December 2016

Summary:
Studies on sustainable hydrogen supply options in Arnhem, Pärnu and Riga

”H2Nodes – evolution of a European hydrogen refuelling station network by mobilising the local demand and value chain”

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Preface

This summary is based on three studies provided by

- ECN (18th of November, 2016). *HRS Arnhem: Exploration of local renewable production options for transport*. European project: H2Nodes project.
- NT BENE (19th of November, 2016). *Activity 1.1. Study of Sustainable Hydrogen production pathways within larger region round Pärnu.* European project: H2Nodes project.
- Latvian Academy of Sciences (21th of November, 2016). Sustainable hydrogen production and demand for Riga. European project: H2Nodes project.

The summary is provided by ECN, and has been validated by the authors of the other two studies.

1. Introduction

Introduction of hydrogen in transport faces a classical chicken-and-egg problem: FCEVs will require dedicated HRSs (Hydrogen Refuelling Systems), but the introduction of such stations requires concrete and substantial market demand. In order to tackle this problem, the city of Arnhem, Pärnu and Riga are participating in a European (TEN-T) project called "H2Nodes - evolution of a European HRS network by mobilising the local demand and value chains".

These cities have been chosen because they are pioneering locations for hydrogen supply:

- **Arnhem** (the Netherlands) is excellently positioned for a pioneering role in the introduction of hydrogen vehicles and refuelling infrastructure: the city hosts a relatively large share in foreseen 'first users' of FCEVs, both for buses and passenger vehicles. Besides, the region is home to various companies active in the hydrogen chain, and there is sufficient access to potential hydrogen supply. In this context, a hydrogen refuelling station (HRS) will be developed at the Kleefse Waard industrial zone in Arnhem.
- **Pärnu** (Estonia) has been chosen as the location for a hydrogen plant and a HRS because of the City of Pärnu's desire to acquire hydrogen fuel cell buses, the availability of renewable energy from the grid and given the city's geographic location along the North Sea - Baltic core corridor along "Via Baltica" (E67 from Helsinki to Kaunas). The hydrogen plant and HRS in Pärnu will be constructed at Raba Street 31, 80047 Pärnu, Estonia. This site is located 125km south of Tallinn and 230km north of Riga, Latvia.
- In **Riga** (Latvia) and its suburbs (within 30 kilometres from "Rigas Satiksme" bus and trolleybus depots) there are multiple potentially suitable sites for hydrogen production. Via electrolysis, two thermal electrical stations ("Rīgas TEC-1" and "Rīgas TEC-2"), one hydro-electric power plant ("Rīgas HES"), and a heating plant ("Imanta") which produces electrical energy, could supply electricity. Alternatively, a biological waste treatment plant and landfill gas from LLC "Getliņi EKO" could become input of an Steam Methane Reforming (SMR) unit. The HRS' site which has been selected, Vienibas gatve 6, is in ownership of Riga's regional transport agency Rīgas Satiksme.

In this document, main outcomes of the three studies have been summarized, addressing the following questions:

- Which hydrogen production routes have been studied?
- Which routes have been identified as most feasible for the short and the long term?

Finally, the differences in the outcomes of the three different studies are explained.

2. HRS in the municipality Arnhem, the Netherlands

ECN was requested to explore and assess possible routes to deliver regionally sourced green (renewable) hydrogen at the foreseen refuelling station. For this, an analytical framework was established, taking into account four criteria: energy performance, greenhouse gas (GHG) footprint, economic performance and sustainability. The Well-to-Wheels analysis of future automotive fuels and powertrains in the European context, functioned as the main literature source to assess the energy performance and GHG footprint of the various hydrogen production routes (JEC, 2014).

The refuelling station at Kleefse Waard will initially be supplied by hydrogen from steam reforming of natural gas (SMR). On the longer term, the station may consider changing to electrolysis. Initially, the HRS' capacity will be 85 kg H_2/day, with the possibility of a scale-up to 200 kg H_2/day, which corresponds to an input of 150.000 to 400.000 m^3 green gas. To be absolutely sure the hydrogen used in Arnhem is renewable, the city investigated possible regional sources of renewable hydrogen. This can be realised through the greening of the consumed methane in the SMR in various ways, and by the greening of a the electricity consumption in case of a future shift to electrolysis. The following hydrogen production routes were studied:

