HyChain 1, 2 & 3

Energy carriers and hydrogen supply chain

A management summary

Institute for
Sustainable
Process Technology

Foreword

This summary introduces the first findings of the HyChain project, carried out by ISPT and its' partners over the last year. ISPT understands the importance of working together with key stakeholders in complex topics of strategic importance linked to the energy transition. The HyChain project demonstrates this really well.

The reports, tools and data generated in the project provide a reference source that substantially contributes to the current and very active debate on how we scale up clean hydrogen in The Netherlands. The HyChain project helps understanding and interpreting the (inter) national context of the hydrogen value chain: local versus global production, estimates of when clean hydrogen may become available for which applications and at what cost. In particular the important international context is often underrrated. The HyChain project builds a facts base regarding technology, economy, and social and political dimensions of the emerging clean hydrogen market. The Netherlands is uniquely positioned to become the dominant clean hydrogen hub in Europe. Our huge potential of offshore wind, the excellent gas infrastructure and a forward-leaning industry (including network companies) all contribute to this unique position. Now let's make it happen!

Noe van Hulst, Hydrogen Envoy Dutch Ministry of Economic Affairs & Climate Policy, Chairman High-Level Advisory Panel Hydrogen at IEA in Paris

Summary

Hydrogen plays a vital role in creating renewable energy systems. Not only is hydrogen important in the transition to a renewable energy system, but it is also a key component of decarbonization pathways for industry.

In order to increase the understanding of the role of hydrogen in the industrial energy transition, the Institute for Sustainable Process Technology (ISPT) established the Hydrohub Innovation Program. This cooperative program runs inside the System Integration Cluster of ISPT.

As part of the Hydrohub Innovation Program the HyChain project serves a specific purpose: developing and providing a common understanding on the scale of the transition challenge, the available technologies, the correlations, hurdles and tipping points. By using this knowledge the optimum pathways to a decarbonised system can be identified. The focus is on The Netherlands, the Dutch industry, and the time horizon is chosen from today until the year 2050. The consortium consists of key industrial players and knowledge partners. First of all hydrogen demand is mapped, domestic sourcing versus import potential is investigated, and all the most suitable pathways and technologies have been identified and evaluated on the basis of their individual merits. In three sub projects HyChain 1, 2 and 3, this has resulted in three overview reports, a cost calculation model and a series of factsheets. What makes this initiative particularly valuable is the fact that it has been a multi stakeholder exercise which has lead to a supported, peer to peer (over)view, and an up-to-date fact base for further use. Each of the stakeholders in the project, and outside, can work with the material on its own, whether it is industry, policy makers or knowledge institutes. The models allow modification and introduction of specific scenario's and parameters. The initiative is continued by HyChain 4 and 5, which focuses on developing integral supply chain models in support of joint decision making and applying these to investigate both societal impact and geopolitical aspects of the emerging hydrogen economy. The current results have been presented, are accessible to the public, and are ready to be used.

Content

Introduction

With climate change and local emissions high on the public and political agenda, worldwide falling cost of renewable energy production, the development of hydrogen as an energy carrier, and green feedstock, has gained huge momentum in the past few years. The potential of hydrogen (molecules) as an energy carrier, next to electricity (electrons) and the interoperability, is more and more recognised by global leaders. Especially the positive attributes with regard to storage and transport of hydrogen is getting special attention, for these would be problematic in a decarbonised "all-electric" world, without hydrogen. When creating energy systems on the basis of wind and solar power the need for long term storage and transport solutions quickly becomes clear. The intermediate steps starting at the source of energy, via hydrogen production, transport, storage, until the point of use, altogether are called the hydrogen (value) chain. Therefore the acronym HyChain was chosen.

The background of HyChain is to gain insight at a strategic level on how the hydrogen-based supply chains produced from green energy of the future will come about and can play a role in the economy of Western Europe and the Netherlands in particular. The question is how industry can make use of hydrogen, and how it will become available. For example, how local production in industry clusters can relate to large-scale imports; how green and blue hydrogen will develop and correlate; what volumes can come available and in which timeframe the transition will take place.

