a healthier environment and securing energy supply, further innovation provides huge opportunities for the European economy.

- What is HyTrEc about?
  - The Hydrogen Transport Economy (HyTrEc) project aims to improve access to and advance the adoption of hydrogen as an alternative energy vector across the North Sea Region. The project will identify and address structural impediments constraining development of, access to and adoption of this alternative fuel in urban and rural settings.
- What is the idea of this paper's model?
  - The idea of this model is to create a transnational document which shows the out-come of an imaginary hydrogen route through all partner regions as well as helps to identify deficits in this sector.
- Why is it important to evaluate the current situation of Hydrogen in Transport?
  - Hydrogen fuel will be increasingly replace fossil-based fuels and thus be an important component in terms of climate and emissions targets in the transport sector. In addi-tion, the use of hydrogen as a fuel for fuel cell vehicles appears economically the most profitable - compared to reconversion and the use in chemistry.
- What are the European Strategies and Visions
  - The European 20-20-20 strategy targets, The Fuel Cells and Hydrogen Joint Undertak-ing as well as the Fuel Cells and Hydrogen Joint Technology Initiative.
- Regulations, Restrictions and Conditions
  - Evaluate the circumstances (e.g. Obligations of manufacturers and ADR) under which a hydrogen car is able to drive in Europe.
- The journey through the NSR – single stages
  - This section is the main part of this paper. First of all the specifications and layout of the journey are described.
  - Afterwards each stage of the journey is described in detail. This also includes the de-scription of each countries technical data and their hydrogen infrastructure. Addi-tionally each countries road interferences as well as their regulation and restrictions are described.

It applies to all mentioned applications that the necessary technologies in particularly the further develop of the electrolysis is needed. In addition, the policy is challenged to provide the funding spe-cific and regulatory frameworks that allow economic conversion of renewable generated electricity via electrolysis for hydrogen and a corresponding use. For example, the continuation of the National Innovation Program (NIP) with appropriate market support must be ensured and regulatory instruments such as the Renewable Energy Source Act (EEG) apportionment. Furthermore, grid usage fees are designed so that the successful commercialisations of new energy efficiency technologies are conducive. (1)

1. Introduction

What is HyTrEc?

The Hydrogen Transport Economy for the North Sea Region (HyTrEc) project aims to improve access to and advance the adoption of hydrogen as an alternative energy vector across the North Sea Region. The project will identify and address structural impediments constraining development of, access to and adoption of this alternative fuel in urban and rural settings. Hence oil and gas technologies have dominated the energy and transport sectors and enjoyed the benefits of scale effects, and of on-going technological improvements. In what is effectively a monopoly situation, it is difficult to develop less mature alternative technology solutions. This is particularly true of hydrogen technologies, which if used in association with fuel cells, could replace the conventional duo formed by hydrocarbons/combustion systems (engines, turbines, etc.) delivering significant economic and environmental benefits. HyTrEc is part of the Interreg IVB North Sea Region Programme and is partly funded by the European Regional Development Fund.

The HyTrEc project will support the validation, promotion and adoption of innovative hydrogen technologies across the North Sea Region (NSR) and enhance the region's economic competitiveness within the transport and associated energy sectors. In addition, HyTrEc will provide a platform to support the collaborative development of strategy as well as initiatives. Further, it will inform and shape the development of infrastructure, technology, skills and financial instruments to support the application of hydrogen based technologies across the region. Therefore partners from the UK, Germany, Denmark, Belgium, and Sweden are working together to improve cross border collaboration, share best practice and support joint activities. The project will establish a transnational network which will improve accessibility to hydrogen across the North Sea Region as an alternative energy vector by:

- Establishing a North Sea Hydrogen Transport Stakeholder Group, and developing strategies and initiatives to create a fully functioning hydrogen corridor;
- A transnational pilot study to improve the accessibility and connectivity of existing regional hydrogen corridors and supporting the development of hydrogen supply chain infrastructure;
- Piloting a novel, portable hydrogen refuelling station demonstrator;
- Developing a North Sea Region education forum to identify skills gaps and develop training solutions;
- Facilitating access to public and private sector financial instruments which support the development of hydrogen technology;
- Supporting the development of SME clusters to deliver hydrogen infrastructure solutions.

The objectives of the project are to promote:

- Regional accessibility strategies;
- Environmentally responsible energy production practices;
- Developing different modes of transport;
- Transnational transport corridors;
- Efficient and effective logistics solutions;
- Sustainable growth solutions.

To enable the personal exchange of information and ideas, the HyTrEc project partners meet on a regular basis. During these meetings, the members of the project discuss the progress of the working groups and their work packages. The HyTrEc project is divided into five work packages. These include:

- Project Management (work package 1, Aberdeen City Council)
- Communication (work package 2, Aberdeen City Council)
- Skills Development Programme (work package 3, Gateshead College)
- Policy Development and Demonstration – Policy guide to support implementation of the new hydrogen projects in the North Sea Region (work package 4, WaterstofNet)
- Evaluating and Building in Sustainability (work package 5, European Institute of Innovation)

In addition to the biannual meeting, the project is represented at various events and fairs by the project partners. Hence, the aim is to find potential SMEs, investors and funding bodies and to bring them closer to the project or even to involve them in the project. (2)

What is the idea of the task / the model?

The task is to create a transnational document which shows the outcome of an imaginary route through all partner regions. The input for this model is based on feedback of each partner regarding issues which are related to existing restrictions, existing refuelling stations, use of tunnels / ferries. The expected document will build on results of transnational questionnaires.

The model should describe a hypothetical journey with a hydrogen car which is starting in Aberdeen and ending up in Gothenburg. The journey leads through the UK, to Belgium, the Netherlands and Germany, up to Denmark and Sweden. The idea is that all HyTrEc project partners should be "visited" during the trip. Therefore it is needed to analyse the country of each partner and to evaluate which restrictions as well as regulations have to be kept in mind and targeted. The outcome of this paper will be a model of a journey showing the barriers and restrictions that might occur when travelling through Northern Europe (NSR) by a hydrogen car. Parts of the journey will lead through the TERN, the Trans-European Road Network. The aim of the TERN project is to improve the internal road infrastructure of the EU. Therefore it would be interesting to investigate possible restrictions for hydrogen vehicles on this specific road network. Namely the Motorways M25 and M20 in the UK will be travelled during the trip and are part of TERN. (3)

Why is it important to evaluate the current situation of hydrogen in transport?

There is consensus that the development of renewable energies and thus the energy change can only be successful if, the expansion of networks and the technical conditions are created to store the energy sufficiently, thereby to be able to decouple the local and temporally production. This can only be achieved in the required order of magnitude by hydrogen. Hydrogen which is produced via the "Power-to-Hydrogen" approach integrates renewable sources of generation, converts surplus electricity to produce hydrogen or renewable gas, and leverages the attributes of the existing natural gas infrastructure. Power-to-Gas is a highly effective way of integrating renewables. It can provide a rapid, dynamic response to the independent grid operator's signal to adjust to the variations in renewable generation output. The siting of a Power-to-Gas facility is not restricted to any geologic formation as it can be deployed wherever the power and gas grids intersect. It is a scalable technology.

Power-to-Gas provides the unparalleled energy storage capacity in the TWh range—seasonal storage capability. It can charge energy several days, or even consecutive weeks, without needing to discharge the stored energy. Unlike other energy storage technologies, Power-to-Gas provides the means to both store and transport energy. By storing hydrogen or substitute natural gas in the existing natural gas pipeline network and associated underground storage facilities, the stored energy can be discharged where and when it is needed most. This results in higher overall integrated system efficiency. (4) Thus, Power-to-Gas can be used in many ways:

- As an energy source in connection with the natural gas grid,
- use for stationery power production,
- as chemical raw material, or
- as fuel for the transport sector.

Hydrogen fuel will increasingly replace fossil-based fuels and thus be an important component in terms of climate and emissions targets in the transport sector. Additionally, fuel cells are inherently more efficient than internal combustion engines and thus the use of hydrogen as a fuel for fuel cell vehicles appears economically the most profitable - compared to reconversion and the use in chemistry (5). However, besides the classic actors such as the automotive and oil industries also new players like the energy industry need to be motivated and involved in the transport sector

2. Strategies and Visions

European Union

The European strategy targets, known as the "20-20-20" targets, set three key objectives for 2020:

- 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. (6)

The targets were set by EU leaders in March 2007, when they committed Europe to become a highly energy-efficient, low carbon economy, and were enacted through the climate and energy package in 2009. The EU is also offering to increase its CO2-emissions reduction to 30% by 2020 and to 80% by 2050 if other major economies in the developed and developing countries commit to undertake their fair share of a global emissions reduction effort. The European Commission has published a communication analysing the options for moving beyond a 20% reduction by 2020 and assessing the risk of "carbon leakage".

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 competitiveness. Additionally, headline targets of the "Europe 2020 strategy" focuses on smart, sustainable and inclusive growth. This reflects the recognition that tackling the climate and energy challenges will contributes to the creation of jobs, the generation of "green" growth and evokes a strengthening of Europe's competitiveness. It is estimated that meeting the 20% renewable energy target could have a net effect of creating around 417.000 additional jobs, while getting on track to achieve the 20% energy efficiency improvement in 2020 is forecast to boost net employment by approximately 400.000 jobs. (7)

The energy carrier hydrogen and the use of fuel cells can contribute significantly to achieving the objectives of European policy, especially in the areas of energy security, air quality; reduction of greenhouse gas emissions and industrial competitiveness. In a political environment that stimulates research, development and deployment, both can be attractive as well as competitive and enable market forces in a position to bring these essential benefits for the community over time. However, traffic applications play a crucial role. Since, the development of fuel cell drives for vehicles hydrogen is a major driver of the overall development. Other applications play an important role, too, especially combined heat and power (CHP) fuel cells for decentralized power generation. Early markets, including those for specialized vehicles (e.g. forklifts) and portable devices are established since 2010. In addition, stationary applications will reach the broad market establishment by 2015 and transport services to the mass market by 2020 (7).

