HRS Arnhem: Exploration of local renewable production options for transport

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Abstract

In the city of Arnhem a new hydrogen refuelling station will be developed. Objective is to provide regionally sourced green hydrogen at this station. Commissioned by the municipality, ECN has developed and applied an analytical framework to assess various production pathways for green hydrogen production. On the short term, local production with steam methane reforming scores best, provided the used natural gas is greened through the purchase of renewable guarantees of origin. Relevant regional sources were also identified. An interesting but still uncertain route is the use of local biogas from a nearby wastewater treatment plant. On the long term, electrolysis options can also become attractive, depending on cost reductions for this route and with the use of green power certificates. A concise review of permitting and other legal issues revealed no bottlenecks for specific routes.

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Summary

The municipality of Arnhem participates in the EU project H2Nodes. In this context, a hydrogen refuelling station (HRS) will be developed at the Kleefse Waard industrial zone in Arnhem. 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 footprint, economic performance and sustainability. Regional relevant production routes were explored by interviewing about 15 parties; experts, project developers and other relevant stakeholders. In a multi-criteria assessment, weighting factors provided by the client were used to finally rank the various options. Finally a concise review was done on related permitting and other legal matters.

Our key findings for the short-term (1-5 years) are as follows:

- Local hydrogen production through an Steam Methane Reforming (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 weighting 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), our findings are as follows:

- 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.

1

Introduction

The attention for hydrogen as an element in a renewable energy economy is increasing again. Particularly for the transport sector, it is an energy carrier that can prevent decentralised end-of-pipe emissions of CO_2 and air pollutants such as NOx and fine particles. With the recent introduction of the first serially produced fuel cell electric vehicles (FCEVs), the perspective for hydrogen in transport has become more concrete.

Introduction of hydrogen in transport faces a classical chicken-and-egg problem: FCEVs will require dedicated HRSs (HRS), but the introduction of such stations requires concrete and substantial market demand. In order to tackle this problem, the city of Arnhem is participating in a European (TEN-T) project called "H2Nodes - evolution of a European HRS network by mobilising the local demand and value chains". The city 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[1].

Within the context of the H2Nodes project, a HRS is foreseen in Arnhem, to be located at the Kleefse Waard industrial zone. This refuelling station will initially be supplied by hydrogen from steam reforming of natural gas (SMR, steam methane reforming). On the longer term, the station may consider changing to electrolysis. Initially, the HRS' capacity will be 85 kg/day, with the possibility of a scale-up to 200 kg/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 wants to investigate 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.

Specific to the situation in the Netherlands in this context is that both methane and electricity can also be made renewable making use of guarantees of origin (GOs). In contrast to several other EU countries, the Netherlands have a system of GOs not only for renewable electricity, but also for renewable natural gas from the grid.

[1] See THRIVE final report http://www.ecn.nl/docs/library/report/2011/e11005.pdf

The city of Arnhem has commissioned ECN to identify and assess both short-term and long-term routes for the delivery of locally sourced renewable feedstocks for hydrogen to the HRS, including reviewing related permitting and other legal issues and providing a recommendation on the most suitable supply pathway. Other parties involved are PitPoint and HyGear. PitPoint, an expert in green fuel refuelling systems, will both operate the HRS in Arnhem and purchase the natural gas and GOs. On the site of HyGear at the Kleefse Waard, hydrogen via an SMR will be supplied to the HRS.

The starting point of the research was identifying the hydrogen production pathways and mapping of the local renewable energy projects. Subsequently, an analytical framework was established to assess the different hydrogen production routes. This framework has been designed on the basis of ECN's expertise and is substantiated by literature and the input of the experts who have been interviewed (Appendix A: Experts interviewed). Chapter 2 presents the analytical framework, focussing on the specific hydrogen production chains that were introduced in it, and the criteria on which the chains were evaluated.

We explored the local specific situation by interviews with experts on the HRS and with local potential suppliers of green feedstocks. The key outcomes of the expert interviews give insight in the scope and objectives of the H2Nodes project, and the plans for the HRS . The interviews with local potential suppliers and other stakeholders provided information on possibly interested suppliers of GOs in the region Arnhem/Nijmegen for the short- and the long-term, the market value of GOs and the performances of alternative production routes. Chapter 3 outlines the main findings of the interviews.

In Chapter 4 we shortly describe the permitting and legal issues associated to the HRS and on-site production of hydrogen. This exercise is limited to a qualitative indication of key issues and a semi-quantitative score on the level of efforts that will need to be put in to overcome the issue.

The outcomes of Chapters 2 and 3 are bundled and put into a multi-criteria assessment framework, ranking the different merits of the routes among each other for the short- and the long term. These draft results were presented to and discussed with representatives of the city of Arnhem in a workshop, in which the participants were invited to attach different relative weights to the various criteria and see the impact of on overall outcome. The results of this session, including the ranking of most preferred supply routes for renewable hydrogen feedstocks on the short and longer term are presented in Chapter 5.

2

The analytical framework

The main goal of this study is to explore local renewable hydrogen production options for transport. Hydrogen can be produced through different routes before it eventually will be supplied to the HRS at Kleefse Waard. The analytical framework is the key tool for assessing the different routes to produce hydrogen. The various hydrogen production routes score different on (full-chain) energy, CO_2, economic performance and sustainability. Before we will explain the assessment criteria, we introduce the identified hydrogen production routes.

2.1 The studied hydrogen production routes

Hydrogen production options currently available on the market either use SMR (from methane) or electrolysis (of water using electricity) as conversion technology. Various other production options are under development, but these are not expected to become commercially available within the time frames we use in this study. Our short-term horizon is typically 1-5 years; our long-term horizon is 5-10 years.

Focus is on decentralised production options, where the hydrogen is produced close to the HRS. Concrete initiatives for large-scale central hydrogen production in the region were not found in the mapping phase of renewable energy projects and potential hydrogen sources.

For the analysis, we identified the following (renewable) hydrogen production routes:

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 (JEC, 2014).

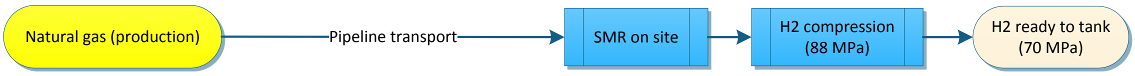

Figure 1 - H_2 production route 1: *H_2 production by SMR on-site with an input of natural gas.*

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 GOs.** Currently, the production of green gas mainly takes place though fermentation biomass waste streams. There are various options, i.e. mono-fermentation of manure, co-fermentation of manure and other organic substrates, fermentation of municipal waste and a digestion of waste water in a sewage treatment plant (STP). These distinct green gas production routes have different energy, CO_2 and sustainability performances. In the analytical framework, these routes are therefore split up in separate hydrogen production routes.

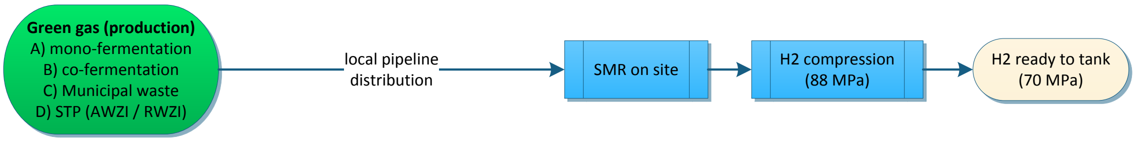

Figure 2 – H_2 production route 2: *H2 production by SMR on-site with an input of green gas, which is supplied through the natural gas infrastructure. Four options for green gas production are studied: A) mono-fermentation, B) co-fermentation, C) Municipal waste, D) Sewage treatment plant (STP. In Dutch: AWZI = AfvalWaterZuiveringsInstallatie or RWZI = RioolWaterZuiveringsInstalltie).*

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.** In most of the cases raw biogas is firstly cleaned (e.g. by drying and extracting H_2S) and then upgraded to green gas, inter alia by filtering out the CO_2. By doing this, the green gas is qualified to be fed into the natural gas infrastructure. However, if production and supply of biogas is near to consumption, it may be beneficial to directly supply the biogas to the SMR unit. The SMR unit should then be adapted to cope with an input of biogas. According to HyGear (de Wit, 2016), this technology is not instantly ready to use, though it should be technically possible; there is simply no market for it yet. We included this route because it corresponds with a potential future supplier (Veolia) of biogas for the HRS at Kleefse Waard.

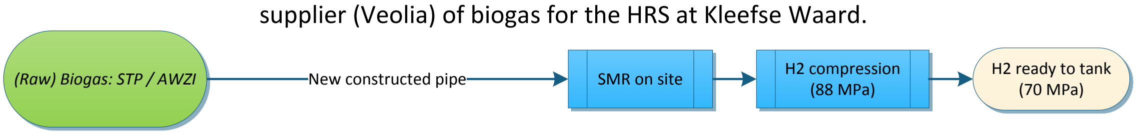

Figure 3 – H_2 production route 3: *H_2 production by SMR on-site with an input of (raw) biogas, which is physically delivered by a newly constructed pipeline.*

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.

   If green gas is physically supplied, in our understanding, no GOs are issued. However, it will increase the hydrogen production costs. The green gas producer, which supplies green gas in the natural gas infrastructure, obtains a revenue by selling the GOs. It seems fair to assume that also in the case of physical delivery, the producer would like to receive these revenues.