- **Route #1:** Hydrogen production by an SMR installation on-site of the HRS, with an input of natural gas. This fossil fuel hydrogen reference-production route is included to compare both renewable and non-renewable routes.
- **Route #2:** Hydrogen production by an SMR installation on-site of the HRS, with an input of green gas supplied through the natural gas infrastructure. Greening the hydrogen production is done by buying green gas certificates. This is an interesting route for the Netherland, because the elaborated natural gas infrastructure.
- **Route #3:** Hydrogen production by an SMR installation on-site of the HRS, with an input of biogas. The biogas is physically supplied through a newly constructed pipe.
- **Route #4:** Hydrogen production by an SMR installation on-site of the HRS, with an input of green gas, supplied by a newly constructed pipeline or a LNG truck. The Netherlands can rely on its elaborate natural gas infrastructure. Therefore, this is not a likely production route for the Netherlands. However, it may be an interesting route for other European countries with a less elaborated natural gas infrastructure.
- **Route #5:** Hydrogen production by electrolysis on-site of the HRS, with an input of renewable electricity (anonymous certificates).
- **Route #6:** Hydrogen production by electrolysis on-site of the HRS, with an input of renewable electricity (solar and wind energy).
- **Route #7:** Hydrogen production by electrolysis on-site of the HRS, with an input of the EU electricity mix. This reference-production route has simply an input of the EU-

electricity mix without GOs. This fossil fuel hydrogen production route is included to compare both renewable and non-renewable routes.

ECN's key findings for the short-term (1-5 years) are:

- Local hydrogen production through an SMR unit next to the HRS is most fit, using natural gas from the grid, with the purchase of guarantees of origin (GOs) for renewable methane ('green gas certificates'). This green gas is biogas that has been upgraded and fed into the natural gas grid. Routes via GOs clearly score better than routes with physical delivery of green gas.
- Co-fermentation of manure and other organic substrates has the best perspective as production route for the GOs: of the routes with concrete regional projects, it generally scores best in our analytical framework, taking the clients weighing factors into account. Concrete projects that could (potentially) deliver these GOs are Groen Gas Gelderland and Green BioPower.
- As third- and fourth-best options, routes through GOs were also identified, but then with GOs from municipal waste digestion and waste water treatment, respectively. Concrete relevant projects are ARN and Veolia.
- As a second-best option, SMR hydrogen production was identified that makes use of the physical delivery of biogas from the Veolia waste water treatment plant at Kleefse Waard. However, specific costs will strongly depend on the investment costs to construct a new pipeline and the biogas price. If eventually Veolia is planning to produce biogas or green gas, a more in-depth calculation will be needed to substantiate this option.

For the long term (5-10 years), ECN's key findings are:

- The order of attractiveness for the SMR routes generally stays the same as for the short term. If, however, mono-fermentation of manure is going to be established (which was not foreseen on the short term), this route can be a long-term better choice because the mono-fermentation route accompanied with GOs scores better than the other routes using GOs.
- Depending on the related speed of technology development and cost reduction, hydrogen production options based on electrolysis also become attractive (when greened through the purchase of green power GOs), potentially even more attractive than the routes via an SMR.
- This, however, strongly depends on the relative cost reduction rates in SMR and electrolysis, and uncertainties in these are such that a final winner cannot yet be identified.

Finally, the concise review of the regulatory frameworks indicates that there are no major differences between the various routes in terms of permitting and other legal issues. Some foreseen activities are more common than others but permitting procedures, regulations and norms and standards are available for all of them.

3. An HRS in the municipality of Pärnu, Estonia

NT BENE explored and assessed possible production pathways to deliver regionally sourced green (renewable) hydrogen in or around Pärnu before applying for the INEA grant. The Well-to-Wheels analysis of future automotive fuels and powertrains in a European context, served as the backdrop for assessing the energy performance and GHG footprint of various hydrogen production pathways (JEC, 2014).

NT BENE had been authorised to represent the City of Pärnu in the FCHJU (Fuel Cells and Hydrogen Joint Undertaking) Bus Coalition as of 2015 as the City of Pärnu was interested in employing fifteen FCEV buses on public transport routes. (Twelve buses have been allotted to Pärnu, Estonia in conjunction with the 2017 FCHJU call).

Given the above and possible expansions in the number of FCEVs serving or trafficking via Pärnu, NT Bene set out to map the sources for producing renewable hydrogen in and around Pärnu given a demand of 420 kg H_2/day. In their assessment, NT Bene took due note of national priorities and cross-cutting opportunities regarding the utilization and de-carbonization of biomass and other energy and power sources. Possible sites were identified in a technological park in Pärnu - specifically on Raba Street as all the power sources mentioned below were in close proximity.