The EU targets a ten-year research, development and demonstration program, to close the gaps in technical marketing. These include:

- Procedures for hydrogen production, with a focus on their potential to contribute within a reasonable time to achieve the policy objectives. Hydrogen from hydrocarbons as a bridging technology is important for market entry, and in connection with the separation and storage of carbon certain applications could even stay long term. The reforming fossil fuel technologies pave the way for future renewable energy sources and biomass. In parallel, the hydrogen production from renewable and carbon-free energy sources must be explored.
- Procedures for hydrogen storage. Although it needs to be worked intensively on the current procedures, new storage methods and principles are important, if not crucial.
- Fuel cell technologies, in which the material research is an essential technological driving force for both fuel cell and hydrogen systems.

The EU strategy and vision key challenges are:

- Improvement of durability, performance and efficiency of fuel cells;
- Storage of hydrogen on board of vehicles;
- Competitive hydrogen prices (production and distribution costs);
- Development of methods for the mass production of fuel cell stacks and systems.

Public investment (such as a joint European technology initiative [Joint Technology Initiative - JTI], the Member States and the regions) together with the activities of the private sector must at least reach the current level of funding for research and development of the main global competitors. The next step to close the gap between research and development are on the one hand marketing on the other hand the creation of large-scale demonstration projects, so-called "lighthouse projects". To do so the following criteria's are needed:

- A limited number of significant sizes, with a focus on the transport applications;
- Selected "hydrogen communities" with early markets and stationary applications as the main driver.

In addition the policy framework and financial planning for significant and long-term public contributions and incentives are also essential. (7)

In May 2014, the EU formally agreed to continue the Fuel Cells and Hydrogen Joint Technology Initiative under the EU's new funding programme for research and innovation, Horizon 2020. Implemented by the Fuel Cells and Hydrogen Joint Undertaking (FCH 2 JU), this second phase will continue to contribute to the objectives of the Joint Technology Initiative through the development of a strong, sustainable and global competitive Fuel Cells and Hydrogen sector in the Union with a ring-fenced budget of 665 M€, complemented by, at least, an equivalent level of investment by the industrial and research partners. The FCH 2 JU proposal is a part of the Innovation Investment Package worth a total of 22 billion euros, proposed by the European Commission to support research and innovation in key areas of the economy, boost economic growth and the creation of jobs and help face the most important societal challenges. The FCH 2 JU operational activities will focus on:

- Lowering costs and increasing lifetimes and efficiencies of fuel cells and hydrogen production technologies;
- Demonstrating large-scale renewable energy storage capability with hydrogen; and reducing the use of specific critical raw materials. (8)

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is a unique public private partnership supporting research, technological development and demonstration (RTD) activities in fuel cells and hydrogen technologies in Europe. Its aim is to accelerate the market introduction of these technologies as well as realising their potential as an instrument in achieving a carbon-lean energy system. Fuel cells, as an efficient conversion technology as well as hydrogen as a clean energy carrier, have great potential to help cut carbon dioxide emissions, reduce dependence on fossil fuels and contribute to European economic growth. The objective of the FCH JU is to bring these benefits to Europeans through a concentrated effort from all sectors. (9)

National

a. United Kingdom:

The 2003 Energy White Paper and the 2006 Energy Review are cognisant of the use of hydrogen, and set appropriate and worthwhile aims for the UK over the long term.

Energy White Paper

The Energy White Paper details the government's new energy policy to ensure that “energy, the environment and economic growth are properly and sustainably integrated”. Furthermore, it creates forward plans to avoid over-dependence on imported energy by developing renewable energy sources within the UK. There are four goals for the UK government's new energy policy:

- Cutting carbon dioxide emissions;
- Maintaining the reliability of energy supplies;
- Promoting "competitive markets in the UK and beyond";
- Ensuring that every home is adequately and affordably heated.

Description of the implementation:
Energy efficiency is the cheapest and safest way of addressing all four aims. This can be achieved through policies to raise the energy efficiency of products and buildings. To increase the renewable energy supply, to reduce carbon emissions and the UK’s dependency on imported energy. The increase of funding for capital grants for renewable energy and adapting electricity distribution networks so that renewable energy sources can both take from and add to the national grid. Carbon emissions trading scheme means to set caps on emissions in industry to provide clear incentives for

investment in energy efficiency and cleaner technologies. Technological innovation to support research and development into new long term options (such as hydrogen economy) as well as allowing current renewable energy supplying to demonstrate their potential'. (10)

Energy Review

The potential for carbon savings from hydrogen is immense, because hydrogen vehicles do not emit carbon locally; in the long term, hydrogen could reduce transport emissions to near zero. But hydrogen does not exist naturally in the forms needed for commercial use and more energy is consumed in making it than is released when it is used. Unless there is a great increase in the amount of carbon-free energy available to produce hydrogen in the UK, its main benefits will be to reduce demand for oil rather than to reduce carbon emissions. Much work also needs to be done on fuel cell technology, hydrogen storage technology and hydrogen distribution before hydrogen cars can compete with conventional vehicles on performance, cost and convenience. The Department for Transport analyses at what steps would need to be taken to develop a hydrogen transport economy. (11)

UK H2 Mobility project

H2Mobility brings together the utility, gas, infrastructure, fuel retail and car manufacturing sectors with three government departments. The project evaluated the potential for hydrogen fuel cell electric vehicles (FCEVs) to contribute to the decarbonising road transport. The project analyses the potential barriers to overcome and potential investment required to make the UK a leading global player in the hydrogen fuel cell electric vehicles market. It sets out a roadmap to commercialise hydrogen fuel cell electric vehicles in the UK from 2015.

The H2Mobility evaluation phase was completed at the end of 2012. Phase 1 is a report which summarises key findings and outlines a scenario for the roll-out of hydrogen fuel cell electric vehicles to consumers. Phase 2 of the H2Mobility project started in March 2013. It has the objective to develop a business case. The main tasks of the UK H2 Mobility project are:

- Evaluation of the potential demand for FCEVs over time;
- Determination of the hydrogen refuelling network necessary to support the consumer demand and planned its development;
- Identification of a mix of production methods able to provide cost-competitive hydrogen to the consumer while delivering significant CO2 emissions reductions;
- Quantifying the benefits of establishing FCEVs in the UK market.

The UK H2Mobility project was created to evaluate the potential of, and develop a roll-out strategy for, FCEVs in the UK. Hydrogen transport has the potential to deliver significant benefits in four areas.

- Decarbonising road transport;
- Creating new economic opportunities for the UK;
- Diversifying energy supply;
- Reducing local environmental Impact of road transport.

The UK H2Mobility project was initiated to address the challenge of commercialising FCEVs and hydrogen refuelling in the UK: how this could be achieved, the probable timescale and the associated costs and benefits. Companies from across the FCEV and hydrogen value chain, together with the interested government departments, recognised that a successful market introduction is likely to require co-ordinated and simultaneous action. UK H2Mobility focuses on the timeframe 2015 to 2030 and evaluates this as the key period to establish FCEVs on the market. (12)

Figure 2: Hydrogen hybrid for a GREEN Aberdeen (Source: HyTrEc)

Support package for ultra-low emission vehicles in the UK: 2015 – 2020

The Deputy Prime Minister announced a funding package of 500 million £ to support the development and use of ultra-low emission vehicles (ULEVs) all the way out to 2020. These ULEVs are seen as an important part of the government´s plans for a sustainable and modern transport system which promote economic growth and benefits the environment. The support package covers a wide range of activities topics. Thus 100 million £ are planned for research and development activities. More than 200 million £ shall be used to stimulate the market for ULEVs by granting financial aid to potential buyers of such vehicles. 4 million £ are used to support the gas refuelling infrastructure for heavy good vehicles. Beside these many other priorities are set within this package. (13)

b. Belgium and the Netherlands

Belgium

Due to the complex governmental structure and authorities, there is no policy on hydrogen and fuel cells in Belgium, yet. The Belgian Science Policy Office released a project called "Development of Tools to evaluate the potential of sustainable hydrogen in Belgium" in 2006. It intends to be the first step in a scientific assessment of hydrogen in the Belgian context. The results of the project can be summarized as follows:

Figure 3: WaterstofNet hydrogen refuse truck (Source: WaterstofNet)

- Development of databases with international knowledge and experiences on hydrogen;
- Development of a Hydrogen module within MARKAL-TIMES, illustrated by a scenario calculation;
- Development of an initial technology assessment on hydrogen, focussed on the scenario;
- Preparation of a translation of the progress in foreign legislation and licence procedures on hydrogen;
- Preparation of a definition of relevant policy issues concerning hydrogen. (14)

On the other hand Belgium has a strong group of industrial players covering the complete value-chain of hydrogen, like for example hydrogen gas suppliers, biggest hydrogen network underground, electrolyses system- and hydrogen bus builders. These industry players are very committed. In 2009 WaterstofNet started an Interreg-project for the realisation of regional sustainable hydrogen projects. Within this project refuelling stations, a stationary power-plant and applications on hydrogen, were built with only regional players and still being operated to this date. At the moment Belgium is going to work on an H2Mobility Belgium.

The Netherlands

In the Netherlands, the ministry of Infrastructure and Environment have produced a couple of documents and also a vision on a “sustainable fuel mix” for the Netherlands (15). This ministry was also involved in the preparation for “driving on hydrogen”. It has decided to have all the busses within the public transport sector to be zero-emission before 2025. Also all new cars sold from 2035 onwards, have to be zero-emission.