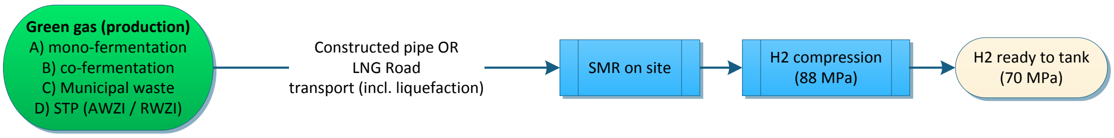

Figure 4 – H_2 production route 4: *H_2 production by SMR on-site with an input of green gas, which is physically delivered by a newly constructed pipe of an LNG truck.*

5) **Hydrogen production by electrolysis on-site of the HRS, with an input of renewable electricity (anonymous certificates).** Alternatively, green hydrogen can be produced by electrolysis via a PEM or AEL system (PEM = Proton Exchange Membrane, AEL = Alkaline Electrolyte). The PEM system has the advantage that it operates at a higher current density, which results in a smaller area required to produce to same amount of hydrogen to an AEL. On top of that, a PEM system can operate at a higher, thus requiring less power to supply compressed (800 bar) hydrogen (TKI Gas, 2016). Greening the hydrogen is done through purchasing anonymous green electricity certificates. These certificates include a mix of renewable electricity sources.

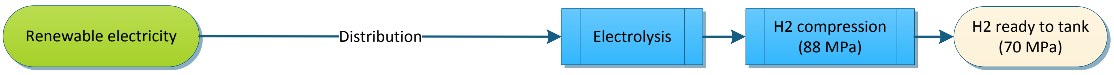

Figure 5 – H_2 production route 5: *H_2 production by electrolysis on-site. Greening of the hydrogen is done by purchasing anonymous green electricity certificates.*

6) **Hydrogen production by electrolysis on-site of the HRS, with an input of renewable electricity (solar and wind energy).** In contrast to the previous route, the greening of the hydrogen is done through purchasing solar or wind electricity certificates. This implies that green electricity production has a no CO_2 impact.

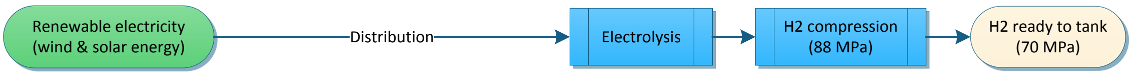

Figure 6 – H_2 production route 6: *H_2 production by electrolysis on-site. Greening of the hydrogen is done by purchasing anonymous green electricity certificates.*

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.

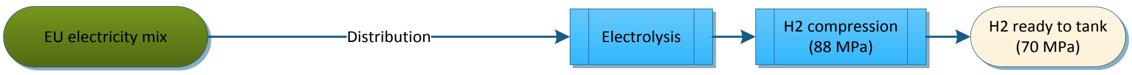

Figure 7 – H_2 production route 7: *H_2 production by electrolysis on-site with an input of (raw) biogas. Greening of the hydrogen by anonymous green electricity certificates.*

These various hydrogen production routes were assessed and evaluated based on the criteria explained in the next section.

2.2 The evaluation criteria

The analytical framework is the key tool for the assessment of the various H_2 production routes. It focuses on four criteria. Below we introduce them, including the data sources we used to provide the relevant data for each production route.

A) Energy performance

- The metric for the energy performance is 'Energy expended' in [MJ primary energy/MJ H_2].
- The literature source we used is the '*well-to-tank analysis of future automotive fuels'* study, done by JRC, EUCAR and CONCAWE (JEC, 2014).
- The first production pathway (hydrogen thermally produced by SMR with an input of natural gas) and the fifth, sixth and seventh production pathways(hydrogen production by electrolysis) are entirely presented in the JEC study. For the other production routes, we combined the JEC-production routes of biogas through fermentation and hydrogen thermally produced by SMR with an input of natural gas.
- For the biogas route we assumed that the energy and CO_2 performance are equal to the performance of the green gas pathways. The input of biogas reduces the SMR efficiency, however the increased energy requirement and ($CO_{2\text{-eq}}$) footprint levels out with the energy required and the ($CO_{2\text{-eq}}$) footprint caused by upgrading of the biogas.

B) CO_2 performance

- Hydrogen production pathway CO_2 emission [g CO2eq/MJ H_2]
- The literature source we used is the '*well-to-tank analysis of future automotive fuels'* study, done by JRC, EUCAR and CONCAWE (JEC, 2014).
- For the CO_2 performance, we combined the JEC-production routes and made the assumption in similar way as we did for the energy performance.

C) Economic performance

- H_2 production costs [€/kg H_2]
- The hydrogen production costs include the capital investments of the SMR or electrolyser (CAPEX), operational costs of the SMR or electrolyser (O&M), energy costs, GO-costs and for some production routes '*Stimulering Duurzame Energie*' (SDE+) subsidiary rates. We assumed that the operating time of both the SMR and electrolyser are 8000 hours a year.[2]

[2] The production costs for a kg of hydrogen are strongly related to the running time. If the running time is lower, the production costs will increase. Nevertheless, for the semi-quantitative economic comparison there is no issue because both the SMR and electrolyser routes are calculated for a running time of 8000 hrs/y.

- The literature source we used is the '*multi-annual work plan 2014-2020'* report*,* written by the Fuel Cells and Hydrogen Undertaking (FCH JU, 2014). On top of that, for the economic performance ECN's expertise on hydrogen production was required.
- On the basis of our information and the interview outcomes on the market for green gas and green power certificates, we identified a price range for the certificates. In the analytical framework we used the average green power and green gas certificate prices.
- We considered that the green gas and green electricity routes obtain a SDE-subsidy and in practice, therefore, have a similar energy price as the fossil fuel routes. The green gas and green electricity prices are equal to the prices of natural gas and conventional electricity, respectively. However, for the hydrogen production routes 3. and 4., no SDE subsidy is received because only SDE subsidy is obtained when the green gas is fed into the natural gas infrastructure. The SDE-subsidy of (only) the STP biogas (3.) and green gas (4.) pathway is relatively low, about 0.50 €/kg H_2, and as a result the price increase is limited.

D) Sustainability criteria

- We identified the following sustainability criteria: *acidification, eutrophication, summer smog, land-usage, toxicity.*
- The literature source we used is a study of CE Delft called '*How sustainable is biogas?'*, (CE Delft, 2013). Moreover, ECN's expertise on the sustainability of the alternative production routes has been used.
- For the hydrogen production routes with an input of green gas we used CE Delft's data on the sustainability criteria. Moreover, we based the sustainability evaluation on the fact that the effects of non $CO_{2\text{-eq}}$ emissions, caused by acidification, eutrophication and summer smog, are reasonably correlated with the CO_2 performance (CE Delft, 2013).
- The non-green gas production routes are evaluated on the basis of ECN's expertise on sustainability. As a result, we scored the production routes directly in a semi-quantitative way.

Eventually, the various production routes are scored in a semi-quantitative way, first on each separate criterion. We normalised the outcomes on a scale from one to ten. The 'best route' gets a score of ten, whereas the 'worst route' get a score of one. More precisely, a score of ten for the energy, CO_2, or economic performance corresponds respectively with the lowest expended energy, CO_2 footprint or H_2 production costs. In the multi-criteria assessment (see chapter 5), a total score was generated by applying (client-determined) weighting factors.

The business models that the initiators such as PitPoint foresee and the technology readiness level of the routes were not introduced as criteria in the analytical framework, but were used to select the routes as short (2015 - 2020) or long-term (2020 - 2025) feasible to implement.

3

Key interviews outcomes

The interviews were executed at the premises of the municipality of Arnhem, at the site of the interviewee or (some) by telephone. To be able to reach the green gas suppliers and experts in the field of hydrogen production, Theo Tijsse-Klasen and Marc de Kroon (municipality Arnhem), Johan Voshaar (Groen Gas Gelderland) and Ellart de Wit (HyGear) assisted in identifying relevant parties to contact.

In total we have had 13 (in-depth or telephone/mail) interviews. Key points were directly fed into the analytical framework. Relevant information that did not directly link to this framework was collected in an overview note of interview highlights. The main outcomes of the interviews are presented below.

3.1 Main outcomes in-depth interviews

- *Green Bio Power BV - co-fermentation*

  Green Bio Power B.V. develops co-fermentation installations that run on an input of one-third of manure, one-third of food, agro-residues and other digestible waste-steams, and one-third of grass. According to the SDE-subsidy scheme, this composition belongs to the category 'allesvergisting'. However, for the evaluation of this production route, the process is considered as (extended) co-fermentation.

  Presently, an optimized plant operates in Switzerland and a fermentation plants is being constructed in Almelo. The fermentation plant in Almelo is going to produce both green gas and bio-LNG. The input will be 165 kilotons of biomass per year and the output is 12.5 million m^3 green gas.

  For the long term, Green Bio Power B.V. is considering Duiven as one of potential future locations for the production of green gas. Duiven is an attractive location because of the proximity of harbour facilities on the

Nederrijn, which facilitates the supply of biomass and dispatch of cleaned digestate to e.g. Germany. Moreover, the waste heat of AVR Duiven could create synergy to pre-treat the grass to increase its fermentability.

→ ***To conclude, this production route has no short-term potential, on the long-term there may be potential for the supply of GOs .***

- *ARN Weurt – fermentation of municipal waste*

ARN started in 2012 the construction of, and currently operates a fermentation plant with, an input of 38.000 tons of municipal waste coming from the region Nijmegen. ARN has sold their GOs of 2.5 million m^3 green gas to Connexion, that is the public transport operator in the Arnhem region.

PitPoint operates the refuelling infrastructure for the delivery of CNG to the Connexion buses and is responsible for purchasing the GOs. PitPoint also plays a role in the HRS of Arnhem, and is therefore the stakeholder to get in contact with for possible arrangements about combining the purchase of GOs for the HRS Arnhem and green gas transport of Connexxion. Besides, there is the (technical) possibility to scale-up to 70.000 tons of municipal waste. Though, currently there is not enough municipal waste to utilize this scale-up.

The prices for GOs will be set on the basis of bilateral trade. Roughly speaking, 0.05 – 0.012 €/m^3 green gas is a good indication for green gas GO prices→

→ ***To conclude, no short-term potential and there could be a long-term potential for the supply of GOs.***

- *Groen Gas Gelderland, Engie – co-fermentation*

Groen Gas Gelderland (GGG) is a cooperation between Biogas Holding B.V., a subsidiary company of Engie, and Biogas Plus B.V, a subsidiary company of Eneco. In April 2016 these two holdings collaborated to realize and eventually operate a biomass fermentation plant in Bemmel (Arnhem), located in the municipality Lingewaard. The production facility, a co-fermentation installation, will have an input of 72.000 tonnes biomass. The biomass has an composition of 50% manure, 30% grass and 20% food- and agro-residues. The output will be 6.9 million m^3 green gas, which will be fed into the regional natural gas infrastructure.

