A Hydrogen Exchange for the Climate

An initial exploration

Advantages
Conditions
Requirements
Possibilities
Growth Path
Perspective

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Note: *This is an English translation of the original report in Dutch: "Een Waterstofbeurs voor het Klimaat". If there would be any dispute about content, the Dutch original is decisive.*

Executive summary

This study explores the possibilities for a hydrogen exchange, partly based on the previous experience of the establishment of the electricity exchange and the gas exchange. This hydrogen exchange is made possible by the anticipated role of hydrogen as an important new climate-neutral energy carrier in the Dutch energy transition. This gives a hydrogen exchange added value: as a catalyst in the build-up phase of the market, and as a facility for better economic optimisation once the hydrogen market is mature.

Several preconditions apply to a hydrogen exchange, partly based on previous experience with the establishment of the electricity exchange and the gas exchange. It requires a developed market with enough different suppliers and demanders, as well as a physical trading point or energy infrastructure where market participants can find each other to exchange surpluses and deficits.

One difference is that, at the time, the electricity and natural gas exchanges were created by liberalising an existing situation where the market and the infrastructure were in place beforehand. In the case of hydrogen, both the market and the infrastructure have yet to be largely built up. It takes time (approx. 6 - 10 years) to realise the necessary hydrogen infrastructure and also to bring the climate-neutral hydrogen production up to the required level. The hydrogen exchange must therefore be built up in phases, with the exchange growing along with the market.

In the final situation, several options are possible as trading points: new hydrogen hubs in the making or announced; the existing hydrogen pipelines of the industry; future landing hubs for hydrogen imports; storage facilities for hydrogen; and the announced hydrogen “backbone” of the Gasunie (by converting part of the gas infrastructure). Ultimately, the hydrogen backbone will be the most decisive element since all other infrastructures will be connected to it. This backbone can also serve a variety of market participants: electrolysers; other climate-neutral hydrogen sources; hydrogen power plants; suppliers of H_2 for transport and the built environment; and large industry, for fully continuous processes.

This is a favourable situation for an exchange with added value. In terms of volatility and temporal dynamics, the hydrogen market is expected to be half-way between the electricity market and the gas market. This creates added value for the economic optimisation process and for optimising the dynamic matching of supply and demand. This will reduce costs, especially if this is an exchange that works for all market participants across the network, without barriers.

- **Ultimately, a hydrogen exchange based on a hydrogen backbone and with sufficient diversity of players, can operate on a virtual trading point across the entire infrastructure**, and thus be accessible to all trading parties. This exchange has added value in the economic optimisation process of the hydrogen market. Ideally, this network should also be internationally connected to allow foreign parties to participate.

In the final situation, this will be very similar to the successful gas and electricity exchanges. Based on the experience with these exchanges, several conditions are important in order to achieve liquid trading.

- **Open access and network operation by an independent network operator, with a single access rate: parties pay this to operate across the entire network (‘postage stamp tariff’)** and can trade with all other parties there. Ideally, this should include services such as quality conversion, so suppliers with different qualities of hydrogen are facilitated and can easily participate in the market (following the model of the gas trading site TTF).

- **Markets for ancillary services, where market participants supply products to the network**

operator for the operation and quality assurance of the hydrogen network. These markets are already operating for electricity and gas. Ideally, these markets (e.g. f balancing markets, or storage capacity auctions) should be bundled with the regular market (the spot market), so they reinforce each other (an example was the organisation of an auction for gas storage capacity by the APX-ENDEX exchange). This also reduces costs for both the network operator and the market participants.

However, as mentioned before, this situation with a developed market with a backbone will only arise over time. The question is whether it is feasible to create a provisional market during this start-up period that can be supported by an exchange or pre-exchange activities. If that is the case, the exchange can play a role in the development of the market and grow along with it.

In this context, there are four possibilities, based on experience:

- **Launching an exchange in the start-up period at an already completed or existing physical trading point (or points) for hydrogen if there is sufficient market diversity.** The backbone will then incorporate this point into the larger national infrastructure, after which the physical trade can migrate to a virtual point across the entire infrastructure. Several foreign gas exchanges have successfully followed this development in the past. Physical starting points could be, for example, the new hydrogen infrastructure of the Groningen Seaports, in the port of Rotterdam, expansion of the hydrogen pipeline already in operation in Zeeuws-Vlaanderen, the Amsterdam/IJmuiden port region, and possibly other locations. At such sites, imports of sustainable hydrogen (or derivatives such as ammonia and LOHCs) may also play a role.

- **Starting a trade in "Guarantees of Origin" of green or decarbonised hydrogen between such locations, also in the period prior to the backbone.** There may not be enough liquidity at each point individually at the outset, while there is a need for trade between points, for example, because this involves hydrogen with different levels of CO_2 emissions. As long as there is no connecting backbone, Guarantees of Origin can be traded that represent the value of the CO_2 reduction.

- **The launch of a hydrogen price index based on a so-called "pricing panel"** in which the various market participants are regularly consulted on the current trading price. The traders then regularly issue quotes for the purchase and sale of hydrogen, from which a price index for hydrogen is distilled and published by the exchange in formation according to fixed rules.

- **A market for a possible blending obligation.** The modalities of a possible national mandatory blending of hydrogen are being studied. The exchange initiative could play a role in the transparent introduction of hydrogen for such a blending obligation. This will, however, depend on whether and how such a blending obligation is implemented, as well as on other factors.