To develop a policy for the sustainable fuel-mix, that meets these aims, the government together with over 100 organisations, representatives from industry, civil society organizations and research institutions developed this vision. A Dutch H2Mobility study is ongoing at this moment, following the German, UK and France H2Mobility studies.

c. Germany

In the past years, the German government and industry developed different models to establish a sufficient hydrogen infrastructure. The hydrogen infrastructure includes the access and opportunity to buy hydrogen cars, the access to hydrogen refuelling stations and their further expanding as well as the access to garages and service points. In January 2014 the German Federal Motor Vehicle Office announced that 85.575 hybrid vehicles (of 43.851.230 registered vehicles in total) are registered in Germany (16). About 300 of them are hydrogen powered only (17). Furthermore, Germany has currently 26 hydrogen operative refuelling stations. 14 hydrogen refuelling stations are operating with public access (with or without prior arrangements) and 20 hydrogen refuelling station provide hydrogen for passenger cars (CGH2, 350 bar and 700 bar pressure).

By 2015, the German government projects a supply network of hydrogen refuelling stations with at least 37 operating hydrogen filling stations. 35 of them will have public access (with or without prior arrangements) and 36 will provide fuel for passenger cars (CGH2, 350 bar and 700 bar) (18). According to the National Innovation Program (NIP) of Germany, 400 hydrogen refuelling stations will be built by 2025 in Germany (19). Some of the developed models to establish a sufficient hydrogen infrastructure say that at least 50 hydrogen refuelling stations are needed to guarantee a basic national coverage.

Figure 4: Hydrogen refuelling stations in Germany (Source: H2stations.org by LBST)

Currently there are only a few service points and garages in Germany which are specialized in hydrogen vehicles. Most of them deal mainly with LPG but can also handle hydrogen cars. This service network is going to be expanded as soon as the hydrogen market is established. Nowadays, most of the hydrogen car manufactures have a five to ten year warranty and service included. Therefore it is yet not the need for many hydrogen specialized garages. In case of a break down or emergency of a hydrogen car, the General German Automobile Club (ADAC) is prepared to deal with it anywhere in Germany. Hydrogen car manufactures in Germany are: Audi, BMW, Ford, Honda, Hyundai, Mercedes-Benz, Nissan, Opel, Renault, Toyota and Volkswagen (20). Although, most of them only produce prototypes or on a small scale, it still proofs that the car manufactures in Germany are prepared to bring hydrogen cars on the market as soon as the customer ask for it. The current price in Germany for one kilogram of hydrogen is about nine Euros.

National innovation programme for hydrogen and fuel cell technology (NIP)

The Federal Ministry of Transport, Building and Urban Development (BMVBS) has launched in cooperation with the Federal Ministry of Economics and Technology (BMWi), for Education and Research (BMBF) and the Ministry of Environment (BMU), the NIP. The program is part of the High-Tech Strategy for Germany and adapts to the "fuel strategy of the federal government". The NIP provides a common framework for numerous hydrogen and fuel cell research projects in science and industry. The public-private partnership (PPP) has a 10 year view. The Federal Government and industry provide a total of 1.4 billion euros for research, development and demonstration projects. The project duration is set until 2016.

To bring the numerous product and applications of hydrogen and fuel cell technology equally forward and to tackle markets specific challenges in the market preparation, the NIP is divided into three program areas:

- Transport and hydrogen infrastructure: This includes the preparation and operation of hydrogen-powered vehicles and related infrastructure, as well as applications in related areas such as electricity supply on board aircraft.
- Stationary energy supply in the private and industrial sector: In particular, the use of stationary fuel cell systems in residential buildings, in the commercial, in industrial plants and on ships will save a lot of fossil fuels and CO2.
- Special markets: The application spread of this programme, ranges from the critical power (IT / Telecommunications) to logistics (forklift) to fuel cell applications in the leisure and tourism sector.

Within the program areas, the practicality and reliability of components and systems for future commercial use are systematically prepared in the context of demonstration projects:

- The demonstration project CEP: The “Clean Energy Partnership” merger has set itself the goal to demonstrate the suitability for everyday use of hydrogen as an alternative fuel in vehicles and to test the infrastructure of hydrogen fuelling stations.
- The demonstration project CALLUX: The goal is to develop existing technology in the area of domestic energy through the purchase, installation and operation of 800 fuel cell heating units of the energy supply companies towards reliable and roadworthy systems. So it should be possible to prepare the launch of natural gas-powered fuel cell heating appliances.
- The demonstration project NEEDS: The goal is the development of standardized fuel cell systems in combination with biomass recycling plants (biogas, sewage gas, pyrolysis, synthesis) in the field of industrial plants to supply energy.

- The demonstration project e4ships: The use of fuel cells for energy supply on large ships and ferries.
- Demonstration project Bodensee (Lake Constance): The power supply of recreation vehicles (RVs, caravans) and the drive of recreational vehicles (boats, light vehicles) are tested by means of fuel cell systems.
- Demonstration project critical power supply: The application of fuel cells in the uninterrupted power supply, for example, in digital mobile radio (TETRA network). (21)

The Mobility and Fuels Strategy of the German Government

The key messages of "The Mobility and Fuels Strategy of the German Government" can be summarized as follows:

- European and international context:
    - Germany can become the leading market for innovative technologies and sustainable mobility solutions, and the provider of energy-efficient products on the global market. With regard to transport technologies, it is important to extend the advantage that has already been gained. Particular attention should be paid here to the establishment of strategic alliances, for example in the areas of electro mobility, hydrogen technology, LNG for shipping and, in particular, alternative fuels for the aviation industry.
- Perspectives:
    - Modes of transport: In the future, the greatest potential for CO2 savings is probably to be found in public and private transport. Extensive decarbonisation of public road transport and private motor vehicle transport is technically possible in the long term through the increased use of electricity and hydrogen as well as battery and fuel cell technology and the use of renewable sources of energy, supplemented by measures on the vehicle. This development is indeed necessary in order to meet the German government's energy and climate targets up to 2050.
    - Sources of energy fuels/problem of ILUC (indirect land use change): Gas and renewable methane as a storage medium are also becoming more important (power-to-gas / hydrogen). The fact that methane does not have the mixing limits imposed on hydrogen is positive. In addition, the raw material base for bio-methane is broader than for other biogenic fuels, which fosters the use of ILUC-free raw materials.
- Action areas:
    - From 2015, biofuels that have a particularly good greenhouse gas balance will count more heavily towards the greenhouse gas avoidance quota (greenhouse gas quota). If it transpires that certain particularly innovative biofuels require particular encouragement and going beyond the general quota-based support, the German government will look into suitable measures.

- From 2017, the first series-produced fuel cell vehicles are expected on the market. The industry is currently also working on concepts to expand the hydrogen infrastructure in Germany. In view of this, the German government will investigate whether steps should be implemented to support the market introduction of hydrogen as a fuel used in fuel cell vehicles, and if so, what these steps should be.
- Set up the “Zukunft Lkw” (truck future) innovation initiative. Focal points include possible development pathways for the truck with the aim of safeguarding energy sources over the long term through alternative fuels and innovative drives as a supplement to the diesel engine, as well as improved vehicle design (including analyses (technical / economic /infrastructure) for the use of CNG, LNG, dual fuels and long-term options for electrification / hydrogen).
- Fuels: as in maritime shipping, LNG is a promising fuel for inland shipping. Biofuels (including vegetable oil, biodiesel) may be of interest for selected areas. In the long term, hydrogen based on the existing renewable energy potentials could be used, possibly in the form of liquefied hydrogen for large vessels, as well as with compressed gaseous hydrogen
- Fuel cell technology: Research and development efforts for fuel cell vehicles have had concrete success. Large automobile manufacturers have announced that the first series-produced car with fuel cells will be launched in the coming years (as of 2017). The relevant activities by government, science and industry are gathered together under the umbrella of the “national innovation programme for hydrogen and fuel cell technology”.
- Together with science and industry, the German government will continue the innovation and research activities in the field of hydrogen and fuel cell technology in Germany and support this within the framework of the NIP. Particular attention will be paid to market activation here.
- To support market preparation and ensure competitiveness with other alternatives, the German government will investigate whether steps should be implemented to support the market introduction of hydrogen as a fuel used in fuel cell vehicles, and if so, what these steps should be. (22)

d. Denmark

The Danish hydrogen and fuel cell venture has since 2003 been built on two national strategies. These have directed the overall goals and general framework. In 2003 the Danish Energy Agency and Energinet.dk, both public funding, sent out a general strategy for development and research in fuel cell technologies. This strategy was drawn up in collaboration with the interested companies and research environments. The Danish Energy Agency added to the strategy in 2005 when it established a research and development strategy regarding hydrogen technologies – a strategy which also underlined the close connection between the development of hydrogen and the fuel cell technologies.

The effort to create the two strategies has produced a shared comprehension of the outstanding Danish core competences. Furthermore, it has strengthened the awareness of the necessity of dynamic co-operation between public and private actors. The strategies' recommendation to create an efficient organizational framework for the national effort led to the establishment of The Danish Partnership for Hydrogen and Fuel Cells in 2007. This was one of the first public-private partnerships focused on environmentally efficient technology. The strategies have also enabled the state-funded energy programs to optimize the utilization of their resources in this area.

The aim of the two national strategies is to ensure that Danish research and developments are focused on core competences. More specifically the strategies focus partly on areas where Denmark retains particular qualifications and a strong position, and partly on areas showing great market potential globally. Additionally, the strategies aim to involve Danish industries in the endeavour to commercialize products and systems solution in order to secure a leading position for Denmark in this field. Finally, the support for Danish research, development and demonstration must be flexible enough to adjust to international advances.