NT BENE identified and studied the following five regional hydrogen production pathways:

- **Route #1:** Hydrogen can be produced using electrolysis with a power supply of 3.2MW and 10kV from the national electricity grid using certified renewable electricity from the nearby cogeneration plant which runs on woodchips. The cogeneration plant lies in close proximity to the sites identified at Raba Street, Pärnu.
- **Route #2:** Hydrogen can be produced using electrolysis using solar power produced in a 10MW solar plant. NT Bene identified a former landfill site, which could be turned into a solar farm in close proximity to the sites identified at Raba Street.
- **Route #3:** Production of renewable hydrogen using SMR and biogas from a newly planned biogas plant in Pärnu (also utilizing gas from the Rääma bog area) to be built in close proximity to the sites identified on Raba Street. PAIKRE Ltd. (owned by the City of Pärnu) planned to construct a biogas plant with an annual capacity of 1,300,000 Nm^3 biogas. A local pipeline could easily supply biogas to the identified sites on Raba Street.
- **Route #4:** So-called “trigeneration”. A direct fuel cell plant using a bio-methane and natural gas mixture, which co-produces hydrogen in addition to electricity and heat i.e. *a combined heat, hydrogen, and power (CHHP) installation.*

NT BENE's key findings for the short-term are:

- The H_2 electrolyser plant and HRS would be constructed on the same site in the technological park in Pärnu, which is approximately 300m from "Via Baltica" (Baltic core corridor). In December 2015 a leasehold agreement was signed for Raba Street 31.
- Initially, hydrogen would be produced via electrolysis from water and renewable electricity bought from the grid via Elektrilevi Ltd. The plant would be capable of producing 450 kg H_2/day.
- The construction of the 10 MW solar power would commence in 2017 in order to meet the deadline for operating a zero-emission hydrogen production process by 2018. A direct line would be established from the solar plant to the hydrogen plant and HRS site at Raba Street. From a GHG-footprint perspective, this production pathway has the lowest impact on the environment and global warming. As stipulated in the GA, NT BENE set out to produce hydrogen transport fuel via a totally emission free production process using 100% renewable energy sources in order to reduce the carbon dioxide footprint of and reliance on fossil fuels. Moreover, using solar power also makes it attractive in terms of the business case as the Estonian government subsidises the production of green energy (solar and wind). Having the subsidy (a subsidy for 12 years) confirmed in time, requires commissioning of the solar plant by year-end 2017.

On top of that, NT BENE has charted two long-term options of national importance vis-s-vis the decarbonisation of power and energy which should be explored. For this power and energy decarbonisation the demand for H_2 for transport purposes should increase.

- Expected from 2019, the biogas plant mentioned above will be able to supply 1,300,000 Nm^3 biogas through a local pipeline. The supplier PAIKRE Ltd. is interested in supplying biogas. We have been advised by the Institute of Chemistry at the University of Tartu that the most efficient way to decarbonize biomass is to use H_2. This could lead to an environmentally and economically viable cross-cutting opportunity.
- An opportunity for the future is to produce hydrogen by "trigeneration" (direct fuel cell or electrolysis) using a bio-methane and natural gas mixture. Potential suppliers have not yet been identified and contacted. However, we believe that all cross-cutting efforts aimed at minimizing GHG levels, should be pursued.

Regarding the regulatory framework and our short-term 2016-2018 operating plans, only one issue emerges. NT BENE will need to ask for permission from the Estonian Competition Authority to construct a direct line from the solar power station to the H_2 plant in order to facilitate the accessibility to solar power.

4. An HRS in the municipality of Riga, Latvia

Latvian Academy of Sciences was requested to explore and assess possible routes to deliver regionally sourced green (renewable) hydrogen at the foreseen refuelling station at Vienibas gatve, Rīgas Satiksme 2nd trolleybus depot. The technical specifications for HRS are based on the detailed design study prepared by Hydrogenis.

The HRS will be able to supply around 270 kg H_2/day to busses and vehicles with dual pressure of 350 or 700 bar. In the research Latvian Academy of Sciences evaluated relatively big (thermal) power plants: the "Rīgas TEC-1", "Rīgas TEC-2", "Rīgas HES" and the heating plant "Imanta" were studied. These power plants currently operate in 'stable regimes' with a maximal base output of heat and electricity due to technological and economic reasons. On top of that, these power plants have to sustain the electrical energy supply to the city of Riga. Therefore, Latvian Academy of sciences analysed the available amount of electricity from these plants that can be utilized for electrolysis.