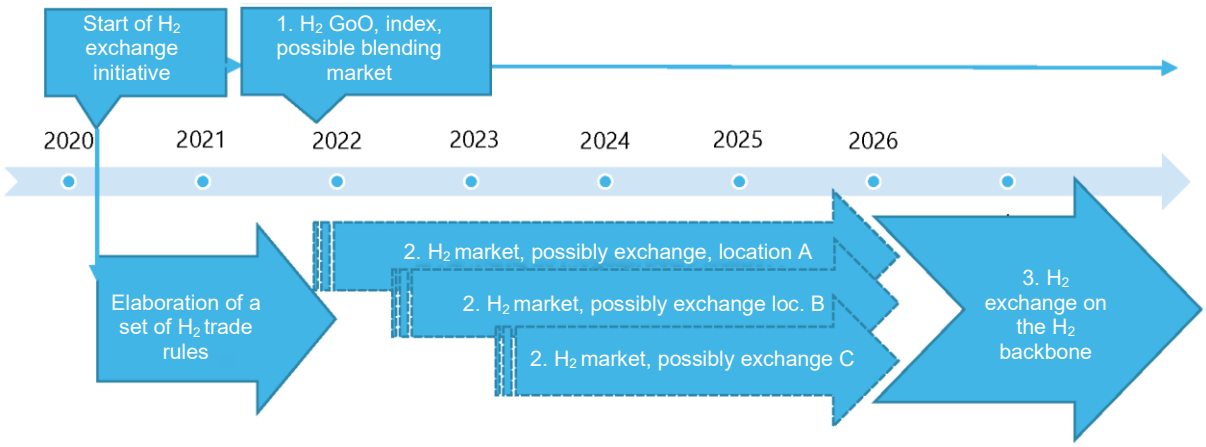
Such provisional exchange products are steppingstones for the market in the run-up to a full-fledged hydrogen trade. Together with the positive final perspective of the exchange trading on the backbone, this creates a good development trajectory which allows the development of the hydrogen exchange to grow along.

The Netherlands has a unique starting position due to its cost-efficient approach to sustainable energy, its location, which is perfect both for offshore wind and the landing of hydrogen imports, the role that Dutch industry plays in hydrogen, and, of course, the unique gas infrastructure that will be converted and used for the transport of hydrogen. The Netherlands also has a track record when it comes to energy exchanges: as the designer of the system of market coupling of the European electricity exchanges, and, of course, the creation of Europe's leading gas market at the TTF.

All in all, this means that the Netherlands has an excellent opportunity, that deserves to be developed further. In this regard, it is recommended to take an appropriate initiative. Such an initiative should be structural, aimed at the launch, development and expansion of the exchange initiative as it grows with the development of the Hydrogen Market as a whole. Three elements can be distinguished subsequently:

1. Forerunners of the exchange initiative also paving the way for the market: a system for guarantees of origin and the trade therein, including between possible locations, and, if possible, a price index for hydrogen and/or a market for a possible blending obligation.
2. Regional physical markets in the start-up phase based on the hydrogen infrastructure at one or more port locations or hydrogen carriers such as ammonia or LOHCs, whether in combination.
3. The final hydrogen market on the hydrogen "backbone" around a virtual trading point, over a network with a postage stamp tariff with international connections to other countries.

This can be summarised in the following timeline (schematic, times are examples and depend on practical developments):



In order to set this up in a coherent manner and based on the experience from previous exchange initiatives, it would be best to set up an initiative group.

Such an initiative group would then deal with the main preconditions and condition-setting activities such as the initial design of a hydrogen price index and the criteria of a system of guarantees of origin. In addition, a set of trade-enhancing rules can be elaborated as advice to the emerging hydrogen networks locally and nationwide, in cooperation with the network owners and/or intended network operators.

Such an approach has already yielded positive results: at the start of the electricity and gas exchanges and also in the international context with European market coupling of the electricity markets. This experience can be used for the establishment of the hydrogen exchange.

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1. Introduction

Hydrogen is increasingly attracting interest as an important part of the energy transition. No greenhouse gas is released when hydrogen is used. Hydrogen is therefore regarded by many as a climate-neutral energy carrier for the future. The Climate Agreement therefore devotes a great deal of attention to hydrogen. Due to the position that hydrogen will occupy in the future and the many ways in which it can be produced and used, with a variety of producers and users, the development of the trade in hydrogen will become important. As a result, the possibility of a hydrogen exchange has also become of current interest.

There are several potential sources of climate-neutral hydrogen: based on sustainable electricity by means of electrolysis, conversion from natural gas using CCS, and various other sources. And there are multiple applications: in industry and as a source for back-up power plants, but also in transport and the built environment.

As a result, many new sources and customers can emerge creating a greater diversity of supply and demand, both constant and with variations over time. An effective exchange of surpluses and deficits through a market could be jointly beneficial and also beneficial for the energy transition. If this takes place via a hydrogen exchange, it can have benefits for both major and minor players.

That is why the Ministry of Economic Affairs has commissioned a brief initial study into the possibilities of such a hydrogen exchange.

This study was carried out by B. den Ouden as founder (1999) of the APX energy exchange and former director, until 2013, of the Dutch APX-ENDEX energy exchange. The analyses in this project were carried out based on his extensive experience both in energy exchanges and in energy transition.