Engie (formerly GDF SUEZ) and Eneco are both responsible for the supply of the green gas and GOs. Engie is currently in the orientation phase when it comes to the trade of the GOs. The supply of GOs becomes (more) interesting for Engie in the following cases: (1) setting a long-term contract for the purchase of GOs (~8 years, as for example is the case with bus concessions), (2) bundling of the purchase of GOs with the green-gas-driven regional bus transport because then the GOs volume for the HRS project can multiply, and (3) combining the supply of GOs with the physical supply of natural gas. Besides, Engie acknowledges the value of regional supply of GOs in this innovative project. However, the actual (regional) added value has to be weigh up by Engie.

→ ***To conclude, this production route has a short-term potential of the supply for GOs.***

- *Veolia – AWZI / STP*

  Veolia is the utility company at the industrial site Kleefse Waard (IPKW, IndustriePark Kleefse Waard). Since July 2014, Veolia is the owner of an STP (AWZI) installation. This STP is running on the industrial residue-streams of the IPKW. The system, which was built in 1950, has been maintained and renovated. However, the control system for optimization of process condition in relation to variable industrial waste water streams is outdated.

  Thus, presently Veolia is both trying to increase the STP's energy efficiency and applying for the (local) license to produce biogas. Veolia's intention is to use the biogas as a feedstock for their internal heat production. Nevertheless, Veolia may be interested if the physical supply of biogas to the SMR at the HRS is financially beneficial.

  → ***To conclude, Veolia is a long term potential for the physical supply of biogas and for the supply of GOs.***

On top of interviewing green gas suppliers, we had in-depth interviews with experts in the field of hydrogen production.

- *HyGear - expert in SMR technology*

  In this H2Nodes project, HyGear will supply the SMR unit to produce hydrogen. In a previous project, called HyMove, HyGear has already operated an SMR at a HRS. In that project they produced green hydrogen simply by purchasing green power and green gas from the energy company Essent, via the public electricity and gas grid.3 The current HyGear SMR units cannot run on biogas with its relatively high CO2 content. With some adaptations, that is technically possible but the market for SMR units on biogas simply isn't there yet.

- *PitPoint - expert in green fuel refuelling systems*

  PitPoint is an expert in green fuel refuelling systems. PitPoint has already installed CNG/green gas and LNG refuelling systems and operates electric vehicle charge points. PitPoint will both operate the HRS in Arnhem and purchase the natural gas and GOs. With their experience as CNGnet, they are well-informed in the market for green gas certificates.

  According to PitPoint, byproduct hydrogen from industrial processes, like chlorine production and methanol production, should be included in the multi-

[3] In our analysis we did not include the auxiliary energy to run a SMR system. We expect that this electricity usage will be negligible and that the green electricity certificate market is not such a scarce market as the green gas certificate market.

criteria analysis. However, in the region Arnhem and Nijmegen we have not identified sources of industrial by-product hydrogen.

Figure 8 gives an overview of the short- and long-term green gas suppliers.

Project	Route	Producing now?	Start add. production	GOs still to be sold?	Interest in reg. client?
GBP BV	Co-ferm.	No	Unclear, if	n.a.	Yes
ARN	Mun. Waste	Yes	? (possible)	No	Yes
GGG	Co-ferm.	No	2017	Yes, partly	Yes
Veolia	AWZI	No	~2018	n.a.	Yes

Figure 8: *an overview the potential green gas suppliers.*

3.2 Main outcomes telephone/mail interviews

- *Groen Gas Gelderland, Eneco - co-fermentation in Bemmel*

Next to Engie, Eneco will also trade part of the certificates produced in this project. Eneco has no interest in supplying GOs for the reason that a volume of 150.000 to 400.000 m^3 green gas is a not cost-efficient volume to supply. At the moment we contacted Eneco, they were already in contact with other companies to sell their GOs in lagers volumes. If there is a possibility to bundle the purchase of GOs with the green-gas-driven regional bus transport, the volumes might become interesting for Eneco.

- *Friesland Campina – mono-fermentation InnoFase Duiven*

This option was discussed with Luc Velhorst of the municipality Duiven. Friesland Campina is in the orientation phase of an initiative to realize a mono-fermentation plant at the industrial site InnoFase, which is located in Duiven. AVR Duiven and the regional water management authority (Waterschap) Rijn en IJssel (WRIJ) are collaborating in this project. Additionally, the initiative called Jumpstart may give mono-fermentation a boost through assisting dairy farmers in obtaining financial resources, permits and SDE-subsidy. Recently, the Dutch ministry of Economic of Affairs has recognized this as an important initiative and proposed a (extra) subsidy of 150 million euro's for specifically mono-fermentation within the SDE subsidy scheme. Applying for this subsidy budget will start In 2017 (Rijksdienst Nederland, 2016).

According to Velhorst, the initiative is still in its orientation phase and it was, therefore, not possible to get in contact with the initiative Jumpstart. However, as we will show in the multi-criteria assessment, mono-fermentation is a high-scoring production route in terms of the four assessment criteria. For the municipality of Arnhem to be up-to-date about the developments of this project, Luc Velhorst can be contacted.

- *Waterschap Rijn en Ijssel (WRIJ) – RZWI / STP*

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WRIJ could be a potential green gas supplier, according to Luc Velhorst. We were not able to get in contact with the responsible project manager Coert Petri (WRIJ), probably due to other internal priorities.

- *'Sleeping' consortium of AVR Duiven, Siemens and Engie – AVR hydrogen production*

AVR Duiven, Siemens and Engie collaboratied in an initiative to produce hydrogen at the AVR Duiven. The project was about producing hydrogen with an input of electricity during the hours of low electricity prices. At the first hand, this seemed financially attractive, but the relatively high investment costs and low operational hours resulted finally in an negative business case. Thus, this consortium is currently dormant, and for the HRS installation in Arnhem this is not an potential supplier of hydrogen in the foreseeable future.

- *Top Kalvermesterij in Wekerom (Barneveld) - mono-fermentation*

This project has a low potential because there are difficulties in obtaining the permit for the fermentation installation due to problems related to local odour nuisance.

- *Klarenbeek duurzame energie in Klarenbeek (Apeldoorn) – mono-fermentation*

This project has a low potential for the supply of GOs for Arnhem because the GOs are already sold to the paper mill Arjowiggins in Ugchelen. The permit for the biogas production was issued by the municipality of Apeldoorn, though the locals are presently appealing the permit.

- *Greenferm in Apeldoorn – mono-fermentation*

Greenferm is currently working on obtaining a permit for producing biogas through the fermentation of manure. We contacted Greenferm, though at that time they were not interested. Berend Dunsbergen will be the person involved in selling the GOs.

- *Groen Groen Nederland – Johan Voshaar*

Assisted in the project to get in contact with Green Bio Power B.V., Greenferm, Top Kalvermesterij, Parneco Renkum, and Klarenbeek duurzame energie.

- *Vertogas, Daniel Pol*

In the region of Arnhem and Nijmegen, there is a scarcity of green gas certificates. Therefore, it may be interesting for the municipality of Arnhem to get in contact with national suppliers of GO´s. Vertogas provides a list of national suppliers on their website (Vertogas, 2016).

The contacts below were also provided by Theo Tijsse-Klasen and Johan Voshaar, but we have not spoken with these organizations directly for the following reasons.

- *Attero in Wilp – CHP municipal waste*

  Currently, the municipal waste of the region Apeldoorn is the feedstock of the CHP installation of Attero. We did not get in contact with Attero to talk about the possibilities for green gas production for reason they run an CHP installation.

- *Parenco B.V. in Renkum – demand for GOs.*

  Parenco B.V., a paper mill in Renkum (Ede), has a demand for and not a supply of GOs to make their paper production process more sustainable.

4

Permitting and other legal issues

In this review of permitting and other legal issues, we focus on the activities that will take place at or directly nearby the HRS. Therefore, issues related to the refuelling station itself, the local hydrogen production and the distribution of its energy feedstocks are discussed. Regulatory matters relating to e.g. the production of green gas are left out of scope here.

4.1 An All-in-one Permit for Physical Aspects

In the Netherlands, the General Provisions Act 'Wabo' (Wet Algemene Bepalingen Omgevingsrecht) is the basis for many of the permits that are needed in relation to activities that have an impact on the physical living environment. The Act lays down the rules for granting a so-called All-in-one Permit for Physical Aspects (Omgevingsvergunning)[4]. It enables members of the public and companies to use one transparent procedure to apply to one competent authority for permits for activities that impact on the physical environment. The Act replaced around 25 former separate permits for such matters as construction, spatial planning, listed buildings and the environment by a single one-stop-shop permit covering all activities. Within a project, Wabo thus makes it possible to perform different activities (construction, installation, assembly, use) with one all-in-one Permit for Physical Aspects. In the coming years, the Wabo will be succeeded by the 'Omgevingswet' (Ow) an even more integrated Act on the living environment; this text is based on the current legal setting.

[4] For more detail and background: http://rwsenvironment.eu/subjects/all-one-permit/

Hydrogen refuelling facility

The integration of a hydrogen refuelling facility in an existing refuelling station requires an all-in-one permit for construction (the old building permit) and establishing or changing a facility (the old environmental permit). In case of a completely new refuelling station an additional check will be needed whether the location fits within the prevailing zoning plan. If not, the station has to be relocated or the zoning plan should be adjusted. This can take considerable time, so it is advisable to check new projects with the current zoning plan in advance.