In the research several locations and related hydrogen production routes were evaluated:

- **Route #1:** Hydrogen production through electrolysis with an electricity input from the thermal electrical stations "Rīgas TEC-1" and "Rīgas TEC-2". A direct electricity connection from these stations to an electrolyser is foreseen for onsite production at the bus depots or next to the thermal electrical stations. Also the hydrogen delivery options by SMR from the thermal plants were assessed.
- **Route #2:** Hydrogen production through electrolysis with an electricity input from the hydroelectric power plant "Rīgas HES". A direct electricity connection from these stations to the hydrogen production plant (electrolyser) is foreseen.
- **Route #3:** Hydrogen production through electrolysis with an electricity input from the heating plant "Imanta". A direct electricity connection from these stations to the hydrogen production plant (electrolyser) is foreseen.
- **Route #4:** Hydrogen production by SMR with an input of biogas from the biological waste treatment station BAS "Daugavgrīva".
- **Route #5:** Hydrogen production by SMR with an input of biogas or landfill gas supplied by the company "Getliņi EKO".

The distance from the Rīgas Satiksme bus and trolleybus depots to the nearest hydrogen station does not exceed 30 kilometres.

In the research, several sites for the hydrogen production plant and the HRS were evaluated, including options to place the HRS directly at the locations of Rigas Satiksme's bus and trolleybus depots. Three depots were studied. Regarding the fact that there are no specific rules and regulations, the general maximum safety distance and safety measurements apply on deployment of hydrogen refuelling stations (HRS). These general rules and conditions could

have significant constraint for setting up and placing the infrastructure for the HRS in the 7th bus depot and 1st trolleybus depot. The constraints are limited for the 2nd trolleybus and 6th bus depots and as a result these sites has been chosen for the HRS for the short- and the long-term, respectively

The following short-term scenario is sketched:

- With the assumption that it is possible to obtain the necessary amount of electricity from the thermal electrical stations "Rīgas TEC-1", "Rīgas TEC-2" or the hydroelectric power plant "Rīgas HES" , hydrogen will be produced by electrolysis and supplied to the Rīgas Satiksme's 2nd trolleybus depot.
- In total 125 trolleybus units are served in Rīgas Satiksme 2nd trolleybus depot. The hydrogen refuelling station (HRS) will be able to supply around 270 kg H_2/day and to store up to 600 kg of H_2. The HRS will be able to provide the necessary amount of hydrogen for 10 FCE-trolleybuses ("HyTrolleys"). To ensure the necessary amount of hydrogen for all 125 trolleybuses in the 2nd trolleybus depot, the HRS should supply approximately 1100 kg H_2/day. The analysis of this location showed that that the site is suitable for the construction of HRS and electrolyser with this capacity.

On top of that, the long-term key findings are as follows:

- Considering the second scenario, if all Rigas Satiksme's buses are replaced by fuel cell buses by the year 2030, the 6th bus depot can be equipped with an HRS. The necessary capacity will be then approximately 5000 kg H2/day.
- The hydrogen production by electrolysis with an electricity input from the heating plant "Imanta", which is about one kilometre away from the 6th bus depot, depends on the decisions and long term energy strategy of the municipality of Riga, which is the dominant shareholder of "Rīgas Siltums". It is concluded from the "Riga city sustainable energy action plan for smart cities 2014 to 2020" that there is no proposed action for initiating hydrogen production in heating plant "Imanta" until the year 2020. Thus, hydrogen production from this heating plant has to be included in further guidelines, in terms of a sustainable energy plan for Riga, after 2020.
- All obtained biogas of the biological waste treatment plant "Daugavgrīva" is diverted to a cogeneration power unit. Hence, there is no available biogas for hydrogen production until the year 2025.
- Precondition of the polygon-gas is required to ensure a certain purity of biogas. However, this purification equipment technology is not yet ready to utilize on industrial scale. Also due to diverse types of the landfill gas, a complex landfill gas purification processes has to be developed.

5. Explaining the difference between Arnhem, Pärnu and Riga

- The selected short- and long-term hydrogen production routes are different between the three cities because the locally available sources of energy are different. The production processes of hydrogen are simply adapted to the regionally available energy sources.
    - This refuelling station of **Arnhem** will initially be supplied by hydrogen from SMR of natural gas. Biogas is initially not yet available, but biogas and green gas show short-term potentials. Moreover, the local party HyGear has experience with the implementation of SMR installations from previous projects, which enables hydrogen production through SMR.
    - In **Pärnu** the production of hydrogen, for the short-term, will be based on electricity utilizing electrolysis. The hydrogen production by SMR is only a long-term option, because the biogas plant is expected to be realized in 2019.
    - For **Riga** in the short-term, hydrogen will be generated by electrolysis because no short-term biogas suppliers were identified.