ISPT brought industrial stakeholders in the value chain and knowledge partners together to discover which key questions need to be understood in order to optimally meet the needs for hydrogen during the transition to a low-carbon industry. Based on these questions, the project was divide into the following five stages:

1. Understanding demand in industry - Assessment of the current state and future trends;
2. Understanding overseas supply - Economic analysis of energy carrier production, import, transportation and storage;
3. The pieces of the puzzle to connect supply and demand - Technology assessment of the full value chain;
4. Bringing the pieces together - System assessment of scenarios for the Netherlands;
5. Understanding the impact – Societal and geopolitical implications.

The Netherlands, as many other countries around the world, is in the process of energy transition. This densely populated highly industrialised nation was long dependent on own natural (gas) resources, combined with (significant) imports. Netherlands is a highly developed society with strong positions in financial services, chemical industry, refining, steelmaking, horticulture, and logistics via road, water and rail. The industrial clusters find their origins in good access to low cost fossil resources combined with the conversion and logistics thereof.

The major industrial clusters are located in 5 areas (listed alphabetically):

- Amsterdam Noordzeekanaalgebied
- Delfzijl-Eemshaven-Emmen
- Geleen-Chemelot
- Rotterdam / Moerdijk
- Zeeland Vlissingen Terneuzen

HyChain focuses at The Netherlands, but also takes into account the neighbouring countries, and even some sources far away. Netherlands is an importer of energy and energy carriers and a major transit country for energy carriers and intermediate products, it has a hub function.

For supply chain development it is essential to look at how the local situation is connected to the outside area. HyChain places The Netherlands and direct surrounding countries central to understand how local demand and supply can develop through the transition. The Netherlands now imports major fossil sources and may transition into renewable based energy and feedstock imports, as well as how these relate to domestic production. At the same time The Netherlands is a hub to transport much of the imported fossil sources downstream to our neighbouring countries, and even some sources far away.

The HyChain project was set up to better understand, map, evaluate and model the emergence of renewable based supply chains. The HyChain project serves a specific purpose: developing and providing a common understanding at the scale of the challenge, the available technologies, the correlations, hurdles and tipping points.

The aim of HyChain in general is: *How can we make an optimization of the full hydrogen value chain to deliver the lowest cost, carbon neutral hydrogen to Dutch industries, and which barriers and bottlenecks stand in the way?*

HyChain explores the possible future role of hydrogen in different end-use sectors in the Netherlands with focus on industrial demand under transition. Furthermore the project considers other alternative energy carriers for the various demand sectors, and the system implications connected to these alternatives.

In HyChain 1 potential demand volumes for hydrogen in the future have been explored, as well as tipping points which would change the picture. In HyChain 2, (international) sources of hydrogen were mapped to examine how attractive import from different regions could be. HyChain 3 is a technology assessment that gives an overview of the technologies needed to build a supply chains – covering conversion, storage and transport technologies for transport of hydrogen and direct derivatives (e.g. ammonia, methanol, and other molecules). This database is a starting point for the next phase of the project, HyChain 4 and 5, in which integral value chains will be explored, and which will start as of 2020.

The following summarizes the key findings of each of the three projects.

Marco Waas, Nouryon

Nouryon sees itself as a player in the future hydrogen market. Even today Nouryon delivers substantial quantities of by-product hydrogen.

"HyChain is important to us because it gives us more insight into the value chain and offers the possibility to make our own Nouryon business cases and to solve the unknowns therein. The relative competitive position, the business climate for the Netherlands and thus also for Nouryon are better understood through HyChain."

Nicolien van der Sar and Marijke Kellner-Van Tjonger, Gasunie

Gasunie not only transports natural gas for domestic and international use, but also stores natural gas in caverns and owns an LNG terminal. In the future there may also be a role in the transport and storage of hydrogen and as the owner and operator of large-scale open access conversion equipment. Gasunie wants to speed up the energy transition and needs insight to facilitate that process. HyChain makes a good contribution to this.