Storage of liquid and gaseous fuels in aboveground and underground tanks, and the dispensing of fuels to road vehicles are activities that are regulated under the Activity Decree (Activiteitenbesluit). The Activities Decree and the associated Activities Regulations (Activiteitenregeling) regulate in total about 100 different types of activities that are relatively easy to standardize. The Activities Regulations for activities related to refuelling stations refer to various documents in the Publication Series of Hazardous Substances (PGS documents). These documents contain the provisions and regulations for the construction, installation, design and operation of fuel delivery installations, including internal safety distances between fuel delivery installation components, and between the fuel delivery installation and fuel delivery truck (if applicable). External safety distances for various types of refuelling stations are regulated under the External safety facilities Decree (Besluit externe veiligheid inrichtingen; Bevi) and are described in the associated External safety facilities regulations (Revi).

Currently, standardized regulations are in place for liquid fuels, compressed natural gas (CNG) and liquefied petroleum gas (LPG). PGS documents for liquefied natural gas (LNG) and hydrogen have been drafted and adopted [5], and also recommendations for external safety distances have been developed. However, these documents and recommendations have not yet been formally implemented in the related Decrees, and thus are not yet in force as part of the formal regulations. As long as activities are not covered by official regulations a permit application must be accompanied by a dedicated quantitative risk assessment for the proposed activity.

On-site hydrogen production facility

The All-in-one Permit for Physical Aspects also covers the construction and operation of an on-site hydrogen production facility. This facility may produce some noise, and the permit may impose requirements on the maximum level of noise emissions to the surroundings. In general, the amount of hazardous substances contained in the production facility represent a limited risk from environmental perspective, and will not lead to additional requirements on top of existing requirements for operating a production facility of the anticipated size. Apart from that, the facility has to comply with regulations regarding explosion safety as set out in the ‘Arbo’ Decree (Working Conditions Decree). This Decree contains the provisions of European Directive 1999/92/EC (also known as ATEX 137), describing the obligations associated with risk of explosion.

[5] PGS 33-1 Natural gas: installations for delivery of LNG to road vehicles, and PGS 35 Hydrogen: installations for delivery of hydrogen to road vehicles (PSG, 2015).

Energy delivery for on-site production of hydrogen

On-site production of hydrogen through reforming of methane or electrolysis may require adjustment of the site connection to the public natural gas or electricity grid. An application can be filed to the local network operator, and the normal legal framework, regulations and norms and standards for installing or changing a network connection are applicable. No permit is needed.
One of the identified options for local renewable hydrogen is to produce hydrogen by on-site reforming of biogas from a nearby wastewater treatment plant. This would require a new pipeline between the wastewater treatment plant and the refuelling station. A new pipeline requires an All-in-one permit for Physical Aspects for installation of a pipeline. The applicable procedures and regulations are the same as for construction of natural gas pipelines. Specific guidelines for biogas pipelines have been defined by the national organization of natural gas and electricity systems operators (Netbeheer Nederland), based on norms and standards for natural gas pipelines. Biogas pipeline distribution is a non-regulated activity, but is advisable to involve network operators and related infrastructure companies in the installation of a biogas pipeline because they are familiar with the legislation, regulation and the applicable norms and standards.

4.2 Permits procedure

The ‘Wabo’ Act embodies two procedures for granting a planning permit, i.e. a standard procedure and an extended procedure. The standard procedure applies to the most common projects of a simple nature. The extended procedure is for projects with complex environmental or fire safety aspects. The two procedures have been aligned with the generic regulations of the General Administrative Law Act as far as possible and also contain some additions and amplifications.

The decision-making time under the standard procedure is 8 weeks, which may be extended once by 6 weeks at most. As the decision-making time is a deadline, a missed deadline will automatically result in issue of a permit. The All-in-one Permit will then be granted in conformity with the application.
The extended procedure requires the competent authority to decide within 6 months of receiving the application. This period is extendable once by 6 weeks at most if the subject is highly complex or controversial. A permit will not be automatically granted if the period of 6 months (or the extended period) is exceeded. The All-in-one Permit granted under this procedure will take effect on expiry of the time allowed for appeals.

The Act provides two types of legal remedy in the standard and extended procedures. Decisions taken under the standard procedure may be challenged by means of an objection. An application for judicial review may subsequently be lodged with the district court, thereafter it is possible to lodge an appeal with the Council of State. In the case of an extended procedure, stakeholders will be given an opportunity to respond to the draft permit. Applications for judicial review of subsequent decisions may be lodged directly with the district court and appeal then lies to the Council of State.

4.3 Enforcement

The authority competent to issue the All-in-one Permit will be responsible for enforcement of the permit and other regulations named in the Act under administrative law. In a small number of situations, a different authority has been designated to enforce certain matters. Requirements have been laid down to promote the quality of enforcement. The Act further regulates the minister's supervision of performance and enforcement of the All-in-one Permit system.

5

Multi-criteria assessment hydrogen production routes

The results of the interviews and the literature about the various hydrogen pathways, for the short-term and the long-term, are collected and put into a multi-criteria assessment framework, ranking the different merits of the routes among each other. Initially, the relative weights for the four assessment criteria are equal.

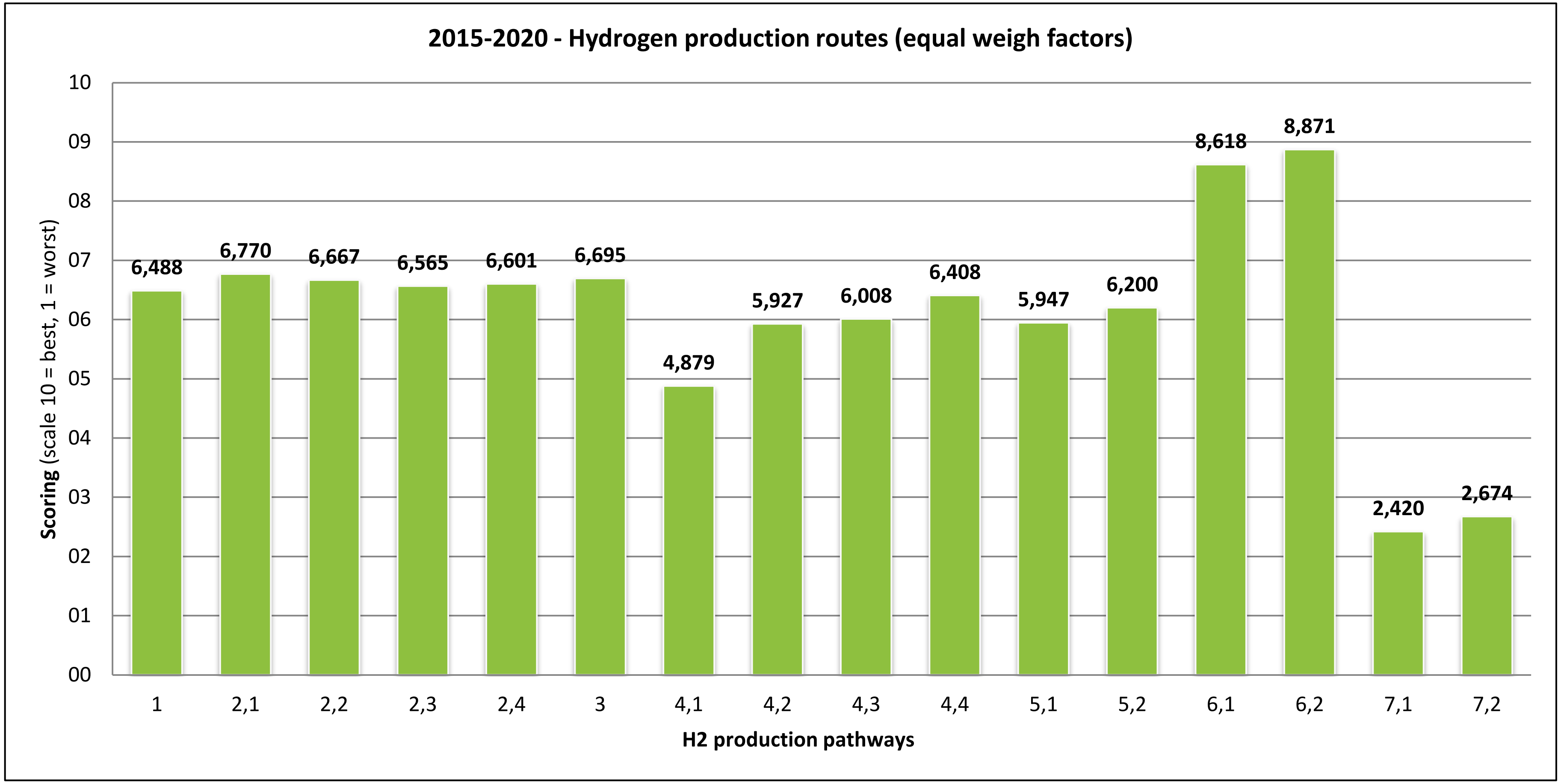
Following the initial assessment, the results were presented and discussed with the municipality of Arnhem and HyGear. The framework allowed the client to attach different relative weights to the various criteria and see the impact on the overall outcome. In total four respondents have given their relative weights. Subsequently, this resulted in the ranking of the various hydrogen production pathways.

5.1 Results phase 1: equal relative weights

The first results of the multi-criteria assessment rank the various hydrogen production pathways with equal relative weights. The results are presented in Figure 9.

When looking at the short-term, the four green gas pathways (2.1 – 2.4) and (raw) bio pathway (3.) have the highest final scores. In this timeframe, electrolysis options are not considered feasible given the decisions already made in the project.

For the longer term, electrolysis could become an option. Of the various options, electrolysis coupled with the purchase of solar or wind energy electricity certificates (routes 6.1 and 6.2), obtains the highest final score. However, according to Ellart de Wit of HyGear, the prospected (decrease) in hydrogen production costs by electrolysis, are not self-evident; they are subject to uncertainties because electrolysis is not yet a well-established technology (de Wit, 2016).