In addition to this, Denmark has become skilled in the art of collecting results and information across disciplines and in integrating these in efficient systems solutions. On top of this, the energy technological state funded programs are strategically and efficiently co-operating to develop the framework for the technological effort in Denmark. At first, this collaboration was mostly evident in fuel cell (in 2003) and hydrogen (in 2005) research and development strategies. In 2005, the Nordic Transport political Network started a project called "Hydrogen Highway Link Network". The purpose was to link 15 hydrogen refuelling stations across Denmark to create a country-wide hydrogen highway.

Later on these strategies have been elaborated by shaping concrete development goals for the separate technologies. The co-operation between researchers, the industry and state-funded programs was extended further at the establishment of The Danish Partnership for Hydrogen and Fuel Cells in 2007. This efficient organization of the hydrogen and fuel cell industry has made it possible to optimize the use of the limited Danish funds granted for research, development and demonstration. Trusting and professional relations between vital industrial partners have been established. In collaboration with public stakeholders, these partners have updated the strategic development goals and milestones for the commercialization of the technologies.

Strategies: The need for support and resources

In 2005 it was estimated that the need for state-funding for hydrogen and fuel cell technologies would be 1.5-2.0 billion Danish crones (0,2 - 0,27 billion Euros) up until 2015 as a supplement to the industry's private funding. Since the composition of the strategies, the total state funding (including the Danish share of the EU's energy programs) has increased from almost 50 million kroner (6,71 million Euros) in 2004 to more than 200 million kroner (26,82 million Euros) in 2010. In addition to this, regional district funds have also benefitted the hydrogen and fuel cell area to some extent. (23)

During the past decades Danish energy policy has been built on three main objectives:

- The sustenance of a high level of supply assurance. This is to be ensured through extensive domestic production of energy and by dispersing the supply to include multiple sources of energy.
- The Danish energy policy must contribute to the improvement of the environment and climate, particularly by limiting the emission of greenhouse gases such as CO2.
- The Danish energy policy must support the effort towards sustainable economic growth. This support must come in the form of new energy technologies which can create export growth and an increase in manufacturing jobs. The development of an efficient energy network will ensure stable prices for the consumers. Further to this, stable prices will benefit the global competitiveness of the Danish business and trade community.

Hydrogen and fuel cells are technologies which will benefit and contribute to all of the three objectives of the Danish energy policy. (23) The new Danish Strategy for Hydrogen and Fuel Cells "Balancing the Future Danish Energy System" was finished in December 2012 by The Danish Partnership for Hydrogen and Fuel Cells. The New Strategy is a renewal of the existing Hydrogen Strategy and was done as a continuation of the new Danish political energy goals, which includes the main goal to phase out all fossil fuels by 2050. (24)

e. Sweden

Hydrogen Sweden

Hydrogen Sweden is a non-profit Public Private Partnership with around 50 members and investors from local, regional and national government as well as the industry, research and NGO's. The partnership promotes a balanced and pragmatic approach to hydrogen. The mission of Hydrogen Sweden is to facilitate the introduction of hydrogen as an energy carrier in Sweden. To do so Hydrogen Sweden initiates demonstration projects, disseminates information and strengthens the collaboration between actors from various fields with a joint interest in hydrogen technology.

Hydrogen Sweden is one of the founders of the Scandinavian Hydrogen Highway Partnership (SHHP) whose vision is to make the Scandinavian region one of the first European hydrogen societies. The Scandinavian network dealt with a significant number of projects of which many have had large investments' budgets for cars and infrastructure. Additionally, Hydrogen Sweden is partner in the TEN-T financed project HIT (Hydrogen Infrastructure for Transport) which will deliver a first proposal for an implementation plan during 2014. The targets are to develop national implementation plans for Sweden, Denmark, the Netherlands and France. The development of each should consider the existing implementation plans of Germany and the UK. The 25 organizations participating in the Swedish HIT-study can be seen as an early Swedish H2Mobility initiative.

Policies for transport and infrastructure

In Sweden applies a range of policy instruments to reduce the transport sector's climate impact. In the past years, ethanol, biodiesel and biogas have been introduced as alternative fuels. Electric vehicles (BEV and PHEV) get off the starting blocks. Introduction of hydrogen vehicles and hydrogen infrastructure in society relies so far on limited regional and local initiatives.

To guarantee competition between alternatives, Sweden considers that the support of technologies for renewable fuels should be “technology neutral”. There are critics to this approach as it is difficult to implement such a vision. The reason is that the conditions to establish new technologies on the market differs between different fuels, as for hydrogen it requires a new production- and distribution line as well as new vehicles technologies. A specific law was introduced 2005 to increase the availability of renewable fuels, and made it mandatory for filling stations to provide at least one alternative fuel. However, the law mainly led to an installation of an ethanol pump which is also the cheapest option. Later, a subsidy for other renewable fuels was introduced. Thus, in combination with other factors, biogas pumps were built at existing or new refuelling stations.

In 2008, the Swedish government set a limit value of greenhouse gases emissions to the atmosphere in 2050. The target for the transport sector is to achieve a fossil free vehicle fleet till 2030, as an intermediate target for a transport sector. In addition, Sweden defined and analysed this in the public investigation "Fossil Independence for Road Transport” (*Fossilfrihet på väg*). The definition of a fossil-free fleet of vehicles is, according to the investigation, a road transport whose vehicles primarily are powered by bio-fuels or electricity (including Fuel Cell vehicles). Therefore, a national roadmap for a wider introduction of zero emission and biogas vehicles is expected soon. Incentives and subsidies are discussed and proposed in the investigation, among others different versions of a bonus-malus regulation. Nevertheless it is still too early to know how it will be designed. Both the conservative/liberal block and the socialist block advocated such a system in their campaigns for the past election in September 2014.

The Swedish FoU effort Mistra Fuel Cell Program was a national coordinated approach to safeguard and increase knowledge and research within academics and business. The program was running between 1997- 2010 with a budget of 121 MSEK (12 Mio. Euro). After 2010, fuel cells and hydrogen a technology has been managed in a technology watch program, recently reformed to be closer linked to the Swedish vehicle industry. During the first decade of the century, several regional initiatives in the south west of Sweden were established. Regions and cities tried to make sure that its industries and businesses were updated and development in the hydrogen business. In 2003, a network organisation was set up in 2003 as a regional project, and developed into a national member organisation for public and private stakeholders.

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3. Regulations, Restrictions and Conditions

European Union

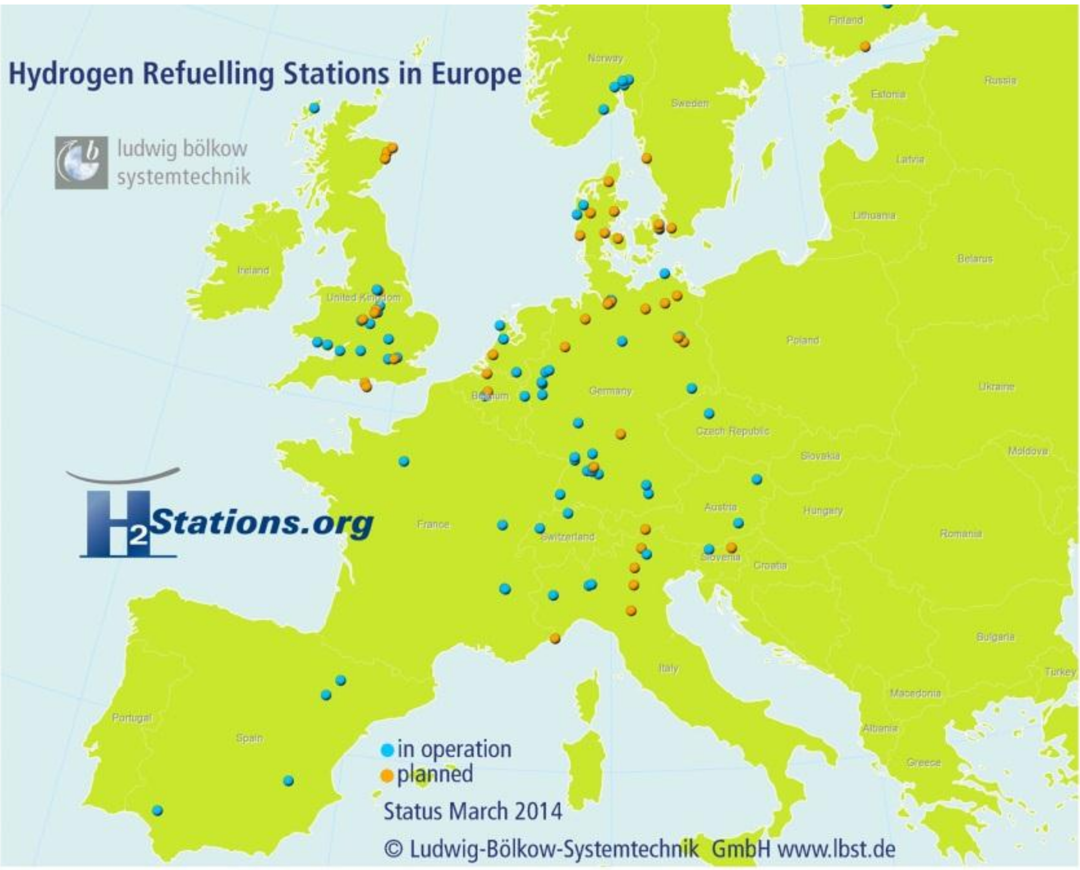

Figure 5 Hydrogen Refuelling Stations in Europe
(Source: H2stations.org by LBST)

Type-approval of hydrogen-powered motor vehicles

The production of hydrogen-powered, eco-friendly vehicles on the European car market is becoming increasingly important. The European Commission therefore considers it necessary to establish uniform technical requirements for the type approval of motor vehicle category to support their free movement within the internal market.