"Cooperation between the network companies (TSO and DSO) and with industry is crucial for the success of the energy transition. HyChain shows that hydrogen is an indispensable link in the energy transition, whether it is green, blue or yellow (import) hydrogen. Gasunie has experienced the process and cooperation as transparent and open. The findings were well shared among the partners. ISPT has played an important role in establishing connections between stakeholders. Collaboration is important and ISPT has facilitated this well."

HyChain 1

HyChain 1 investigated the development of expected demand for hydrogen in the industry, as energy carrier and feedstock, and provided insight into technological applications.

What are the tipping points influencing the shift from incremental change towards rapid growth in a hydrogen economy, across various sectors. In other words, what set of conditions gets the system really rolling?

The leading question here was how energy and feedstock demand in the process industries may change when aiming to become carbon neutral. The main focus of the HyChain 1 report is to explore the major tipping points influencing the shift from incremental change towards rapid growth in a hydrogen economy, across various sectors. The work performed involved literature research, workshops and interviews and building demand scenarios. The outcome resulted in a report.

The key takeaways of HyChain 1 are:

- Netherlands is Europe's second largest hydrogen producer estimated at 10 billion m3/a (~800kt/a).
- The Netherlands are well-positioned, based on the potential of offshore electricity production at the North Sea, existing gas infrastructure and the large industrial and maritime sector.
- Enough storage capacity for hydrogen in salt caverns can be created in 2050 to meet seasonal fluctuations in national demand. This is a real opportunity for the Netherlands.
- The study reveals there is a large uncertainty in the projected future use of hydrogen in The Netherlands, therefore a minimum (0,8Mton/a) and maximum (13Mton/a) scenario has been investigated.
- Uptake of domestic hydrogen is not only determined by its competitiveness with import of hydrogen, but also by the extent in which large quantities of offshore wind must be integrated into the energy system (supply driven).
- Any scenario with considerable hydrogen demand as energy carrier, will rely on considerable amounts of hydrogen import.
- In the maximum scenario, the largest demand sectors are: aviation, shipping, industrial heat and feedstock. (Followed at distance by built environment and mobility). Aviation and shipping together could account for almost half of the total annual demand.
- Additional imports of hydrogen would roughly account to three times the required maximum demand scenario to cover the current volumetric turnovers of energy through the Netherlands.
- Closely following and connecting to developments in neighbouring trade partner countries like Germany is absolutely necessary.
- A shift from solid and liquid energy carriers to gaseous hydrogen means that Dutch exports can face competition from surrounding countries with a gas infrastructure.
- Biomass potential (availability, price, market uptake) has a very large influence on the final hydrogen demand.
- Acceptance of CCS will have impact on availability of hydrogen, so do certificates of origin.
- Safety perception of hydrogen is a critical element. Early application of hydrogen in mobility sector could lead to early societal acceptance.
- Competitiveness of domestic green hydrogen will influence how easy a 95% CO2 emission reduction pathway is likely to be.
- Availability of offshore wind is an enabler for green hydrogen production and green hydrogen production is an enabler for offshore wind.

Kees Biesheuvel, DOW

Dow today supplies by-product hydrogen and is (also) a buyer of hydrogen in the future, so HyChain is very relevant to us. Now we get our carbon from oil derivatives, in the future with hydrogen we get the carbon from circularity and industrial symbiosis. I would say "HyChain is beyond the hype of hydrogen"

"The Kalavasta model revealed that the global availability and production of hydrogen is not as evident as you might expect from a technical point of view. This has less to do with technology, much more with politics, and access to finance, for example. This is important to recognize when making choices for local production or import. By discussing with stakeholders, irrespective of short-term and commercial interest and/or politics, and looking for certainties and facts, it has contributed to a better and more shared image. Companies are looking for these securities. This would have been more difficult without HyChain. In the energy transition it is important that policymakers also see that larger whole, there are sometimes step functions in the global system change. HyChain provides insight into global developments, likely landing sites of hydrogen demand (sectors) and the correlations."