Legend:

1. Natural gas (NG), SMR, NG infrastructure

2.1 Green gas (GG) (mono-fermentation), SMR, NG-infra.
2.2 GG (co-fermentation), SMR, NG-infrastructure
2.3 GG (municipal waste), SMR, NG-infrastructure
2.4 GG (AWZI / RWZI), SMR, NG-infrastructure

3. (Raw) Biogas (AWZI), SMR, constr. pipe

4.1 GG (mono-fermentation), SMR, LNG-truck or constr. pipe
4.2 GG (co-fermentation), SMR, LNG-truck or constr. pipe
4.3 GG (municipal waste), SMR, LNG-truck or constr. pipe
4.4 GG (AWZI), SMR, LNG-truck or constr. pipe

5.1 PEM electrolysis, (anonymous) RE elec. certificates
5.2 AEL electrolysis, (anonymous) RE elec. certificates

6.1 PEM electrolysis, wind/solar elec. certificates
6.2 AEL electrolysis, wind/solar elec. certificates

7.1 PEM electrolysis, EU mix
7.2 AEL electrolysis, EU mix

Figure 9: *a bar chart presenting the scores of the various hydrogen production routes. The four criteria - energy performance, CO_2 performance, H_2 production costs and sustainability – have equal relative weights.*

Hydrogen production routes	Identified regional suppliers	Final score	Energy performance	CO2 performance	H2 production costs	Sustainability criteria (semi-quantitative)
			10 = best, 1 = worst	10 = best, 1 = worst	10 = best, 1 = worst	10 = best, 1 = worst
1) Natural gas (NG) --> H2 production by SMR on-site, NG infrastructure						
1. Natural gas SMR on-site		6.5	9.6	4.7	8.7	3.0
2) Green gas --> H2 production by SMR on-site with GO's - transport green gas by NG infrastructure						
2.1 Mono-fermentation - NG infrastructure		6.8	1.8	10.0	8.2	7.0
2.2 Co-fermentation - NG infrastructure	*GGG: Engie & Eneco*	6.7	4.1	8.4	8.2	6.0
	Green BioPower B.V.					
2.3 Municipal waste - NG infrastructure	*ARN Weurt*	6.6	6.3	6.7	8.2	5.0
2.4 AWZI / STP - NG infrastructure	*Veolia*	6.6	6.3	6.9	8.2	5.0
3) Raw biogas --> H2 production by (specialized) SMR on-site - physical delivery by pipe						
3. AWZI / STP - raw biogas - constructed pipe	*Veolia*	6.7	6.3	6.9	8.6	5.0
4) Green gas --> H2 production by SMR on-site - physical delivery (contructed pipe or LNG, average)						
4.1 Mono-fermentation - green gas - LNG/pipe		4.9	1.7	9.9	1.0	7.0
4.2 Co-fermentation - green gas - LNG/pipe		5.9	3.9	8.2	5.6	6.0
4.3 Municipal waste - green gas - LNG/pipe		6.0	5.9	6.6	6.5	5.0
4.4 Municipal waste - green gas - LNG/pipe		6.4	6.1	6.8	7.8	5.0
5) Electrolysis - EU electricity mix + Green elec certificates (anonymous source)						
5.1 PEM - certificate		5.9	1.0	7.2	6.6	9.0
5.2 AEL - certificate		6.2	1.0	7.2	7.6	9.0
6) Eelectolysis - Renewable electricity + Green elec certificates (wind of solar farms)						
6.1 PEM - solar / wind certificate		8.6	10.0	7.9	6.6	10.0
6.2 AEL - solar / wind certificate		8.9	10.0	7.9	7.6	10.0
7) Electrolysis - EU mix						
7.1 PEM - Electrolysis EU mix		2.4	1.0	1.0	6.7	1.0
7.1 AEL - Electrolysis EU mix		2.7	1.0	1.0	7.7	1.0

Table 1: the results *multi-criteria assessment. The various hydrogen production pathways are scored based on the four criteria in a semi-quantitative way. The four criteria energy performance, CO_2 performance, H_2 production costs and sustainability – have equal relative weights.*

Some of the scores of the four single criteria are self-evident, others need some explanation (*Table 1*). For each criteria, we give an explanation for the high, intermediate and low scores.

Energy performances

The pathways 1. (natural gas, SMR) and 6. (electrolysis, solar or wind GOs) both score high on energy performances. This is due to the fact that the production of natural gas requires little energy because it is simply extracted from wells, whereas the spent energy to obtain wind electricity is merely the energy loss at transportation of electricity through the grid. Biogas and green gas have to be produced. This includes a conversion step and cleaning processes which introduce energy losses.

The green gas and biogas production routes (2.2 – 2.4, 3. and 4.2 – 4.4) have intermediate energy performances. The physical delivery of green gas (average of LNG-trucks and the physical delivery by a constructed pipeline) also decreases the energy performance a bit.

The expended energy for the fermentation of manure (mono-fermentation) is relatively energy intensive compared to the other green gas pathways and this results in a lower energy performance. Also the production of hydrogen through electrolysis with the EU electricity mix results in a low energy performance. This is due to energy losses which occur in the production of electricity from thermal power plants (natural gas, coal, nuclear, biomass) that are part of the mix.

CO_2 performances

The production pathways with lowest (CO_2-eq) footprint are the green gas routes of mono- and co-fermentation and the electrolysis route combined with solar or wind GOs. The credits for avoided methane emissions from manure in mono- and co-fermentation results even in negative emissions. The footprint to obtain wind electricity is merely due to the transportation of electricity.

The alternative green gas routes (2.2 – 2.4, 3., and 4.2 – 4.4), and the electrolysis route with anonymous certificates have intermediate CO_2 performances. These green gas and biogas options score lower than mono- and co-fermentation because the methane emission credit is zero and not negative. Some CO_2 emissions occur related to the (ancillary) energy use of the fermentation process and the subsequent gas cleaning processes. The (CO_2-eq) footprint of electrolysis combined with anonymous green electricity certificates (5.), scores less favorable compared to electrolysis combined with wind or solar electricity. The difference mainly results from the fact that anonymous certificates also include renewable electricity generated from biomass, which has a larger CO_2 footprint than electricity from wind, solar and hydropower.[6]

The fossil fuel pathways (the routes 1. and 7.) have the highest ($CO_{2\text{-eq}}$) footprints, and obtains the lowest scores.

[6] We assumed that the CO_2 performance of renewable electricity (anonymous green electricity certificates) is 10% of the CO_2 performance of the EU electricity mix (most electricity is obtained from hydropower and a (small) fraction of biomass).

H_2 production costs

The lowest hydrogen production costs correspond to the natural gas, biogas and green gas pathways. However, the hydrogen production costs for the biogas route are strongly related with the investment costs to construct a new pipeline and the biogas price.[7] If eventually Veolia is planning to produce biogas, a more in-depth calculation will be needed interesting to check our generic calculation. For the green gas pathways, to ensure the greenness of the hydrogen, GOs have to be purchased. On the basis of our information on the market for green gas certificates, we estimate that the increase in energy costs is 0.05 – 0.12 €/m^3 natural gas input which translates into 0.026 – 0.063 €/m^3 H_2 output, or 0.29 – 0.70 €/kg H_2. In the analytical framework used the average value, which is 0.50 €/kg H_2.[8]

The electrolysis pathways result in somewhat higher production costs then SMR-pathways. While conversion efficiencies of both technologies are about the same, electricity is generally more expensive per energy unit than natural gas. For the green electricity electrolysis pathways, to ensure the greenness of the hydrogen, GOs have to be purchased. The increase in energy costs are 1 – 2 €/MWh electricity input which translates into 0.05 – 0.12 €/kg H_2 output.[9]

The hydrogen production costs for pathways that physically supply green gas, through a newly constructed pipeline or through a LNG-truck, are high because a SDE-subsidy can only be obtained when the green gas is fed into the natural gas grid. Besides, such dedicated transport is significantly more expensive than transport through the grid.

Sustainability criteria

Overall, electrolysis pathways using wind and solar electricity represent the highest scores on sustainability. The electrolysis with wind or solar electricity (via GOs), scores better than electrolysis with electricity represented by anonymous GOs because electricity generation from biomass has a larger impact on sustainability metrics like acidification, eutrophication, summer smog, land-usage, and toxicity than electricity from wind and sun.

The sustainability scores of the green gas and biogas routes are lower than for electrolysis with wind and solar electricity, and an anonymous renewable electricity mix. This is for the reason green gas routes have only an input of biomass, which has relatively a higher impact on the sustainability criteria than the other renewable energy sources. To score the green gas and biogas routes, we used the assumption that the

[7] Assumptions (raw) biogas route: a) investment costs newly constructed pipeline: 0.2 M€/km, industrial site, easy workable soil (ACER, 2015). b) Costs (raw) biogas are assumed to be 75% of the natural gas prices. This is an assumption based on the SDE subsidy scheme; for the heat production out of (raw) biogas, 70% of the natural gas price is used. Though, the (raw) biogas should be cleaned for H_2S, which result in an extra of 5% in the costs. c) the CAPEX for a (raw) biogas SMR system are approximately 10% higher compared to an SMR with an input of green gas. This is due to the fact that an larger SMR system is required because the (raw) biogas contains a higher CO_2 fraction. On top of that, the OPEX will increase because the SMR efficiency decreases by 2%. This is caused by the fact that an input of (raw) biogas contains a higher CO_2 fraction. The last two assumptions are based on HyGear's expertise (de Wit, 2016).

[8] For this calculation we assumed a natural gas energy density of 31.6 MJ/Nm^3, a hydrogen energy density of 10.8 MJ/Nm3, a hydrogen density of 0.0899 kg/Nm3, and an SMR efficiency of 65%. Calculation steps for the certificate prices: Step 1) 0.05 – 0.012 €/Nm^3 NG * 31.6 MJ/Nm^3 NG = 0.0016 – 0.0038 €/MJ NG. Step 2) 0.0016 – 0.0038 €/MJ NG * 0.65 = 0.0024 – 0.0058 €/MJ H_2. Step 3) 0.0024 – 0.0058 €/MJ H_2 * 10.8 MJ/Nm^3 H_2 = 0.026 – 0.063 €/ Nm^3 H_2. Step 4) 0.026 – 0.063 €/ Nm^3 H_2 * 0.0899 kg H_2/Nm^3 H_2= 0.29 – 0.70 €/kg H_2.