On the one hand, the study is based on the development of the hydrogen market that is currently emerging. This hydrogen market also requires the creation of an infrastructure, which can be a delivery point for exchange trading. To this end, the study is also exploring the characteristics of energy exchanges and how they may apply to hydrogen.

Several people and organisations were interviewed during the study, for which we are grateful. These interviews have yielded valuable insights that have been incorporated into this report. Given the brevity of this study, it was not possible to aim for completeness in the interviews. Anyone interested in the subject is invited to take note of the content, in the hope that it will contribute to the development of a market for hydrogen that will help achieve the climate targets.

2. The development of the hydrogen market

2.1. Production

Currently, there is already a large amount of hydrogen in the Netherlands, namely some 175 Petajoules (PJ) [1] . This is roughly 5% of the total amount of energy consumed in the Netherlands. This is to a large extent "grey" hydrogen, produced from natural gas reforming with CO_2 emissions, for which there are various industrial producers and users. In addition, hydrogen is produced by industrial parties as a by-product of chemical processes such as the cracking of hydrocarbons for the plastics industry.

In the future, this will be supplemented by:

- Sustainable hydrogen from electrolysis of green electricity (wind and solar energy). This is motivated by market surpluses, or transport problems (onshore or off-shore), or deliberately created for this purpose (such as the NorthH2 project).
- Climate-neutral hydrogen from natural gasification with full pre-combustion CCS; the main initiatives for this are the Magnum power plant project (Vattenfall and Equinor), and the "H-vision" project (industrial parties in the port of Rotterdam).
- Partially decarbonised hydrogen: upgrade of recurrent grey hydrogen installations with CC(U)S, which is already partly being done and which could be further developed;
- New industrial hydrogen sources. An example is the idea of no longer burning the carbon monoxide released at Tata Steel, but converting it into hydrogen via the so-called "water shift" process, the resulting CO_2 to be stored using CCS.
- Import hydrogen, which would be "Green" hydrogen from areas where generation from sun and/or wind is cheaper: empty and/or sun-rich areas, such as deserts. Transport can take place (in order from cheap to expensive, currently known) by hydrogen gas pipelines or by ship: liquid ammonia, liquid organic hydrogen carriers (LOHCs) such as toluene / methylcyclohexane, or liquid hydrogen.

2.2. Trends in sectors

Current market demand comes mainly from industry. At present, this market demand is still strongly linked to production per industrial cluster, which means that there is only a limited market or trade in hydrogen. In addition, there is a small market for road transport.

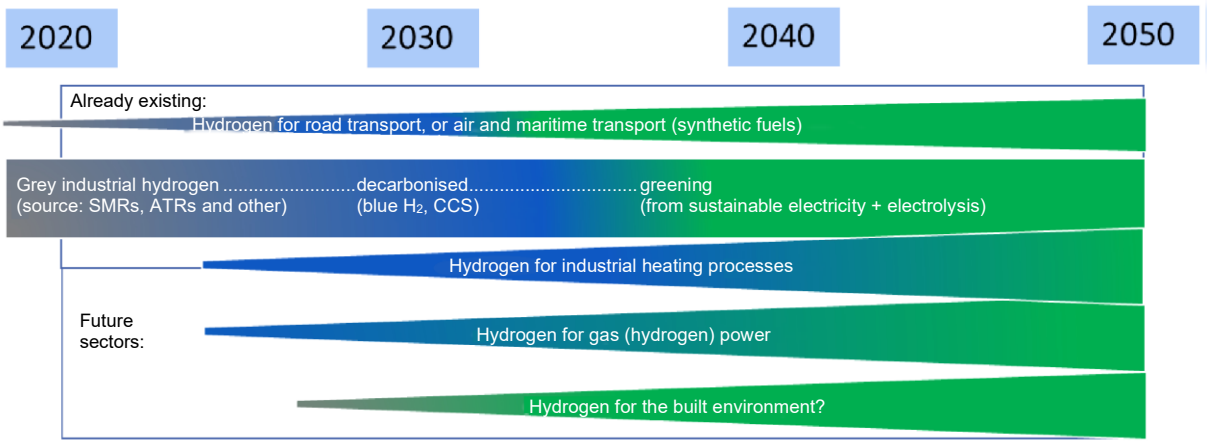
With regard to future final consumption, the main sectors considered are industry and/or power plants and hydrogen for traffic and transport. However, there are also parties (including Stedin, Essent and Berenschot) that are considering hydrogen for homes, based on the cost-effectiveness of increased sustainability. This may involve both pure hydrogen and blending using the existing gas network.

[1] Hydrogen supply and demand now-2030, update November 2019 (Gasunie)

Expectations per sector are roughly as follows, with different scenarios still conceivable[2]:

- The substantial demand for hydrogen from industry, the production of which currently results in CO_2 emissions, will in the future be decarbonised (by means of CO_2 capture and CCS or CCU) and greened (based on sustainable electricity and electrolysis). More hydrogen may be needed for the "new chemistry" based on recycling and biobased. In addition, hydrogen can be used as a fuel for heat processes (the extent to which is uncertain given the competition from electrification).
- H_2 for road transport is gradually growing, especially in long-distance freight transport and in some scenarios also for short-distance and passenger transport, the latter is still uncertain due to the strong competition from electric transport. In addition, hydrogen may become important in shipping, in the form of ammonia.
- The hydrogen-fired power plant will be promising in several scenarios, as important peak supply and back-up in the electricity supply. There is competition from green gas and biomass.
- Hydrogen may also be applied in the built environment. This includes solutions where most of the heat demand is covered by hybrid electrification, and green gas and/or hydrogen still covering a small part (mainly the peaks).[3]
- This will create a need for hydrogen storage with characteristics (size, capacity, storage time) depending on the supply and demand pattern, such as Gasunie' s plans for hydrogen storage in salt caverns (Zuidwending location) or other possibilities.