Act

Regulation (EC) No 79/2009 of the European Parliament and of the Council of 14 January 2009 on type-approval of hydrogen-powered motor vehicles and amending Directive 2007/46/EC (Text with EEA relevance).

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Obligations of manufacturers

The manufacturer must ensure that the hydrogen components and hydrogen systems meet the requirements of this regulation. The owner of the vehicle must provide the approval authorities with appropriate information on the characteristics of the vehicles and the test conditions. Hydrogen components and hydrogen systems shall meet the following requirements:

- The electrical, mechanical, thermal and chemical influences safely withstand;
- To the expected temperatures and pressures during their lifetime reliably withstand;
- Specified in the implementing measures reliably withstand operating temperatures;
- To be constructed so that they can be installed in accordance with the provisions of Annex VI;
- The materials of the components of hydrogen components and hydrogen systems must be hydrogen-compatible;
- Ensure interoperability with hydrogen filling stations;
- Hydrogen systems must be protected against overpressure, the hydrogen components shall be marked in accordance with the provisions of the implementing measures.

Transitional provisions

Since February 2012, national authorities shall consider certificates of conformity for new vehicles as no longer valid, if the vehicles do not comply with the requirements of this regulation. When new hydrogen-carrying components do not meet the requirements of this regulation, the national authorities shall prohibit the sale of these components.

Background:

Sustainable development and environmental protection are key objectives of the European Union. As a fuel, hydrogen could form an interesting alternative to fuels currently used. Therefore, it is extremely important to standardize the technical requirements for such vehicles (in the EU). This is the only way to prevent that different national technical regulations affect the distribution of these vehicles. Thus the act implemented the following definitions:

- Hydrogen powered vehicle means any motor vehicle that uses hydrogen as fuel to propel.
- Hydrogen components: the hydrogen container and all other parts of the hydrogen-powered vehicle, which are in direct contact with hydrogen or components of the hydrogen system.
- Hydrogen system: an assembly of hydrogen components and connecting parts that are built into a hydrogen-powered vehicle, with the exception of the drive system and the accessory drive system. (25)

European Agreement Concerning the International Carriage of Dangerous Goods on Roads (ADR) (26)

The European Agreement concerning the International Carriage of Dangerous Goods by Road was done at Geneva on 30 September 1957 under the auspices of the United Nations Economic Commission for Europe, and it entered into force on 29 January 1968. The agreement itself was amended by the protocol amending article 14 (3) done at New York on 21 August 1975, which entered into force on 19 April 1985. The Agreement itself is short and simple. The key article is the second, which states that apart from some excessively dangerous goods, other dangerous goods may be carried internationally in road vehicles subject to compliance with:

- The conditions laid down in Annex A for the goods in question, in particular as regards their packaging and labelling; and
- the conditions laid down in Annex B, in particular as regards the construction, equipment and operation of the vehicle carrying the goods in question.

Annex A: General provisions and provisions concerning dangerous articles and substances:

- Part 1 General provisions;
- Part 2 Classification;
- Part 3 Dangerous goods list, special provisions and exemptions related to limited and excepted quantities;
- Part 4 Packing and tank provisions;
- Part 5 Consignment procedures;
- Part 6 Requirements for the construction and testing of packaging's, intermediate bulk containers (IBCs), large packaging's and tanks;
- Part 7 Provisions concerning the conditions of carriage, loading, unloading and handling.

Annex B: Provisions concerning transport equipment and transport operations:

- Part 8 Requirements for vehicle crews, equipment, operation and documentation;
- Part 9 Requirements concerning the construction and approval of vehicles.

Applicability of ADR:

Notwithstanding the transitional measures provided for in ADR 2013, which allow compliance with certain requirements contained in previous editions, the editions of ADR published by the United Nations which may be used for compliance are as follows:

- Until 30 June 2013: 2011 edition (ECE/TRANS/215, Vol. I and II), and corrigenda 1 and 2
- As from 1 January 2013: 2013 edition (ECE/TRANS/225, Vol. I and II), and corrigendum 1. (26)

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National Regulations, Restrictions and Conditions

Although the EU prepared guidelines for the use of hydrogen in the transport sector, the national regulations, restrictions and conditions are highly diverse in each considered country. Hence an individual contemplation is necessary. In order to demonstrate and understand each countries provision better they will be illustrated individually in the following chapter. The following chapter will show the each stage of the hypothetical journey through the NSR. Thus it is well suited to demonstrate each provision directly in a specific and relevant case.

4. The journey through the NSR – single stages

Specifications

Before the journey through the NSR begins, some relevant specifications need to be clarified. During the trip from Scotland to Sweden all project partner of the HyTrEc-project will be visited. To do so a hydrogen car is needed. The current prices for hydrogen cars and the hydrogen fuel are quite variable and fluctuating. Hyundai has launched their first large-scale production of Fuel Cell cars. Hyundai announced that the Hyundai ix35 FCEV will be available for European customers in 2015. According to Toyota, their fleet of fuel cell cars will be available for (parts of) the European market from summer 2015 (27). Hyundai proposed that the ix35 shall be available on a monthly leasing contract for roughly 400-500 Euro per month in California, USA (including service and fuel) and for about 1,815 Euro per month in Europe (48 months leasing contract, no deposit and 20,000 Km inclusive) (28). The monthly leasing rate for the European market is currently still uncertain. By 2015, the Hyundai ix35 FCEV shall be available for approximately 65,000 Euro (net) and the Toyota FCV-R shall be available for about 50,000-90,000 Euro (29). The tank capacity of the Hyundai ix35 FCEV is 5.64 Kg at 700 bar and its average consumption is 0.95 kg per 100km (30). Therefore, the driving range of the Hyundai ix35 FCEV is according to manufacturer's instructions 594 Kilometre (31). Currently, the retail price for hydrogen is about 9.50€ (Germany) (31). An upper bound for a H_2 price that is acceptable to the consumer is likely to be < c. 8-9€/kg. This is the hydrogen price assumed in analysis of Aberdeen's HRS economics. A lower price may be more suitable for e.g. vans, so sensitivities to the sale price should be considered.. Thus, all the following assumptions about the consumptions during the single stages of the journey are based on this average consumption.

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The layout of the route

As the following map shows the journey through the NSR will start in Aberdeen, Scotland through England, France, Belgium, Netherlands, Germany as well as Denmark and will be finished eventually in Gothenburg, Sweden. However, the map shows two possible driving routes. Route 1 is the primary route and route 2 the alternative. The document focuses on route 1 but also describes the alternative route. Nevertheless, both routes are possible to drive but route 1 is shorter and less time consuming.

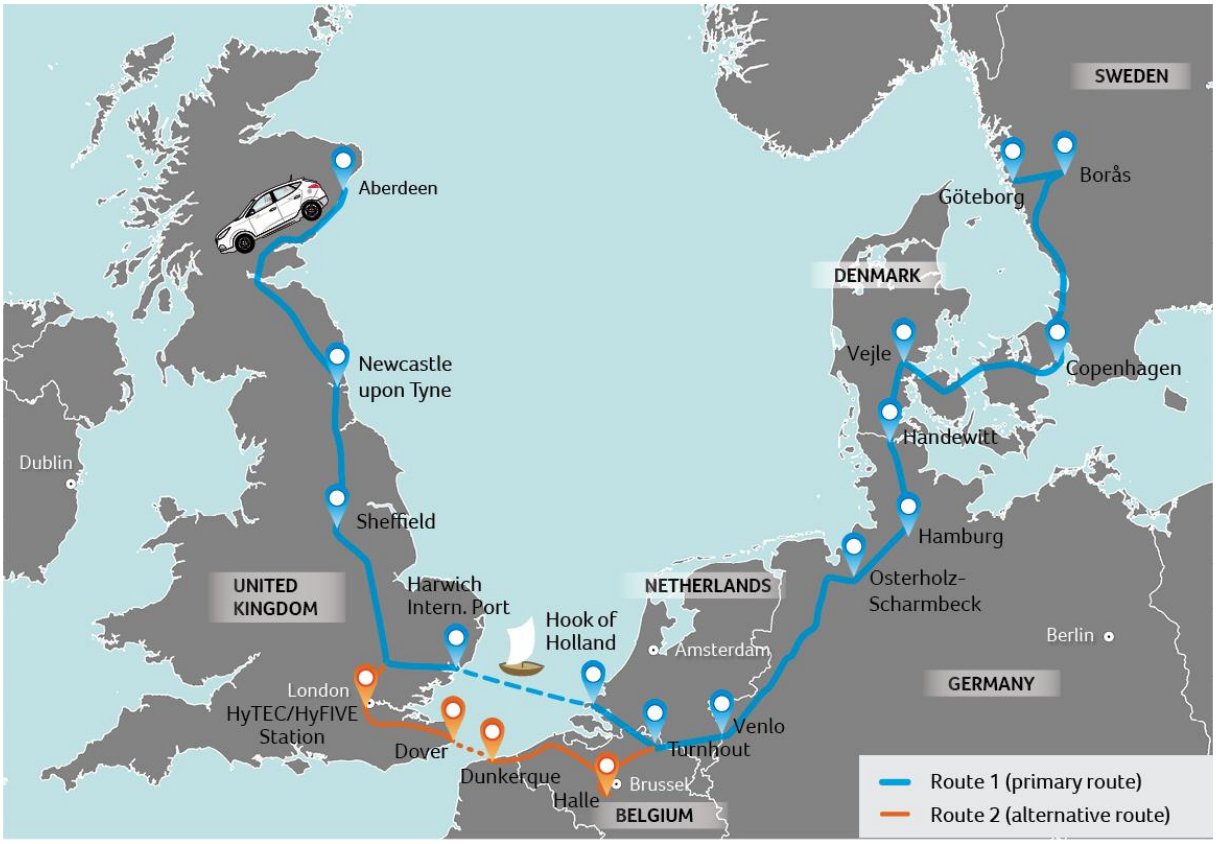

Figure 6: The journey through the NSR (Source: European Institute for Innovation)