HyChain 2

HyChain 2 is all about the role of hydrogen import. It focuses on the cost implications of importing renewable electricity, hydrogen and hydrogen carriers into the Netherlands from an ultimately 2050 perspective. To a background where the domestic demand of today (0.8Mt/a) may increase at minimum twofold and maximum by a factor of 20 to a quarter of current global production volume. A value chain approach is required to evaluate realistic and suitable options to meet the hydrogen demand scenario's. The outcome resulted in a report and a cost model that is available in Microsoft Excel.

Which flows of energy carriers derived from renewable electricity (and in which form) could flow through the Netherlands in 2050, based on lowest costs?

Three main routes of import have been investigated and compared in a model (calculation tool), taking into account a range of supply modes, hydrogen carriers and potential geographical sources of origin. A number of these options have been modelled and results are provided in the report. The model allows modifications and own investigations based on different assumptions and parameters.
The developed high level cost based model calculates the costs of importing renewable electricity, hydrogen and hydrogen carriers from virtually every country in the world to the Netherlands, using a greenfield approach and 2050 as a reference year. The model is accessible to the public and is accompanied by a user guide and a more extensive technical documentation.

The model considers three main *import* routes:

1. Renewable electricity generated and transported via high voltage direct current (HVDC) *cables* to the Netherlands, where it can be used to run an electrolyser to produce hydrogen;
2. An electrolyser fed with renewably produced electricity abroad and the resulting hydrogen is transported to the Netherlands via a gas *pipeline*;
3. Renewable hydrogen produced abroad is used to produce a hydrogen *carrier* which is transported to the Netherlands by ship, where it can be used directly or the hydrogen can be retrieved.

The key takeaways of HyChain 2 are:

- The report features four main chapters i) model user guide, ii) extensive technical documentation iii) results model base settings and variations, iv) collection of country profiles.
- The first results from the model with base settings and base country and technology parameters show limited hydrogen import opportunities: cost competitive hydrogen is generally sourced from within Europe, or from North Africa and the Middle East, transported via gas pipelines, occasionally via HVDC cables and carriers only when these will be used directly as feedstock.
- When departing from the base scenario and using Dutch capital to finance the supply chain, more opportunities arise. Reduced capital risk due to weighted average cost of capital (WACC) effects.
- The model allows to evaluate various base cost dynamics and is sensitive to specific scenario's. It is not a pricing model, and once taxes and incentives are introduced outcomes can look different.
- Eight country profiles are embedded in the current model i.e. Canada, Morocco, Spain.
- For many counties local production cost of renewable electricity, hydrogen and hydrogen carriers are lower than in the Netherlands. Including transport cost and an international renewable energy certification (IRECS) scheme could lead to a viable option on cost basis.
- The developed model gives useful insights and provides guidance, however more work is needed in simulation of specific scenario's and for model verification (HyChain4).

Figure 1: Fertilizer production, YARA Sluiskil Province of Zeeland

Rob Stevens, YARA

Together with our partners we have recently readied a significant hydrogen infrastructure project on an industrial scale: 12km pipeline between Dow and YARA, based on a reused natural gas pipeline. YARA in Sluiskil is traditionally a major consumer of natural gas for the production of fertilizers. The subject of hydrogen for us has already become a daily reality.

"HyChain offers the tools to make better estimates of the cost differences between the various options. What is the relationship between domestic demand and generation and import potential. This is also strategically important information for The Netherlands as a trading country. It is very important to properly understand which part of the energy supply we can electrify from the Industry, Mobility, High-temperature heat sectors, and which part can and must be covered with molecules. The added value of ISPT is in bringing together several parties, in order to get a broader picture. Together you know more than alone. The datasets are becoming more robust."

HyChain 3

HyChain 3 provides fact sheets of the individual building blocks that form value chains, an overview of technologies for conversion, storage and transport.
In a collaborative effort between industry parties and research institutions, key information was collected into fifty-nine fact sheets on technologies for production, conversion, storage, transportation, and reconversion of hydrogen. Next to quantitative information, qualitative risks or opportunities that are known to be associated with specific technologies have been explored and mapped. The outcome resulted in a report and a factsheet database in Microsoft Excel.
At current stage this represents the largest single reference work in the public domain and can be a key reference manual to serve as a starting point for further analysis on hydrogen supply chains.
The main research questions for this project include:

- What are the main technologies in the full value chain of hydrogen generation, conversion, storage, and transportation?
- What parameters (social, economic, technological, and environmental) will determine the future use of these technologies in the value chain?
- How do the technologies score on each of these parameters?