One of the examples of a possible development over time is shown schematically (not to scale) in the figure below:



[2] Also see "Climate neutral scenarios 2050" (Berenschot and Kalavasta commissioned by Netbeheer Nederland, 2020) https://www.tweedekamer.nl/downloads/document?id=92cfa99f-3d82-4c42-9fef-7f74e49ad74b&title=Klimaatneutrale%20energiescenario%27s%202050.%20Scenariostudie%20ten%20behoeve%20van%20de%20integraleinfrastructuurverkenning%202030-2050.pdf

[3] See the transition paths for the built environment in "Climate neutral scenarios 2050" (Berenschot and Kalavasta commissioned by Netbeheer Nederland, 2020)

2.3. Development of variation patterns and the need for a market

The current demand from industry is continuous, as is production. The demand for hydrogen for road transport is much smaller in volume, is stored and is therefore buffered over time. That means little time variation currently, so little market incentive. This will change in the future:

- Sustainable hydrogen from electrolysis of green electricity (wind and solar energy) is of course highly weather-dependent over a period of days and weeks (hydrogen from wind) or day/night, days and season (hydrogen from the sun). This is much more volatile than the current hydrogen production.
- Hydrogen power plants have a large day/week variance (as back-up for sustainable energy) and possibly also a seasonal variance (because of winter peaks caused by electric heat pumps).
- If hydrogen enters the built environment, it will be highly seasonal and dependent on weather patterns. Seasonal storage of hydrogen, as is currently the case with natural gas, will then be necessary.

The time variation of the new hydrogen supply and the new hydrogen demand is therefore much greater on different time scales. The market will be characterised by surpluses and shortages, time-dependent and per type of supply or demand. It is then of great general economic interest to have a market in which parties can exchange surpluses and shortages, thus reducing the overall variations for the market as a whole.

This will obviously also create the need for hydrogen storage with different characteristics (size, capacity, storage time) depending on the supply and demand pattern. However, if the parties can eliminate part of the surpluses and shortages in advance via a market, the overall costs will be lower, and storage will be used more effectively. Where there is a market, this will be the first option to handle the fluctuations in the market. Especially if these variations are short-term, an exchange (spot market) is an effective way to handle this.

It is interesting to look at the time scale on which these price fluctuations will take place in the future hydrogen market, compared to the existing electricity and gas markets:

- In the electricity market, constantly fluctuating demand and production must always be in perfect balance with each other; in principle, storage is not part of the system. As a result, prices can even vary greatly per hour, in addition to day/night variations, week patterns and longer-term movements in price levels.
- The hydrogen market will probably be a bit slower because with hydrogen, like gas, there is always some storage in the pipeline system (the so-called “line pack”). Given the typical volatility in the future supply and demand of hydrogen (e.g. electrolysis of wind and solar power), more price variations will be seen at different parts of the day, day/night, weeks and seasons.
- The current natural gas market is even slower in comparison: large-scale cheap gas storage in the system, so few price differences on a daily basis, larger fluctuations on a seasonal basis, and movements linked to the world market over several years.

In terms of volatility and temporal dynamics, the hydrogen market is therefore expected to be half-way between the electricity market and the gas market. The exchange then creates added value for the economic optimisation process and for optimising the dynamic matching of supply and demand. This will reduce costs for the market as a whole, especially if this is an exchange that works for the entire network.

3. Why a hydrogen exchange?

What is the reason for an exchange in general and, more specifically, a hydrogen exchange? In general, an exchange leads to greater efficiency in trading and also reduces trading risks. As a result, transactions are more efficient (closer to the economic optimum) and more accessible, allowing more parties to trade with less risk. It therefore promotes the volume of trade, which favours economic optimisation, and thus a better allocation of factors of production and, consequently, a better economic result. The functions of an exchange are as follows:

A. Covering surpluses and shortages
B. Market optimisation and flexibility
C. Price discovery
D. Auctioning and trading of ancillary services
E. Anonymous trading with ensured settlement, equal opportunities for large and smaller market participants
F. Forward market and portfolio optimisation
G. Catalyst of developments

Partly based on the analysis of the future market, the following picture of the future for a hydrogen exchange is emerging on these points.

A. **Covering surpluses and shortages.** Section 2.3 has already explained why market participants in the future hydrogen market may have various surpluses and shortages. These can be traded between market participants (bilaterally), however, experience shows that these can be handled more efficiently on an exchange (spot market) than bilaterally. In addition, the trade is anonymous, which reduces the risk to each of the parties. After all, there is less chance of "squeezing" a party with, for instance, shortages, and also less dominance of larger parties over smaller ones, because everyone trades with everyone anonymously on the exchange. Suboptimal market behaviour is thus reduced, while market quality is improved. This improves the economic optimum and reduces the risks for market participants.