a. United Kingdom

Technical Data

The journey through the United Kingdom starts in Aberdeen and leads all the way down to Harwich International Port. This is a distance of 886.8 km or 551 miles which means, that there is a need to have at least one stop to refill the car. The total time needed to take the tour is approximately 10 hours and 40 minutes. The whole tour would be split up in 3 single stages with one stop-over to refill the car (Alternatively it would be possible to drive from Gateshead College directly to Newcastle up-on Tyne. At Newcastle Port is a ferry service to Amsterdam. This service is operated by DFDS who makes no restrictions on the transport of a hydrogen vehicle with one of their ferries. They just ask to inform in advance that a hydrogen fuelled vehicle will be on board. No other special regulations oc-cur. DFDS is also operating a ferry link from Dover to Calais and vice versa. This alternative route could be important if it turns out that the provided data about average consumption is not accurate enough. If the alternative route is chosen, it is recommended to drive to the CUTE hydrogen station in Amsterdam to refill the car. After the refuelling it is recommended to continue the ride to the pro-ject partner WaterstofNet in Turnhout, Belgium (138 km)). The hydrogen consumption during the tour through the UK amounts to be about 8.43 Kilogram. The current national price of hydrogen re-fuelling is about 7£/kg (32). It was decided to plan a stop-over at the ITM Power Green Hydrogen filling station in Sheffield. It is the closest hydrogen refuelling station to Aberdeen. The distance be-tween Aberdeen and Sheffield, including a stop-over at Gateshead College, could be reached with a full tank of hydrogen.

Trip	Distance	Fuel Consumed	Travel time
Aberdeen – Gateshead College	365 km , 227 mi	3.4675 kg	4 hours 50 min.
Gateshead College – Sheffield filling station	203 km, 126 mi	1.9285 kg	2 hours 18 min.
Sheffield filling station – Har-wich International Port Ferry transfer	319 km, 198 mi	3.0305 kg	3 hours 32 min.
Alternative: Sheffield filling station – HyTEC / HyFIVE station (LHR)	265 km, 165 mi	2.52 kg	2 hours 53 min.
HyTEC / HyFIVE station (LHR) – Dover Port	169.2 km, 105 mi	1.61 kg	1 hour 51 min.
TOTAL	887 (1002.2) km, 551 (628) mi	8.4265 (9.526) kg	10 hours 40 min (11 hours 52 min.)

Table 1: Technical Data UK

Hydrogen Infrastructure

The hydrogen infrastructure in the UK varies between each member country. There are currently nine operating filling stations in Eng-land, two in Wales and two in Scotland (Aber-deen refuelling station at Kittybrewster is still to be built, but should be operational by the

Figure 7: Aberdeen hydrogen refuelling station under construction.

end of 2014) while one of them is located in the Hebrides (18). Seven further hydrogen stations are planned in England. Thus, England's hydrogen infrastructure is better developed than the rest of the UK.

There are differences between those hydrogen filling stations regarding the type of fuel offered and accessibility. Most of them offer compressed hydrogen (CGH$_2$) with a pressure of 350 or 700 bar. Due to different filler plugs not all of them are able to serve passenger cars but they do serve buses, and importantly, not all of the filling stations are publically available. Nine of the 13 operating stations are open for public access but at some of them an appointment has to be made in advance.

	Public Access (with or without prior arrangement)	Providing fuel for passenger cars (CGH2 350, 700)	Total
Operating	9	11	13
Planned	3	5	7

Table 2: Hydrogen Refuelling Stations UK (18)

Besides the operating and planned hydrogen stations there are more refuelling stations envisaged within several projects. One of those projects is the UK Hydrogen Highway which is split up in a Northern and a Southern part. The Northern Hydrogen Highway is located on the eastern coast of Scotland, north of Aberdeen. It is planned to develop this region as a show case for future technologies in the field of renewable energies and energy efficiency. Further prospected filling stations are planned to be built at the Isle of Wight within the Eco-island Project. This hydrogen infrastructure is planned to produce and provide fuel for maritime as well as road vehicles.

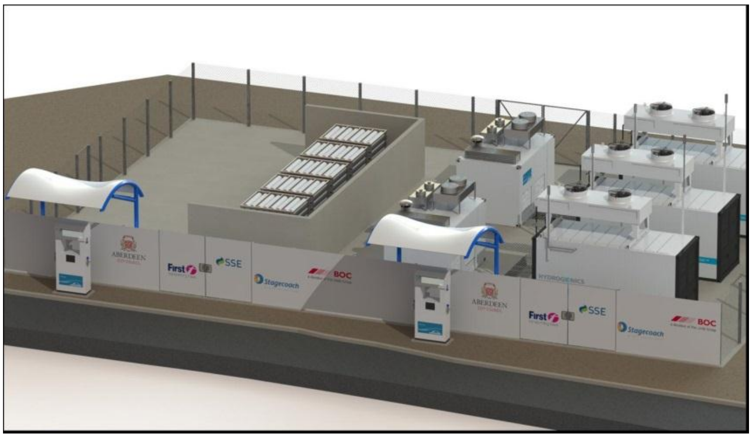

Figure 8: Aberdeen hydrogen refuelling station overview (Source: Aberdeen City Council)

For the purposes of the assumed hypothetical journey the current hydrogen infrastructure in the UK may be characterized as absolutely sufficient, not taking into account that there is no filling station with public access in Aberdeen. Currently, there is only one hydrogen filling station that serves the Aberdeen bus fleet which means that the filler plugs would not fit on a passenger car. Nevertheless, as part of the Aberdeen City Hydrogen Energy Storage project, a second refuelling station is being built to the South of the City which will be publicly accessible and able to refuel at 350 & 700 bar (buses and cars). Another problem may occur when maintenance works are required. Currently, no garages or service points which offer special services for hydrogen vehicles could be found. This is not a problem as long as the works do not affect the engine, the pipes or the tank (hydrogen components). Nevertheless, a hydrogen maintenance facility is being integrated into the council's existing fleet depot at Kittybrewster to service the bus fleet and fleet vehicles as part of the Aberdeen Hydrogen Bus Project. Hence, there is potential for this to become available to additional vehicles in future.

Road Interferences

There are some incidences on the way from Aberdeen down to Harwich International Port. The first one occurs in Edinburgh when crossing the Forth Road Bridge which leads across the Firth of Forth at a length of 2.5 km (1.5 mi). But there are no special restrictions or requirements at this bridge for hydrogen vehicles as long as they are licensed to be driven on the public road network.

When travelling to Gateshead College the River Tyne has to be crossed. This is possible via several bridges or the River Tyne Tunnels. For the purposes of this journey it is assumed that the River Tyne Tunnels are used. Here special regulations occur for hydrogen vehicles. River Tyne Tunnels are classified as category "D" according to the "European Agreement concerning the International Carriage of Dangerous Goods by Road" (ADR) (33). This means that restrictions occur for any dangerous goods which may lead to a very large explosion, a large explosion, a large toxic release or a large fire. Further the ADR states that fuel cell cartridges containing liquefied flammable gases or hydrogen in metal hydrides are classified as dangerous goods (UN No. 3478, 3479) (34). The Tyne Tunnels Byelaws do not explicitly prohibit passing the Tunnels with a FCEV but it may be assumed that it falls under the category of dangerous goods. Thus it is recommended to inform the tunnel manager in advance (35). A corresponding request at the River Tyne Tunnels had no result so far.

Regulations and Restrictions

There is no common regulatory framework for the admission and use of hydrogen vehicles in the UK. Driving a hydrogen fuelled vehicle is illegal unless a special permission, a Vehicle Special Order (VSO) is possessed. That means that every car which uses hydrogen as a fuel has to be registered for a VSO individually. The issuing authority is the Vehicle Certification Agency, a national executive agency of the UK´s Department for Transport and it is responsible for the Type Approval of all road vehicle used in the UK. For the application process all available technical information about the vehicle such as data regarding the hydrogen system as well as the details of the components used is needed.

Further a detailed map of the vehicle operational area has to be submitted. If a VSO is obtained, it is valid for one year within England, Wales and Scotland. Different regulations occur in Northern Ireland. The application and certification process is free of charge.