[9] We assumed an efficiency of electrolysis for PEM and AEL of 56% and 61%, respectively. Besides we assumed a lower heating value of kWh/kg H_2 LHV.

effects of the non $CO_{2\text{-eq}}$ emissions, caused by acidification, eutrophication and summer smog, are reasonably correlated with the CO_2 performance (CE Delft, 2013). Based on this assumption and ECN's expertise, we ranked the various green gas and biogas pathways in a semi-quantitative way.[10]

Finally, the natural gas pathway and the electrolysis pathway with EU-mix electricity have the lowest score on sustainability. Both are largely fossil based. The natural gas based pathway has a somewhat lower impact on sustainability than the electrolysis route with EU-mix electricity, although the mix also includes a share of renewable electricity. Overall the still considerable share of coal (27%) in the EU electricity outweighs the positive effect of the renewables. In combination with the additional conversion step for electrolysis, this results in a lower score on sustainability compared to direct production of hydrogen from natural gas.

5.2 Results phase 2: including relative weights

In the second phase, the four respondents gave individually relative weights to four criteria. The results are presented in Table 2.

Table 2: the weighing factors for the multi-criteria assessment.

Criteria	No weighing	Weighing respond. 1	Weighing respond. 2	Weighing respond. 3	Weighing respond. 4
Energy performance	25	10	0	0	10
CO_2 performance	25	15	15	25	30
H_2 performance	25	60	65	50	40
Sustainability	25	15	20	25	20

Based on these relative weights, the four assessment criteria become more or less important in the final score, simply a higher weighing results in a larger impact of that criteria in the final score. The final scores presented in *Table 1* will, therefore, change according to the weighing factors given by the four respondents. These weighed final scores for the various hydrogen production pathways are shown in *Table 3*.

This hydrogen refuelling station will initially be supplied with hydrogen from steam reforming of natural gas (SMR), which is combined with GOs to verify its renewable origin. For the long-term electrolysis is an option. For the short term (0-5 years) we can rank the green gas hydrogen (SMR) production routes as follows:

→ *Mono-fermentation* is hardly implemented yet, thus in the ranking this green gas hydrogen production route is not included in *Table 3*.

[10] We assumed that there is no difference in the sustainability criteria if the green gas or biogas is delivered by the natural gas infrastructure or in a physical way (by a newly constructed pipe or LNG-truck). The main impact on sustainability is caused by the biomass (and subsequently de biogas or green) production.

Table 3: the *multi-criteria assessment framework. The various hydrogen production pathways are scored based on the four criteria in a semi-quantitative way. The four criteria - energy performance, CO_2 performance, H_2 production costs and sustainability – have equal relative weights. The numbers between brackets in bold represents the ranking for short-term supply options of green gas. The short-term options are ranked by bold numbers.*

Hydrogen production pathways	Final score no weighing	Final score weighing respond. 1	Final score weighing respond. 2	Final score weighing respond. 3	Final score weighing respond. 4
1. Natural gas (NG), SMR, NG infrastructure	6.5	7.3	6.9	6.3	6.4
2.1 Green gas (GG) (mono-fermentation), SMR, NG-infra.	6.8	7.7	8.3	8.4	7.9
Regional cases 2.1: **hardly implemented yet**					
2.2 GG (co-fermentation), SMR, NG-infrastructure	6.7	7.5 **(2)**	7.8 **(1)**	7.7 **(1)**	7.4 **(1)**
Regional cases 2.2: **GGG (Engie) and BioPower**					
2.3 GG (municipal waste), SMR, NG-infrastructure	6.6	7.3 **(4)**	7.4 **(3)**	7.1 **(3)**	6.9 **(4)**
Regional case 2.3: **ARN Weurt**					
2.4 GG STP (AWZI / RWZI), SMR, NG-infrastructure	6.6	7.4 **(3)**	7.4 **(3)**	7.1 **(3)**	7.0 **(3)**
Regional case 2.4: **Veolia**					
3. (Raw) Biogas STP (AWZI), SMR, constr. pipe	6.7	7.6 **(1)**	7.6 **(2)**	7.3 **(2)**	7.1 **(2)**
Regional case 3: **Veolia**					
4.1 GG (mono-ferm.), SMR, LNG-truck or constr. pipe	4.9	3.3	3.5	4.7	4.9
4.2 GG (co-fermentation), SMR, LNG-truck or constr. pipe	5.9	5.9	6.1	6.4	6.3
4.3 GG (municipal waste), SMR, LNG-truck or constr. Pipe	6.0	6.2	6.2	6.2	6.2
4.4 GG (AWZI), SMR, LNG-truck or constr. pipe	6.4	7.0	7.1	6.8	6.7
5.1 PEM electrolysis, (anonymous) RE elec. certificates	5.9	6.5	7.2	7.3	6.7
5.2 AEL electrolysis, (anonymous) RE elec. certificates	6.2	7.1	7.8	7.9	7.1
6.1 PEM electrolysis, wind/solar elec. certificates	8.6	7.6	7.5	7.8	8.0
6.2 AEL electrolysis, wind/solar elec. certificates	8.9	8.3	8.1	8.3	8.4
7.1 PEM electrolysis, EU elec. mix	2.4	4.4	4.7	3.8	3.3
7.2 AEL electrolysis, EU elec. mix	2.7	5.0	5.4	4.3	3.7

- *Co-fermentation of manure and other organic substrates* is well-established in the Netherlands, but are not easy projects in terms of access to feedstock. As noted previously, in the region Arnhem and Nijmegen we identified two initiatives of co-fermentation: GGG (Engie) and BioPower B.V.

  → Based on the multi-criteria assessment, co-fermentation is ranked mainly as the **best route** and once as the **second** best pathway. *TEKST SCORES AANPASSEN.*

- *Fermentation of municipal waste* is well-established in the Netherlands, also as retrofit in waste treatment plants ('composteerders'). As noted previously, in the region Arnhem and Nijmegen we identified one initiative of the municipal waste fermentation: ARN Weurt.

  → Based on the multi-criteria assessment, the municipal waste fermentation production route is ranked as **third** and **fourth**.

- Producing green gas as an output of a *STP (AWZI / RWZI)* becomes well-established in the Netherlands, incorporating green gas production is now a standard option for new plants. On the one hand, the produced biogas can be upgraded to green gas and fed into the natural gas infrastructure. On the other hand, when the production facility is nearby, the produced biogas can directly be used as an input for an adapted SMR. Veolia has an STP at Kleefse Waard and as a result this physical supply pathway of biogas is one of the cases.

  → The production pathway of green gas and feeding it into the natural gas infrastructure, scored at the **third** place.
  → Based on the multi-criteria assessment, the (direct) physical supply of biogas is ranked in **second** place. A <u>disclaimer</u> for this hydrogen production pathway should be noted. The hydrogen production costs, which obtained a high relative weight (*Table 2*), are strongly related with 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 is needed to verify our calculation. The biogas price is assumed to be three-quarters of the natural gas price.

For the long term (5-10 years), our findings are as follows:

- 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 potential because the mono-fermentation route accompanied with GOs scores better than the other green gas routes.

  → Thus, this option should be in included as a long-term potential of green gas delivery.

- Depending on the speed of technology development and cost reduction of electrolysis, these options 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.

→ Thus, taking the uncertainties of cost reduction into account, this option should be in included as a long-term potential.

6

Conclusions

For the assessment of possible routes to deliver green hydrogen at the Kleefse Waard refuelling station, an analytical framework was established, taking into account four criteria: energy performance, greenhouse gas footprint, economic performance and sustainability. In a multi-criteria assessment, weighting factors provided by the client were used to finally rank the various options.

Our key findings for the short-term (1-5 years) are as follows:

- Local hydrogen production through SMR is most fit, using natural gas from the grid, with the purchase of guarantees of origin for renewable methane ('green gas certificates').
- As production routes for the guarantees of origin, co-fermentation of manure and other organic substrates has the best perspective: of the routes with concrete regional projects, it generally scores best in our analytical framework, taking the clients weighting factors into account. Concrete projects that could (potentially) deliver these GOs are Groen Gas Gelderland and Green BioPower.
- 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 for this option 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.
- As third- and fourth-best options, the same route through GOs was identified, but then with GOs from municipal waste digestion and waste water treatment, respectively. Concrete relevant projects are ARN and Veolia, respectively.

For the long term (5-10 years), our findings are as follows:

- The order of attractiveness for the SMR routes generally stays the same as for the short term.
- Depending on the speed of technology development and cost reduction of electrolysis, these options 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 standard conditions are available for all of them.

7
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8

List of abbreviations

GO = Guarantee of Origin
HRS = Hydrogen Refuelling Station
IPKW = Industrial Park Kleefse Waard
NG = Natural Gas
SMR = Steam Methane Reforming
STP = Sewage Treatment Plant; In Dutch:
AWZI = AfvalWaterZuiveringsInstallatie or
RWZI = RioolWaterZuiveringsInstalltie)

Appendix A. Experts interviewed

In-depth interviews

- Green BioPower B.V., Pieter Rutgers and Johan Voshaar (Groen gas Nederland)
- ARN, Peter Drewes
- ENGIE (Groen gas Gelderland), Arno Wurkum and Daan van Hameren
- Veolia, Marianne Mulder
- HyGear, Ellart de Wit
- PitPoint, Erik Büthker

Telephone interviews and mail contact

- Groen Gas Gelderland (GGG), Ab Emmerzaal
- Friesland Campina, Luc Velhorst (municipality Duiven)
- Waterschap Rijn en IJssel (WRIJ) ,Luc Velhorst (municipality Duiven)
- ‘Sleeping’ consortia of AVR Duiven, Siemens and Engie,
  Luc Velhorst (municipality Duiven) en Ellart de Wit (HyGear).
- Top Kalvermesterij, Evert van der Top
- Klarenbeek duurzame energie, Tonnie Veldhuis
- Greenferm, Berend Dunsbergen
- Groen Gas Nederland, Johan Voshaar
- Vertogas, Daniel Pol

We did not have contact with

- *Attero (Wilp)*
- *Parenco B.V. (Renkum)*

Appendix B. Interview notes

This appendix presents the interviews notes in Dutch for the reason that all interviews were done in Dutch. The man outcomes are translated to English and presented in Chapter 3. After the interview, the notes were authorized by the interviewees.