B. **Market optimisation and flexibility.** Rather than hard surpluses and shortages, this is a matter of alternative market supply (or demand) at different prices. The market will provide for an outcome at the best price, and an optimal allocation of production factors. In practice, there is no hard border with the previous category, because parties' surpluses and shortages are often price dependent. For instance, a market participant may currently be able to cover (or avoid or shift) shortages at a certain cost, however, he would rather buy it from the market when the price is better. The same goes for flexibility and storage: since it is available on the spot market at a price, the parties can make use thereof. We expect variations in the supply and demand of hydrogen, but there will also be certain parties who can vary with their production and/or purchasing capacity and are therefore flexible, or parties who can offer storage. If all of this is put into an integrated spot market for hydrogen, everyone will benefit from it. This also promotes the introduction and growth of hydrogen as an energy carrier.

C. **Price discovery.** An exchange is appealing to parties because they know what the "right" price is. This greatly reduces the risks of trading, even for off-exchange trading, which is often related to the exchange index. Three remarks in this respect:

a) There is a distinction between price discovery on the spot market (short-term) and on the forward market (long-term). The spot market is about understanding the intervention prices that are present in the market on a daily basis in order to deal with any shortages and surpluses that may occur at any given moment. The futures market is more about developments affecting the general average price level, e.g. in relation to the world market and CO_2 prices.
b) It is necessary to relate the index price and the type of sourcing. The reason for the new hydrogen market is the transition to a climate-neutral energy supply. This has a price: climate-neutral hydrogen is more expensive than conventional hydrogen with CO_2 emissions, and there are all sorts of gradations in between. For the development of the market, on the one hand, it is welcome that hydrogen from all the different sources can participate in the market, but, on the other hand, this will have to be with a guarantee of origin so the price can be related to the sourcing.
c) Price discovery for hydrogen in the start-up phase is also very important. It is conceivable to create a price index in anticipation of actual exchange trading; this would help to develop hydrogen as a CO_2-free energy carrier. More on this in Section 5.4.

D. **Auctioning and trading of ancillary services.** See the products and platforms of TenneT, Gasunie etc. for balancing, transport capacity (for electricity), storage capacity (for gas) and other ancillary services. For the hydrogen market this is also very important: storage, transport, blending, quality management, balancing and ancillary services. Exchange trading can be started on this basis, ideally surplus/shortage (spot market) and balancing as well as auctioning and trading of storage capacity. By trading all (spot) products and system services on a single exchange, they reinforce each other, as happened previously with the auction for gas storage by the APX- ENDEX gas exchange; this could now also apply to hydrogen storage. This enhances broad access for all market players and reduces overall costs.

E. **Anonymous trading with ensured settlement, equal opportunities for large and small market participants.** We already mentioned the added value of the exchange as an anonymous trading place: parties do not trade directly but via the exchange. The exchange is buyer for the sellers, and seller for the buyers. They do not need to know each other or each other's bids and offers. The exchange also offers guaranteed settlement of transactions through delivery and payment. Since the exchange acts as a middleman, the deals must be guaranteed. The exchange requires collateral from the participants for this; this is done by means of a non-discriminatory system of "clearing and settlement". This anonymity and settlement on equal terms means that smaller parties can also participate in the trade, more so than is the case in the bilateral market. In a hydrogen market with both large (industry) and small players (such as local electrolysis from renewable electricity) this is beneficial.

F. **Forward market and portfolio optimisation.** This is paramount in a mature market. Liquid exchange trading facilitates re-trading to adjust the trading portfolio, thereby reducing portfolio risks. Hydrogen is not yet a mature market, but it may well become so, especially with an international component (imports) and/or multiple sources (blue and green) and consumers (industry, power plants, homes). This generally becomes important in a more developed market. This is addressed in many energy commodities, not only by power exchanges, but also by established commodity exchanges as soon as the market is sufficiently developed.

G. **Catalyst of developments.** This is particularly the case when building new markets, as was the case with energy liberalisation: this worked well for the electricity and gas markets. Conditions enabling the exchange are a focal point for regulating the physical access conditions to the infrastructure, necessary to facilitate a liquid market. If the conditions are good for an exchange, this is certainly also the case for trading as a whole. An exchange initiative is important in a transition project as a focus for the physical access conditions needed to start trading. This was the case with electricity and gas, and we see the same with hydrogen.

4. Conditions for a hydrogen exchange

In our thinking, we start from the conditions necessary for an exchange. These are universal at the highest level and apply to any good, merchandise, security or commodity, including hydrogen.

A. A fixed location or network, with open access for all parties (third party access). Such a "hub" can be a single point or an entire network, provided the access rules are appropriate.

Currently, there is no such hub; hydrogen is produced in the Netherlands at various locations, but these have no connection. Transport between them is not easy at the moment. This is the biggest challenge. There are several options for establishing more connections:

- A dedicated hydrogen network such as the backbone that Gasunie plans to build (unique position of the Netherlands), ideally a point where various hydrogen pipelines come together, including storage and quality conversion (hub functions).
- Regional hydrogen pipelines, which precede the backbone, or provide an initial starting point of that backbone; then trade could begin at such an initial point and be expanded later.
- A hydrogen storage facility as could be built in Zuidwending
- A terminal for the import of hydrogen, or hydrogen carriers such as ammonia.

Important is the hub function with storage, quality conversion and marketability without barriers. The American Henry Hub and the Dutch TTF, for example, have been very successful in this, which is why these hubs are now world leaders.