Conclusion

As it is described above, it would be possible to travel this part of the journey without any serious hindrances or incidences. The hydrogen infrastructure is sufficient but not nationally available. That would make it difficult to travel in Scotland or Northern Ireland. In fact it would be possible to drive a FCEV comfortably in England only. Another point is the infrastructure of the maintenance services. It may be assumed that there are only a very small number of garages and service providers able to handle hydrogen vehicles, at present. Nevertheless, the service for a FCEV is provided by the manufacturer in the most cases anyway. Due to anomalies within EU regulations relating to Hydrogen, Revolve Technologies Ltd (who provided the Council with Hydrogen Hybrid vans) are working with the VCA to submit a formal revision to the emissions regulations to cover Diesel /Hydrogen blends. As such, legislation for H_2 has not yet been included and a VSO requirement is however still required in order to comply with "construction and use" regulations that currently only permit LPG to be used in the UK as a Road Fuel. So it is possible to use a hydrogen fuelled car in the UK but in a limited scope. The hydrogen infrastructure which is mainly concentrated in England as well as the administrative limits and regulations could limit the usability of a hydrogen vehicle.

b. Belgium

Technical Data

The trip from the coastline of the European mainland to the German border would cross two countries: Belgium and the Netherlands. Due to the fact that the project partner is located in Belgium and the Netherlands we would concentrate on this part of the journey regarding the infrastructure and the regulations. The travel distance from Hook of Holland where the ferry from Harwich International Port arrives to Venlo at the German border is 230.9 km or 143.6 mi. It would take approximately 3 hours and 10 min. to travel and about 2.1675 kg of hydrogen would be consumed. Due to the fact that the car was refilled in England the last time, it would be absolutely necessary to go directly to the next available refuelling station in the Netherlands. These stations are located in Rhoon (Rotterdam, Netherlands) and Helmond (NL) and both are operated by the project partner WaterstofNet. Three stop-overs are planned. One stop is required to refill the car in Rhoon, one at WaterstoffNet in Turnhout and one at the WaterstofNet station in Helmond (NL).

Figure 9: Waterstofnet refuelling station Halle (Source: WaterstofNet)

Trip	Distance	Fuel Consumed	Time
Hook of Holland Port – AirLiquide HRS, Rhoon, Netherlands	32 km, 20 mi	0.304 kg	31 min.
AirLiquide HRS, Rhoon, Netherlands – WaterstofNet, Turnhout	87 km, 54.1 mi	0.826 kg	1 hour 8 min.
WaterstofNet, Turnhout - Helmond HRS	63.2 km, 39.3 mi	0.6 kg	50 min.
Helmond – Venlo (Netherlands / German border)	48,7 km, 30.2 mi	0.437 kg	41 min.
Alternative: Dunkerque ferry, France (Route de la Capitainerie Ouest) - Colruyt distribution-center HRS, Zinkstraat 1, 1500, Halle, Belgium	177 km, 110 mi	1.6815 kg	1 hour 47 min.
Colruyt distributioncenter HRS, Zinkstraat 1, 1500, Halle, Belgium – WaterstoffNet Turnhout	110 km, 68.3 mi	1.045 kg	1 hour 17 min.
TOTAL	230.9 (287) km, 143.6 (178.3) mi	2.167 (2.7265) kg	3 hours 10 min (3 hours 4 min.)

Table 3: Technical Data Belgium

Hydrogen Infrastructure

The hydrogen infrastructure in Belgium is arranged very clearly. In fact there are only two hydrogen fuelling stations within Belgium; none is dedicated for filling cars at 700 bar. One station is used for forklifts, it uses an electrolyser to produce green hydrogen (WaterstofNet station in Halle, near Brussels) and the other one is used for busses. The latter relies on hydrogen as a by-product (HighVLoCity in Antwerp). These stations have no public access. Further one station is planned that will offer fuel for passenger cars. It is possible to fuel a car at the station in Halle, but only at 350 bar. In the Netherlands three fuelling stations are operational, at two of them, cars can be filled at 700 bar (Airliquide, Rotterdam and WaterstofNet, Helmond), and the other one is a bus-station in Amsterdam. Three more stations are planned; all of them would be able to fill cars.

Figure 10: Landscape of the WaterstofNet refuelling station in Helmond (Source: HyTrEc)

No specific information could be gathered regarding the availability of garages and service providers that are able to serve FCEV's. All the necessary maintenance will be covered by service contracts offered by the manufacturers in both Belgium and the Netherlands.

	Public Access (with or without prior arrangement)	Providing fuel for passenger cars (CGH2 350, 700)	Total
Operating	4	3	5
Planned	3	2	3

Table 4: Hydrogen Refuelling Stations Belgium & Netherlands (18)

Road Interferences

The first incidence that occurs is the shipping passages from Harwich International Port to Hook of Holland. The operator Stenaline makes no restrictions on the transport of a hydrogen vehicle with one of their ferries. They just ask to inform in advance that a hydrogen fuelled vehicle will be on board. No other special regulations occur. For the sake of completeness other ferry operators were contacted and other ferry links in the UK were elaborated. Some ferry operators ask for a safety data sheet or a prior announcement but no special regulations or restrictions occur. This indicates that it should be very easy to travel a ferry link with a FCEV. Furthermore the other option to cross the channel would be to use the channel tunnel. The regulation of the channel tunnel prohibits any vehicle that is capable of running on flammable gas. Therefore the tunnel would not be suitable to cross the channel between the UK and Belgium. Other road incidences like tunnels or bridges do not occur in Belgium.

Regulations and Restrictions

No interferences which would require special permissions or procedures occur during the trip through Belgium, neither bridges nor tunnels or ferries. Hydrogen cars in Belgium have the same restrictions as LPG in tunnels, parking lots and bridges. Currently, Belgium has two hydrogen cars driving in Brussels. These are maintained and registered in Germany. Hence, Belgium has not yet developed any hydrogen regulations.

Conclusion

The trip through Belgium and the Netherlands via Rhoon (Rotterdam, Netherlands), Trunhout and Helmond could be achieved. The hydrogen infrastructure is not that well developed, but it may be reckoned as sufficient for the prospected journey. But nevertheless for an every-day use it is not sufficient enough. No information regarding the garages and service points as well as regulation and restrictions could be gathered.

c. Germany

Technical Data

The trip from the Netherlands/ German border to the German / Danish border has a length of 626 km or 388.7 miles and takes approximately 6 hours and 41 minutes. About 5.95 kg of hydrogen are consumed during this journey that means that at least one stop-over is necessary for refilling the car. The refuelling of the car will be at the CEP HRS at Hafencity, Hamburg. Between Hamburg and Venlo there is another stop in Osterholz-Scharmbeck where the project partner EIfI is located.

Trip	Distance	Fuel Consumed	Time
Venlo – Europäisches Institut für Innovation (EIfI), Osterholz-Scharmbeck	338 km, 210 mi	3.21 kg	3 hours 26 min
Europäisches Institut für Innovation (EIfI) – Refuelling Station, CEP Hafencity, Hamburg	123 km, 76.7 ml	1,17 kg	1 hour 35 min
Refuelling Station CEP Hafencity – Handewitt (German / Danish border)	165 km, 102 mi	1.57 kg	1 hour 40 min
TOTAL	626 km, 388.7 mi	5.95 kg	6 hours 41 min

Table 5: Technical Data Germany

Hydrogen Infrastructure

The hydrogen infrastructure in Germany is relatively well developed with more than twenty operating hydrogen refilling station all over the country. But it has to be remarked that there are core areas where several stations can be found. Such core areas are Hamburg, Berlin, Stuttgart and the Ruhr area. Between these areas there are some hydrogen refuelling stations. But also large blank areas where no refuelling station can be found. Those areas are mainly in the middle part of Germany reaching from Dresden to Berlin, Wolfsburg, Düsseldorf and Frankfurt am Main to Munich. In the North-Eastern and North-Western part of the country there are also no refuelling stations available except in Rostock at the Baltic Sea shore. Nevertheless, there is an arch of relatively dense hydrogen infrastructure reaching from the South-Western to the Northern part.

That indicates that on the one hand the most dense hydrogen infrastructure in Europe can be found when looking at the bare numbers and on the other hand this infrastructure is concentrated at the metropolitan areas and there is no infrastructure at the rural areas. So in fact this means that driving a hydrogen fuelled vehicle is possible only in these metropolitan areas. The plans for future hydrogen refuelling stations are very ambitious. 37 new stations are planned and most of them will offer public access as well as fuel for passenger cars. The relatively huge number of hydrogen stations in Germany is not taking wonder when considering the ambitious plans of the German federal government. Thus a publically accessible network of 400 hydrogen filling stations shall be established until 2023 (36).

	Public Access (with or without prior arrangement)	Providing fuel for passenger cars (CGH2 350, 700)	Total
Operating	14	20	26
Planned	35	36	37

Table 6: Hydrogen Refuelling Stations Germany (18)

In fact the infrastructure for hydrogen filling stations is relatively well developed in Germany, but the infrastructure of service and maintenance providers for hydrogen technology is not. Only a very limited number of garages which are able to serve and maintain hydrogen cars could be explored. But, as already mentioned before, at this status of the overall development it would not be necessary to have a dense network of service points and garages due to the fact that all the maintenance work will be provided by the manufacturers. But in case of an emergency the German Automobile Club (ADAC) provides trained staff that is able to handle a hydrogen vehicle and to deal with eventual dangers professionally. Further there are special regulations regarding the safety of the working environment and the workers in garages serving hydrogen vehicles. These regulations are laid down in the manual "Hydrogen Safety in Workshops" released by the Employer´s Insurance Association in 2009 (37).

Figure 11: Hydrogen bus and refuelling station (Source: own illustration)

Road Interferences

No interferences which would require special permissions or procedures occur during the trip through Germany, neither bridges nor tunnels or ferries.

Regulations and Restrictions

There are no special regulations regarding the use of hydrogen driven cars. The only required document is a regular motor vehicle registration certificate. Such a certificate can be obtained with the responsible licensing authorities under the same conditions as you would register car powered by fossil fuels. Only if you wish to register a car that was back fitted with hydrogen technology special requirements might occur. The same may apply for buses or utility vehicles. Unless no special regulations occur, hydrogen vehicles should be labelled so that they are clearly recognizable and identifiable from the outside. This is an obligation to ensure that the fire and rescue services can identify the car as a hydrogen vehicle in case of an emergency or accident. Nevertheless, the German fire brigades do not see hydrogen as dangerous as other fuels. Any German authority is able to understand the characteristics of, recognize dangers in advance and respond and adapt in the treatment thereon.