Hoofdpunten gesprek Ellart de Wit, Hygear
24 augustus 2016

Gesprek met Marc Londo, ECN

- In H2Nodes, HyGear will supply the SMR unit to produce hydrogen; PitPoint will operate it and also purchase the natural gas. With their experience as CNGnet, they should be well-informed in the market for green gas certificates.
- In the earlier HyMove project, HyGear has already operated an SMR; by then they simply purchased green power and green gas from Essent in order to be able to claim the hydrogen produced to be green as well.
- The current HyGear SMR units cannot run on biogas with its relatively high CO_2 content. With some adaptations, that is technically possible but the market for SMR units on biogas simply isn't there yet.
- As for regional production or initiatives for green gas: he mentioned Groen Gas Gelderland and ARN (already on our list). Furthermore:
    - There is a wastewater treatment plant at Kleefse Waard, operated by Arriva. Old one, aerobic, but may be modernization into anaerobic (with biogas) is in the pipeline.
    - Also relevant to contact the 'waterschap' persons we already have, although they most probably produce electricity, not green gas.
    - A (solid) biomass plant also operated by Arriva at Kleefse Waard, producing electricity
    - A local wind power project.
    - He knew of the initiative to produce hydrogen at AVR in Duiven. Initially Siemens was very active on this, and AVR believed this would be solution for their 'must run' waste incinerator, which operating hours are now determined by heat demand, which means it often runs at times of low power prices. P2G(2P) hydrogen production was explored as a buffering option (~hours). In a very late stage, AVR became aware of the very poor business case, after which they pulled out with quite some frustration.
    - Duiven might be an interesting location for hydrogen production, simply because a regional bus depot is also there. If in a later stage, say ~50 busses need to be refilled there, local production may become attractive somehow.
- We discussed the views on the perspective for P2G in general. His impression was very much in line with the conclusions of our P2G study.
- HyGear is going to move its production facilities to a place close to the Shell premises. There they will also start producing hydrogen on a larger scale, refuelling tube trucks and gas bottles.
- And we had some discussion on the way hydrogen is now treated in the context of the RED target of 10% renewables in transport. Neither of us knew

the full details, Hydrogen Europe should. Ellards impression was that there is no current financial stimulus for using green hydrogen in transport.

Hoofdpunten gesprek Pieter Rutgers en Johan Voshaar, Green BioPower BV. Arnhem 14 september 2016

Gesprek met Marcel Weeda en Marc Londo, ECN

- BioPower ontwikkelt combivergisters, die draaien op
  - 1/3 mest
  - 1/3 VGI-residuen en andere goed verteerbare reststromen
  - 1/3 groen gras (berm- en natuurgras)
- Het bedrijf heeft en eerst vergister van dit type gebouwd in Zwitersland, dat inmiddels goed geoptimaliseerd is.
- Een vergister in Almelo is in aanbouw. Deze vergister gaat deels groen gas invoeden en deels bio-LNG produceren.
- In de SDE-systematiek valt deze optie in de categorie 'allesvergisting' met het bijbehorende tarief, omdat minder dan 50% van de input mest is.
- Het gaat om vergisters van vrij grote schaal, ordegrootte 165 kton biomassa-input en 12,5 miljoen m^3 output aan groen gas.
- Daarom zoekt het bedrijf ook naar locaties bij (binnen)water: op die manier kunnen grondstoffen over water worden aangevoerd en kan het digestaat (na hygienisering) naar bijvoorbeeld Duitsland worden afgevoerd. Dit scheelt vooral veel verkeersbewegingen over de weg.
- Het bedrijf oriënteert zich op andere nieuwe locaties, waaronder Duiven. De eerste gesprekken daar zijn positief, de locatie is aantrekkelijk en mogelijk is er synergie met de AVR. Restwarmte uit dat bedijf zou kunnen worden gebruikt, ook om het gras voor te behandelen en beter vergistbaar te maken.
- De handel in groengascertificaten zal Green Biopower niet zelf gaan doen maar delegeren aan een certificatenhandelaar.
- Men herkent de (publicitaire) waarde van verkoop van certificaten aan een regionale partij, en dat zou het waterstofvulstation een interessante (hoewel kleine) partij maken voor een mogelijke vergister in Duiven. Tegelijk moeten de certificaten natuurlijk ook gewoon hun (markt)waarde opleveren.

Hoofdpunten meeting Erik Büthker – PitPoint (donderdag 15 – 09)

Marc Londo en Robin Matton, ECN

De verschillende opties om waterstof te produceren zijn aan bod gekomen.

- Elektrolyse heeft qua (energie)ketenrendement een lage presentatie; en wordt daarom (nu) niet als de 'duurzaamste optie' gezien. 'Indien elektriciteit als regenwater beschikbaar is (lees: er veel intermitterende hernieuwbare elektriciteit wordt opgewekt) zou het een goede optie kunnen zijn'.
- SMR heeft qua (energie)ketenrendement een hogere prestatie; waarbij de huidige aardgas-infrastructuur gebruikt kan worden en zo lokaal waterstof geproduceerd kan worden.
- De optie 'industrieel rest-H2', moet niet vergeten worden → uitzoeken of er in de regio Arnhem/Nijmegen 'rest-H2' beschikbaar is en met name hoe de CO2-prestatie van de H2 er dan uit ziet (Chloor-alkaliproductie; Akzo Nobel zit in de regio Arnhem/Nijmegen). Zou op papier de meest 'kosteneffectieve' oplossing zijn; H2 wordt anders simpelweg uitgestoten. Restromen gebruiken om CNG te

produceren heeft zich in het verleden (en nu) bewezen als een kosteneffectieve optie.

De volgende duurzaamheidscriteria voor de productie van waterstof zijn belangrijk gebleken:

- Luchtkwaliteit (lokaal) i.p.v. CO_2 kwaliteit; waar de 'omgeving/omwonenden' wat van merkt.
- De 'duurzaamheid' van de bron om H_2 te produceren: (a) Hoe (groen) is de elektriciteit verkregen? (bijv. uit kolen of uit een overschot windenergie); (b) Hoe (groen) is de biomassa verkregen?; (c) Hoe scoor je rest-H_2'? LBST heeft in een LCA voor het CertifHy project ook gekeken naar CO_2- impacts van deze categorie

Voor de business case is (investerings)zekerheid essentieel.

- De HBE's bieden geen zekerheid voor de lange termijn (perspectief 2020), omdat onduidelijk is hoe het beleid voor biobrandstoffen er na dat jaar uit zal zien.
- De SDE biedt dat ook niet voor aanvragen voorzien ná dat jaar.
- Op dit soort onzekerheden kun je geen business case bouwen.

Groen gas inkoop: volume en energiebelasting.

- De staffel 0 - 170.000 Nm^3 betaal je simpelweg 0.25 euro/Nm^3. Dit is een gegeven voor de business case, de aardgasvraag voor het vulstation kan niet worden gebundeld met andere vraag om zo in een lager tarief te komen.
- Het capaciteitstarief, vanwege de kleine schaal van het project, zal daarentegen meevallen.

Realisatie-termijn vulstation:

- Loop 2017. Oskar Voorsmit (PitPoint) kunnen we benaderen voor de details.

Hoofdpunten gesprek Peter Drewes, ARN, telefonisch
19 september 2016

Hoofdpunten gesprek ARN Peter Drewes 19 september

Specificaties gesprek met ARN afval-energiecentrale in Weurt.

- 2012: bouw vergistingsinstallatie met nageschakelde composteringsinstallatie.
- 38.000 ton GFT afval afkomstig uit de regio Nijmegen .
- (Technische) mogelijkheid om uit te breiden naar een schaalgrootte van 70.000 ton GFT afval per jaar. Momenteel niet genoeg GFT-afval 'beschikbaar' om deze schaalgrootte te gaan benutten.
- Energie uit de afvalcentrale: 50% elektriciteit, 47% warmte, 3% groen gas (2.5 miljoen Nm^3 groengas productie).
- De techniek die wordt gebruikt om het (vloeibare) CO_2 (levering aan de tuinbouw) te scheiden van het groene gas is membraanscheiding.
- Niet gekozen voor WKK maar voor groengasproductie omdat de SDE meer zekerheid bood en biedt.

De groengascertificaten.

- De groengas certificaten (van de 2.5 miljoen Nm^3 groengas) zijn verkocht aan Connexion (OV in de regio Arnhem). De CNG-netten zijn van PitPoint; zij zijn de partij om te benaderen als er nog iets mogelijk is.

- Fysieke levering groengas is niet aan de orde; geen SDE (voor eigen gebruik ARN zelfs eerst invoeding in het net).
- Prijs groengas certificaten: 0,05-0,012 €/Nm^3.

Telefonische 'conference call' ENGIE Arno Wurkum en Daan van Hameren
ECN: Marc Londo en Robin Matton

Specificaties gesprek productie groen gas door Groen Gas Gelderland (GGG).