B. Sufficient trading parties participating in the exchange (suppliers and demanders)

This is also important for the selection of the "hub" principle. Hydrogen is produced and used in many places. Hydrogen cannot be transported cheaply by road, train or ship, so an infrastructure is essential for trade. The more broadly the infrastructure is shared throughout the Netherlands, the better the market performance. This is not just a question of the number of parties involved, but also of the greater diversity of parties with different supply and demand patterns, which means that trade has added value and is being encouraged.

C. A sufficiently standardised commodity or security to be traded.

Hydrogen seems standard but appearances can be deceiving. In practice, it is more complicated:

- Physical production quality: hydrogen is produced in different physical qualities: fairly pure but also less pure, according to need and production method.
- Climate neutrality and CO_2 production signature: hydrogen can be produced in very different ways: sustainable, completely decarbonised, low CO_2 carbon.
- Import: hydrogen can be transported in other forms, such as liquid ammonia. For some applications, it needs to be converted to hydrogen, for others it does not.
- Blending: hydrogen can be distributed and used in pure form, but it can also be blended in the natural gas grid, and possibly even demixed for pure application.

Ideally, the exchange will facilitate hydrogen with different characteristics (produced by different market participants), however, the aim would be to market it as a single product. This requires a certain degree of standardisation. In addition, socialisation of technical conversions (for instance: H- and L-gas) can promote the "hub function". However, it is also important to be able to trace the origin by means of Guarantees of Origin. Ideally, the exchange will also have a system for this.

5. The hydrogen infrastructure as a trading point

5.1. An infrastructure under construction: the “greenfield” situation

In order to trade on the exchange, it is necessary that there is a fixed location where trading takes place, to which a sufficient number of (wholesale) trading parties have access. Since hydrogen is a gaseous energy carrier, this trading point should preferably consist of an open-access pipeline network or intersection of pipelines, as was the case for natural gas.

At present, we do not yet have such a network. The situation with hydrogen is different from when the electricity and natural gas markets were created. The entire physical infrastructure of the latter markets was already in place, albeit monopolistic. This physical infrastructure could be taken as a fixed starting point. The only thing that needed to be arranged was granting access of third parties to the infrastructure by changing the rules and organisational structure. This was an intensive process of liberalisation and re-regulation, but the physical circumstances remained largely the same. The market for suppliers and demanders also remained stable throughout this process.

This is fundamentally different with hydrogen. At present, there is hardly any infrastructure to trade hydrogen at low cost; this has yet to be put in place. The hydrogen market itself must also still be largely formed in the coming years, in terms of both supply and demand. Additionally, there will be many changes within the broader energy transition as well.

We therefore need to create the hydrogen market at the same time as the construction of the physical infrastructure and the growth of the physical market demand and supply in a very dynamic energy environment. This is a unique “greenfield” situation with both disadvantages and advantages.

- On the one hand, a disadvantage is that the fixed physical facts cannot be taken as a starting point, as they were in previous liberalisations. We need to establish the exchange in parallel with the supply and demand of the hydrogen that will be traded on the exchange, and the construction of the infrastructure that will form the physical basis for hydrogen trading. Choices still have to be made in these other areas that could possibly influence the structure of the exchange. That makes the process more complicated.
- On the other hand, an advantage is that we are not dealing with a complicated system change. We can take trade into account from the start when establishing rules, organisations, standards and other arrangements. In addition, there are relatively fewer existing interests to be considered. For many, the hydrogen market is new and offers opportunities. This simplifies the process.

In the previous liberalisation projects, the preparation and formation of the exchange took place in close cooperation with the liberalisation process leading to an infrastructure accessible to all. This automatically led to a close relationship between the exchange and the grid operator. Although the situation is fundamentally different, we believe that this cooperation will also be important in the case of the hydrogen exchange.

5.2. Options for trading locations on infrastructures

Existing industrial hydrogen pipelines

There are already several larger and smaller industrial hydrogen networks. The largest thereof in owned by Air Liquide. The northernmost point of this network is the port of Rotterdam while the largest part is located in Belgium (613 kilometres of hydrogen pipelines, with hubs around the ports of Ghent and Antwerp). At present, these types of existing industrial pipelines mainly transport grey hydrogen, produced with CO_2 emissions.

The advantage of these networks is that they are already in place. However, there are also certain drawbacks:

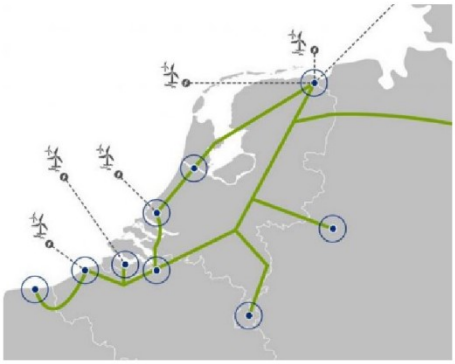
- The capacity of the networks is limited.
- The networks are fully dedicated to the supply of hydrogen to customers and are not intended for trading.
- The networks have limited coverage and lack access to numerous important Dutch industrial clusters, as well as major hydrogen sites such as Terneuzen, Groningen and Chemelot.

Gasunie' s hydrogen backbone

Gasunie wants to take a huge step forward in the hydrogen infrastructure by adapting part of the existing gas infrastructure to make it suitable for the transport and storage of hydrogen to and from the large industrial areas in the Netherlands and to Hamburg and the Ruhr area. Until recently, a realisation period of 10 years was expected, i.e. an initial period until approx. 2030. But recently it became known that the "backbone" could possibly be completed earlier, around 2026.