The technologies are divided into five categories: Production of hydrogen (P), Conversion to energy carriers (C), Transportation (T), Storage (S), and Reconversion to hydrogen (R). All with quantitative KPI's and known risks and opportunities.

The key takeaways of HyChain 3:

- A series of fity-nine factsheets have been developed.
- The technologies have been mapped and evaluated which lead to quantitative KPI's and quality assessment matrices (XLS) per building block.
- Most reconversion options were outside the scope of this work except Ammonia, LOHC and NaBH4.
- The developed data set can be used for the next project HyChain 4, Simulation or stand alone reference for separate work.
- The results of this current stage of work are not harmonised because of different methods of data collection and data sources.
- This project does not evaluate how technologies can be linked to develop supply chains. Thus, harmonizing e.g. in terms of size, flowrate how technologies can be added up together needs to be looked at in follow-up work.

Outlook

The first three HyChain projects have resulted in an extremely valuable dataset and common understanding. However this is a static picture.

HyChain 4 will help answer key questions that producers and logistics companies are currently facing about how and where hydrogen will be produced, transported, stored, and used in the Netherlands in the coming decades. This will play a key role in supporting all of the supply chain actors in deciding which infrastructure to develop, which technologies to invest in, and which partnerships to establish in the coming decades. Data-driven model-based assessment of scenario's will help gaining better and deeper insights. How will chains develop over time? Building chain models that link supply and demand and make investment choices more robust.

Colofon

TITLE
HyChain 1, 2 & 3

SUBTITLE
A management summary

PUBLICATION DATE
December 5th, 2019

AUTHOR
Jaco Reijerkerk *(Ekinetix),* on behalf of the HyChain consortium

PUBLISHED BY
Institute of Sustainable Process Technology (ISPT)

ADDRESS
Groen van Prinstererlaan 37, 3818 JN Amersfoort, The Netherlands

TELEPHONE NUMBER
+31 (0)33 700 97 97

E-MAIL
info@ispt.eu

WEBSITE
www.ispt.eu

ABOUT THIS REPORT
This report is a management summary of the reports of three HyChain projects:
- HyChain 1: Assessment of future trends in industrial hydrogen demand and infrastructure
- HyChain 2: Cost implications of importing renewable electricity, hydrogen and hydrogen carriers into the Netherlands
- HyChain 3: Hydrogen Supply Chain – Technology Assessment

This summary as well as the full reports and tools can be found on www.ispt.eu/projects/hychain.

THE HYCHAIN PROJECT

The HyChain project is initiated by the Institute for Sustainable Process Technology (ISPT) and is part of the Hydrohub Innovation Program. Its mission is 'Largescale electrolysis-based production of sustainable, low cost, hydrogen as a driver for circular industrial chains'. The project is part of the ISPT cluster System Integration. The HyChain central research focuses on the question: *'How can we make an optimization for all the full value chain to deliver the lowest cost, carbon-neutral hydrogen to Dutch industry (domestic and global production) and what barriers and bottlenecks stand in the way?'.*

PUBLIC FUNDING

The project received public funding from The Netherlands Enterprise Agency (RVO) under Grant TSE-18, Grant TSE-17 and Grant TSE-01 Topsector Energiestudies.

CONSORTIUM PARTNERS

FRAMES · Gasunie · Nouryon · OCI Nitrogen · Port of Rotterdam · Proton Ventures · Stedin.net · Vopak · Yara · ECN › TNO innovation for life · TU Delft Delft University of Technology · Royal HaskoningDHV Enhancing Society Together · Kalavasta Climate Neutral Strategies · Metabolic · Quintel Intelligence

WWW.ISPT.EU

Institute for
Sustainable
Process Technology