- GGG is een samenwerking tussen Engie en Eneco, waarbij Eneco en Engie ook samen verantwoordelijk zijn voor de afzet van het groene gas en de GVO.
- Eind april 2016 is de bouw van de vergister gestart.
- Geplande eerste levering 17 april 2017. De productie zal geleidelijk worden opgebouwd naar de nominale productiecapaciteit.
- De thermofiele vergister zal op jaarbasis 72.000 ton biomassa innemen. De input bestaat uit 50% mest en 50% co-substraten (30% gras en 20% bijproducten uit de agrarische industrie en de voedselketen, zoals graanresten en supermarktmix).
- Uiteindelijk zal 7 miljoen m3 groen gas worden ingevoerd in het regionale aardgasnet van Bemmel en Arnhem-Zuid (8 bar aardgasnetwerk). Er is ruimte om uit te breiden naar 10 miljoen m3 groen gas productie, waarbij Alliander een extra verbinding met Arnhem zal aanleggen om de opnamecapaciteit van het net groot genoeg te maken. De locatie van 4 hectare is ook geschikt voor de uitbreiding.
- De opwaardering van het ruwe biogas tot het groene gas wordt gedaan door middel van gaswassing.
- De aanvoer biomassa zal plaats vinden per as/voertuig.
- Het digestaat zal worden gesplitst in een fosfaatrijke dikke fractie (te exporteren naar Duitsland) en een stikstofrijke dunne fractie (aan te wenden in Nederland). Eventuele verdere zuivering en opwerking van het digestaat zit nog in de ideefase

Aanknopingspunten voor een mogelijk samenwerking tussen ENGIE en de gemeente Arnhem/PitPoint voor de realisatie van het waterstofvulstation.

- Voor de korte termijn zal het waterstof-vulstation een aardgasvraag hebben van rond de 150.000 m^3 groengas (per jaar), waarbij voor de lange termijn de schatting 400.000 m^3 is. Dit is een relatief bescheiden volume. Wellicht zou de inkoop van certificaten voor het waterstofvulstation kunnen worden gebundeld met inkoop van certificaten voor de Arnhemse bussen die rijden op groengas. Dit zou een aantrekkelijker volume voor ENGIE opleveren. Dit past bij onze indruk van meer leveranciers dat het volume aan de lage kant is en beter gebundeld kan worden met andere vraag naar certificaten. ENGIE is zelf nog in de oriëntatiefase wat betreft de afzet van de GvO's.
- Het vulstation is onderdeel van een lokaal innovatief project rond waterstof dat ook de nodige (publicitaire) uitstraling zal genereren. Voor dit project wordt expliciet gezocht naar certificaten uit de regio, en andersom kan het ook voor het project in Bemmel publicitair interessant zijn om op deze manier regionaal verder verbonden te zijn. Dit uiteraard naast de reguliere

marktwaarde van de certificaten zelf. De meerwaarde van deze regionale koppeling voor Bemmel is uiteraard aan ENGIE om in schatten.

- Andere overwegingen die voor Engie relevant zijn bij de verkoop van certificaten:
    - Looptijd van de afname: een langere looptijd is aantrekkelijker. Een bus-concessie voor GvO's voor groengas met een levensduur van 8 jaar geeft zekerheid voor de lange termijn.
    - Volume-afname; bij voorkeur een veelvoud van de genoemde 150.000 m^3 groengas (per jaar); een concreet interessant afname volume is lastig te benoemen. De business case hangt ook af de zekerheid van afname en eventuele regionale meerwaarde.
    - Het combineren van de afname van GvO's met de afname van het aardgas zelf.
- De prijs van de GvO's varieert sterk; onze goede indicatie van 5-12 ct/m^3 groen gas wordt niet tegengesproken; er zijn ook cases bekend met hogere prijzen. Engie werkt overigens met prijzen in €/MWh omdat dit de eenheid van de certificaten is.
- Andere dingen die een gemeente als Arnhem kan inbrengen om een case interessant te maken is als in een concessie voor de verwerking van gemeentelijk GFT-afval de voorwaarde wordt opgenomen dat dit moet worden omgezet in groen gas. Ook een coöperatieve houding in het verkrijgen van vergunningen voor een vergister kan helpen, en het helpen bij het vinden van een geschikte locatie.

Hoofdpunten gesprek Veolia Marianne Mulder die zich binnen Veolia bezighoudt met de duurzame-energie strategie in de regio Arnhem en Nijmegen.

ECN: Robin Matton

Algemeen

- Veolia is o.a. energieleverancier op het Industriepark de Kleefse Waard (IPKW).
- Sinds 1 juli 2014 is Veolia eigenaar van de energiecentrale en AWZI. Bovendien is Veolia eigenaar van het elektriciteitsnet en warmwater- en stoomnetten op de Kleefse Waard.

De energiecentrale bestaat uit

- *Ketel 13*: produceert warm water en stoom uit aardgas, voor o.a. partijen zoals Akzo Nobel die op de IPKW gevestigd zijn. Deze ketel heeft onlangs een 'retrofit' gehad om de energie-efficiëntie en de footprint van de installatie te verbeteren. Vergroten van de efficiëntie van installaties is voor Veolia interessant omdat het energiebesparingen, en dus kostenbesparingen, oplevert, en de footprint van haar energieproductie verbeterd.
- *Ketel 8*: niet meer in gebruik. Verouderd en voldoet niet meer aan de NOx-wetgeving. Deze ketel wordt ontmanteld en Veolia heeft de intentie om er een biomassa WKK-installatie (< 15 MWth) voor in de plaats te zetten. Ketel 8 wordt niet omgebouwd, simpelweg verwijderd. Er zal een volledig nieuwe

ketelinstallatie worden gebouwd die los staat van alle bestaande installaties. De installatie zal gevoed worden met houtachtige biomassa (alleen A-hout, maar shred wood and wood chips). Logischerwijs zal de output elektriciteit, warm water en stoom zijn die wordt ingevoed op het stoom en elektriciteitsnet van IPKW. Veolia heeft een leveringsplicht; ‘vergroening’ gebeurd daarom in fases. En het ombouwen van een reeds stilgelegde installatie botst niet met deze leveringsplicht. Het vergunningsproces had veel voeten in aarde, maar verliep relatief voorspoedig (looptijd van een half jaar).

- We hebben de wens het hout uit de regio Arnhem/Nijmegen te sourcen, maar op dit moment lijkt het dat er niet voldoende beschikbaar is. Wij zijn verplicht om de houtachtige biomassa binnen een straal van 100km te sourcen, dus het zal nooit van heel ver weg komen.
- *WKK installatie:* De oude WKK installatie fungeert nu alleen als ‘nood-bron’ voor de productie van elektriciteit en stoom.
- *Veolia* koopt landelijk of via clusters een groot volume aardgas en elektriciteit in.

De AWZI

- De AWZI is een installatie die stamt uit ca. 1950. De installatie is onderhouden en gerenoveerd, maar bereikt nu nog niet de efficiëntie die haalbaar wordt geacht. Dit heeft ermee te maken dat er geen goede afstemming is tussen de ‘lozingsstromen’ van de industrie en stromen die de ‘contactruimte’ met de bacteriën ingaan.
- Het portfolio van de bedrijven/industrie dat gevestigd is op IPKW verandert, en dus de lozingsstromen ook. Voorheen waren er met name chemische bedrijven gevestigd zoals Akzo Nobel. Tegenwoordig zijn ook houtveredelaars, plastic recycling fabrieken, zonnecellen-producenten, etc. op IPKW gevestigd. Afstemming kan verbeterd worden door bepaalde lozingsstromen (tijdelijk) in overloopbaden op te slaan; zo kan er een stabiele bio-activiteit worden gecreëerd in de AWZI. Bovendien kan communicatie (met de industrie) over de type-afvalstromen die in AWZI terechtkomen verbeterd worden.
- Als de bio-activiteit stabiel is, kan er (pas) nagedacht worden over biogas productie. Momenteel wordt er dus nog geen biogas geproduceerd en Veolia ziet het niet gebeuren dat ze binnen twee jaar al gaat produceren.
- Het voeden van het ruwe biogas in de ‘interne loop’ in bijvoorbeeld ketel 13 is aantrekkelijk vanwege de footprint, er is simpelweg minder aardgas nodig.
- randvoorwaarden (vergunningen, investeringswaarden, contracten, bouwwerkzaamheden) moet nog gevormd worden. De eerste gesprekken vinden vanaf volgende week plaats. De provinciale vergunningen zijn rond, maar de lokale vergunningverlening is nog niet gestart.
- Het gezuiverde water wordt gespuid in de IJssel.
- Veolia heeft o.a. ervaring met een AWZI (Douwe Egberts) die biogas produceert in Joure.

Groen gas productie in de toekomst en een mogelijke samenwerking met het waterstofvulstation:

- Het huidig plan is om het ruwe biogas in de toekomst in te voeden in de 'interne loop' van IPKW, waarbij opwaardering in mindere mate nodig zal zijn. Directe hoge temperatuur verbranding vereist niet direct de opwaardering naar groen gas. Groen gas die in het (reguliere) aardgasnetwerk wordt gevoed, heeft deze opwaardering wel nodig.
- Een directe pijpleiding van de AWZI naar het waterstofvulstation kan aantrekkelijk zijn als het vanuit een kostenoogpunt voordelen heeft voor Veolia.
- Het vulstation is onderdeel van een lokaal innovatief project rond waterstof dat ook de nodige (publicitaire) uitstraling zal genereren. Voor dit project wordt expliciet gezocht naar certificaten uit de regio, en andersom kan het ook voor Veolia interessant zijn om op deze manier regionaal verder verbonden te zijn. Dit uiteraard naast de reguliere marktwaarde van de certificaten zelf. De meerwaarde van deze regionale koppeling is uiteraard aan Veolia om in schatten.
- De investerings- & O&M kosten van de opwaardering zijn additioneel als er aan het waterstofvulstation geleverd gaat worden. Eventueel kan een SMR die ruw biogas als input kan verdragen een oplossing bieden.
- De directe pijpleiding moet onder een brandweer trainingscentrum door; dit kan vanwege 'brandgevaar' nog enige voeten in aarde hebben.

Tot slot:

- Verder is 'symbiose'/ circulaire economie een belangrijke bezigheid van Veolia. Een goed voorbeeld: de reststof van een melkfabriek kan bijvoorbeeld als input gebruikt worden in een farmaceutische fabriek.

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