This "backbone" offers many benefits:

- It is intended for the transport and storage of the new climate-neutral hydrogen and has a large capacity.
- The network will include hydrogen storage facilities.
- Open access for third parties on this network (an essential condition for exchange trading) with an independent network operator.
- The network will eventually connect all major Dutch hydrogen sites: Rotterdam/Moerdijk, Terneuzen, Groningen, Chemelot, IJmuiden, allowing all players to participate.
- The network will include sites for the landing of cables from wind farms at sea, sites for the import by ship of green hydrogen or ammonia, and will also be connected to Germany (Ruhr area) and Belgium (Ghent/Antwerp). This concept is also called "green octopus"[4].



All these advantages make the "backbone" the ideal final solution. The only drawback is that it will be some time before it is realised. Not only in terms of the infrastructure, the required volume of climate-neutral hydrogen also takes a great deal of time to realise.

[4] See the presentation of R. Schutte et al. https://www.hydrogen4climateaction.eu/programme

5.3. Options for trading on physical hubs in the start-up phase

The “backbone” with a developed market throughout the Netherlands will only emerge over time. The question is whether it is feasible to create a provisional market during this start-up period. If that is the case, the exchange can play a role in the development of the market and grow along with it.

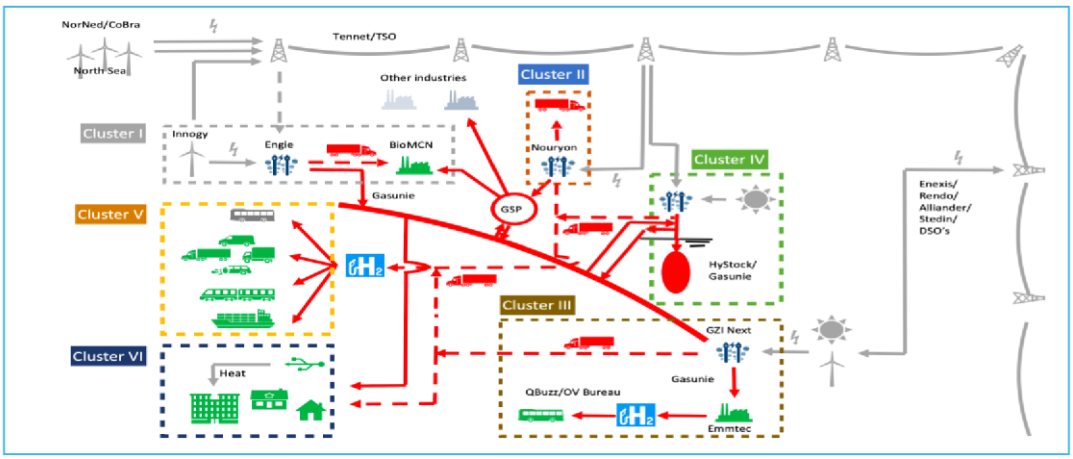
It is therefore worth considering launching an exchange in the start-up period, while the backbone is being built. This would have to be done at an already completed or existing physical trading point (or points) for hydrogen, provided that there is or can be sufficient market diversity. At such sites, the import of sustainable hydrogen (or derivatives such as ammonia and LOHCs) may also play a role.

The backbone will then incorporate this point into the larger national infrastructure, after which the physical trade can migrate to a virtual point across the entire infrastructure. Several foreign gas exchanges have successfully followed this development in the past.

Physical starting points may include:

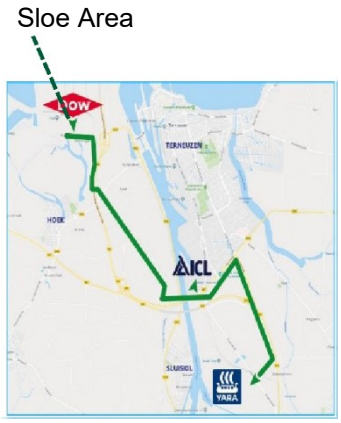
a) The new hydrogen infrastructure of Groningen Seaports

Groningen Seaports has major ambitions in hydrogen. An important part of the industry in Delfzijl, for example, already uses hydrogen. Shell, Gasunie and Groningen Seaports have launched a plan for the construction of Europe’s largest green hydrogen plant[5]. This will enable industry to become significantly greener. There are also plans by Vattenfall and Equinor to convert the Magnum power plant[6] in Eemshaven to hydrogen (based on natural gas with CCS). There is already an industrial hydrogen network[7] in the port of Delfzijl. It was developed in recent years through a unique concept of new flexible hydrogen pipelines. The plan is to quickly expand this network, so there will be 5 to 7 industries with varying hydrogen production and demand within the foreseeable future. In principle, there are sufficient parties to form the basis for a hydrogen hub where trade could take place. Perhaps this location will soon be suitable for exchange trading.



[5] See https://nos.nl/artikel/2324772-plannen-voor-het-arootste-europese-waterstofproiect-in-groningen.html
[6] See, among others https://www.gasunienewenergy.nl/projecten/magnumcentrale
[7] https://www.groningen-seaports.com/logistiek-en-utiliteiten/utiliteiten/#verder

b) The hydrogen pipeline already in operation in the south of Zeeland



In preparation for the backbone, Gasunie has already converted an existing gas pipeline to be suitable for hydrogen. It is mainly used for the exchange of hydrogen between Yara (now the largest Dutch hydrogen producer) and Dow.