Conclusion

It would be possible to travel this part of the journey without any hindrances or interferences. Due to the relatively well developed infrastructure. It is also possible to travel this part of the trip without lacking of fuel. Next to the UK, Germany is the country with the most developed hydrogen infrastructure in Europe. But most of the available hydrogen filling stations are concentrated in only few areas in Germany. These areas are the Ruhr, Stuttgart, Frankfurt, Hamburg, Berlin und partially Munich. Thus an area-wide network of hydrogen filling stations is not available yet. Especially in the middle of the country is almost no infrastructure available. So it would be possible to travel from one place to another but it would be nearly impossible to use a hydrogen car for all-day use outside of the indicated congested areas.

An advantage is that there is no special permission needed as it is the case in the UK. A hydrogen vehicle can be approved for a regular use on German streets in the same way as it is necessary for vehicles driven by fossil fuels. Further no special regulations or restrictions occur for bridges or tunnels unless they are categorized regarding to the mentioned ADR regulations. The infrastructure of garages and service point's cannot be evaluated exhaustively. There are only very few garages in Germany that offer services for hydrogen vehicles explicitly. The employer´s mutual insurance association published a brochure that informs the operators of garages how to ensure the safety of their employees when working with hydrogen vehicles. So the operators are at least informed about the risk prevention and the safety handling of hydrogen vehicles. All in all hydrogen cars could be operated in Germany. But due to the high prices of the cars itself and the fragmentary network of refuelling stations an all-day use is not very feasible.

d. Denmark

Technical Data

During the trip from Handewitt at the German / Danish border to Copenhagen via Vejle, 2.498 kg of hydrogen are consumed. The distance is 351 km and it takes a bit more than three and a half hour to get there. On the way to Denmark the last refuelling station is in Hamburg where the car is going to be filled up. Thus it makes it easy to take the trip and to have a stop-over at Vejle where the project partner Green Network is located. Furthermore, a hydrogen refuelling station is located in Vejle. This hydrogen refuelling station was opened in December 2013 and is part funded by the HyTrEc-Project demonstration. The Copenhagen Hydrogen Network A/S is the operator and Green hydrogen the supplier. The hydrogen refuelling station operates at 70MPa refuelling pressure and its refuelling time equals about 3-4 minutes.

Figure 12: Hydrogen refuelling station Vejle (Source: HyTrEc)

However, it is quite easy and comfortable to travel through the country. Hence it would not be necessary to fill up the car in Vejle because the next refuelling station on the way to Sweden is at Copenhagen which could be reached easily, too.

Trip	Distance	Fuel Consumed	Time
Handewitt – Vejle, Denmark	119 km,74,1 mi	1.13 kg	1 hour 15 min
Vejle - Refuelling Station Copenhagen 1, Copenhagen	232 km, 144 ml	1.368 kg	2 hours 29 min
Total	351 km, 218.1 mi	2.498 kg	3 hours 44 min

Table 7: Technical Data Denmark

Hydrogen Infrastructure

There are not many operating hydrogen filling stations in Denmark yet. But due to the relatively clear size of the country it might seem sufficient. Taking into account that 8 new hydrogen stations are planned it might be assumed that the future hydrogen infrastructure of Denmark is quite well developed. Nevertheless it is questionable whether the infrastructure would be suitable to support an every-day usage of hydrogen cars. There are many islands and many bridges which have to be crossed and ferries have to be used. Thus hydrogen stations should be established at nearly every single island and the distances between the single stations should not be too far to make a daily usage of hydrogen vehicles attractive.

	Public Access (with or without prior arrangement)	Providing fuel for passenger cars (CGH2 350, 700)	Total

Operating	3	3	3
Planned	2	7	8

Table 8: Hydrogen Refuelling Stations Denmark (18)

Road Interferences

The interferences occurring mostly in Denmark are bridges and ferry passages. Bridges that have to be crossed on the trip from Vejle to Copenhagen are the Little Belt Bridge, connecting isle Funen and the mainland, and the Great Belt Fixed Link, connecting Funen and Zealand. Further there is the Oresund Bridge and tunnel connecting Copenhagen and Malmö. No restrictions seem to occur when using these bridges.

Regulations and Restrictions

No special regulations or restrictions apply in Denmark.

Conclusion

The trip through Denmark via Vejle could be easily achieved. The hydrogen infrastructure is not that well developed but it may be reckoned as sufficient for the prospected journey. But nevertheless for an every-day use it is not sufficient enough. No information regarding the garages and service points could be gathered.

e. Sweden

Technical Data

The distance from Copenhagen to Gothenburg via Borås is 391 km of 243 miles and 3.725 kg of hydrogen would be consumed. This means that no stop-over to refill the car is necessary.

Trip	Distance	Fuel Consumed	Time
Refuelling Station Copenhagen - SP Technical Research Institute of Sweden, Borås	329 km, 204 ml	3.126 kg	3 hours 49 min
SP Technical Research Institute, Borås – Hydrogen Sweden, Gothenburg	63 km, 39 ml	0.599 kg	44 min
Total	392 km, 243 mi	3.725 kg	4 hours 33 min

Table 9: Technical Data Sweden

Hydrogen Infrastructure

The Swedish hydrogen infrastructure is still under development. Currently, Sweden has four operating hydrogen filling stations and two more are planned. Only one of the operating stations is publically available.

	Public Access (with or without prior arrangement)	Providing fuel for passenger cars (CGH2 350, 700)	Total
Operating	1	1	4
Planned	2	2	2

Table 10: Hydrogen Refuelling Stations Sweden (18)

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Road interferences

The only interference that occurs is the Oresund Bridge. No hints that it might be forbidden to cross with a hydrogen vehicle or that special regulations are needed could be found.

Regulations and Restrictions

No special regulations neither any restriction occur when driving a hydrogen car.

Conclusion

It should not be a problem to make the trip from Copenhagen to Gothenburg with a hydrogen car. But the hydrogen infrastructure is relatively low developed and still under development. This means that the most operating and planned stations can be found in the South West of Sweden. There is one station in the North of Sweden in Arjeplog, but it is for research and strategic reasons only and not available to the public. Thus it is difficult to have a hydrogen vehicle for all-day use in Sweden. An advantage is that there are no special restrictions and regulations for when driving a FCEV.

Figure 13: Hyundai Sweden (Source: HyTrEc)

5. Conclusion and Recommendations

The outline of the hypothetical journey through the NSR shows that the first steps to a hydrogen based transport sector are done. The distance of the hydrogen journey through the NSR is about 2,487 kilometres or 1,544.miles and the total hydrogen consumption is about 22.77 kg. Thus, the hydrogen vehicle would need at least 4 refuelling stops. However, in this paper, the hydrogen vehicle will need to stop at least 6 times (due to location of the refuelling stations).

The EU prepared guidelines, regulations and restrictions for the use of hydrogen in the transport sector. By publishing the ADR as well as the Regulation (EC) No. 79/2009, the EU created a transnational policy and provision for the use of hydrogen on European roads. By setting obligations to the manufactures and the establishment of a type-approval of hydrogen-powered motor vehicles, a foundation for every EU-member state has been set.

Although the EU has been active in the execution of transnational policies and provisions, most of the member states are still far behind. Almost all of the countries in the NSR do not have cohesive rules and provisions for the use of hydrogen in the transport sector. On top of that, if provisions exist, these tend to vary greatly from each other. In the UK for example, it is required that letters of each fire and rescue department of the corresponding shire that is crossed during the journey are provided. Furthermore the regulation of the channel tunnel which prohibits any vehicle that is capable of running on flammable gas needs to be changed. The research paper of the German TÜV (technical inspection organization) proved that the risk of danger (e.g. explosions) of a hydrogen fuelled car is lower than a conventional petrol or diesel car.

Nevertheless, this creates an enormous effort not only for the driver of the hydrogen car but also for each fire and rescue department. By contrast in Germany for example, the only requirement to use a hydrogen car is to have an approval by the German Federal Motor Vehicle office which is responsible for the registration of vehicles for public road transport. Thus a close cooperation of the countries could lead to a more efficient, cost-effective and faster development of the necessary hydrogen policy and provision.

The same case is the development of a sufficient hydrogen infrastructure. Most countries of the NSR do not have a sufficient hydrogen filling station infrastructure, only Germany and England show a partly sufficient infrastructure. In addition, in case of a break down almost none of the countries have sufficient service points and garages which could deal with a hydrogen car. During the research for this paper only the German Automobile Club (ADAC) seemed to be able to assist in case of a break down. However, this should not be a major problem due to the fact that currently all hydrogen car manufactures provide a four year all inclusive service cover. Although some areas such as Hamburg seem to be suitable, the everyday use of hydrogen is currently in most of the areas of the NSR, not possible.

The problem of the development of a sufficient hydrogen infrastructure seems to be the well-known chicken-egg problem. On one hand, the politics would like to see more hydrogen cars on European streets before they like to invest money into the development of the urgently needed infrastructure. On the other hand, without a sufficient infrastructure potential customers will not consider to buy a hydrogen car if they are not able to refill it. Hence, the car industry needs the hydrogen infrastructure to sell more hydrogen cars.

All in all the development of a cross-sectorial roadmap including the development of economic options for a joint hydrogen infrastructure and the requisite quantity of structures and costs is needed. Additionally, hydrogen must be integrated in transnational fuel legislations. Furthermore, it is important to have constant networking of all actors in the NSR to show support for various target groups and their interests such as research and development, manufacturers, users and service providers, SMEs and crafts; the public sector as well as the general public and media. Additionally a comprehensive approach to sustainability is needed. This could be achieved through the following:

- Ecological, economic and social job creation through innovative markets;
- Competitive, attractive and suitable products with a high energy and resource efficiency for the everyday use;
- Information and participation of citizens and customers.

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