This hydrogen is made from natural gas but is partly decarbonised.
Other possible users are ICL and Zeeland refinery. A quick expansion can be achieved by converting an old naphtha pipeline under the Watershed to hydrogen, which will also bring parties in the Sloe Area into the picture, including offshore wind farms that connect there and that have the ambition to use green hydrogen from electrolysis. This would bring together enough parties (Terneuzen and Sloe) for a hydrogen trade and perhaps for an exchange.

In addition, the region has another advantage: there is already a terminal for ammonia in Terneuzen, which makes it possible to land green ammonia, a carrier of imported green hydrogen.

c) The port of Rotterdam, possibly in combination with Moerdijk

There are various initiatives for decarbonised hydrogen in the port of Rotterdam (project H-vision, Deltalinqs with major industrial partners) and sustainable hydrogen (Port of Rotterdam Authority, BP and Nouryon). The Port of Rotterdam Authority's ambition is to lay a hydrogen pipeline relatively quickly in collaboration with Gasunie, in anticipation of the national backbone. Depending on the realisation of the various plans, this can also provide a basis for trade. Rotterdam is also important from the point of view of the German hinterland's interest in hydrogen imports.

d) Amsterdam/IJmuiden port region

For Amsterdam/IJmuiden, hydrogen will be necessary or desirable for a variety of users.
Of the 2.8 billion m^3 of natural gas currently used in the area, about half is expected to be transformed to hydrogen use. In order to optimally facilitate all users to make the switch, it is necessary to convert from the natural gas network to a hydrogen network, including connection to a national hydrogen network. Port of Amsterdam and Gasunie are currently working on a regional backbone, which will connect Amsterdam/IJmuiden to the national backbone.

e) Market for Liquid Organic Hydrogen Carriers (LOHCs)

LOHCs are organic liquids that can absorb and release large amounts of hydrogen. Toluene and Dibenzyltoluene are promising, especially the latter because of its non-toxic and safe character. One of the options is to transport hydrogen internationally in tankers in the form of LOHCs; this can be landed and stored in regular storage tanks in a port (e.g. one of the above), and then transported to the hinterland in the same form in barges and tankers. LOHCs are already being used to transport hydrogen to, for example, hydrogen filling stations or pilot projects. This is therefore also a way of possibly launching a hydrogen market, in the start-up phase before a market in piped hydrogen is established or in parallel to this market. Eventually, prices for hydrogen in LOHCs and piped hydrogen will be closely related: it will become one market.

Note: It is not yet clear which of the above options is the first to emerge as a basis to launch a market or exchange, and perhaps there are also other options. The options are not contradictory and can be combined. It is advisable to consider all options as opportunities to advance the creation of a hydrogen market or exchange in the run-up to the final hydrogen market based on the "backbone". This will allow the market to grow along with the infrastructure.

5.4. Forerunners via services for Guarantees of Origin, price indices and/or blending

If an exchange cannot yet be established as such because the conditions are not yet in place, it is often possible to launch other services that resemble an exchange or that may result in it.

- Trade in Guarantees of Origin between the different provisional trading points, or a swap system: these are products that allow hydrogen to be traded between different points without the physical preconditions being in place.
- A price index based on a so-called "pricing panel" in which the various market participants are regularly consulted on the current trading price.
- A market for a possible mandatory blending of hydrogen.

In addition to providing such pre-exchange services, this can also serve as a start-up for the exchange organisation and as "community building" of the circle of future participants for the "real" exchange trade. Currently, it is unclear which opportunities are most promising and what should be given priority. These three opportunities are briefly outlined below. At a later stage, it should become clear what is preferable; this may also depend on external developments.

- **Starting a trade in "Guarantees of Origin"**

In the period prior to the backbone, there may already be trading points where green or (partially) decarbonised hydrogen of various CO_2 signatures is traded. See Section 4.3.

There may not be enough liquidity at each point individually at the outset, while there is a need for trade between points, for example, because this involves hydrogen with different levels of CO_2 emissions. As long as there is no connecting backbone, Guarantees of Origin can be traded that represent the value of the CO_2 reduction. This could also be in the form of swaps, where parties act bilaterally to hedge risks.

- **The launch of a hydrogen price index based on a so-called "pricing panel"**

There could be a hydrogen price index as a provisional steppingstone for the market in the run-up to a full-fledged hydrogen trade.

There is currently no hydrogen price index. S&P Platts, active in the pricing of commodity markets, has, however, recently launched a so-called hydrogen price assessment[8]. However, this is not yet a true price index, but rather a derivative; the price of hydrogen is constructed from production methods: with the commodity price of natural gas (plus the cost of steam methane reforming) or the commodity price of electricity (plus the cost of electrolysis, which still leaves much to be desired, e.g. because it does not include all the costs of green electricity). This is how derived hydrogen prices, including for the Netherlands, emerge as a rough approximation[9].

A true hydrogen index is therefore yet to emerge and would be based on quotes in real hydrogen itself, from companies operating in hydrogen. The traders then regularly issue quotes for the purchase and sale of hydrogen, from which a price index for hydrogen is distilled and published by the exchange in formation according to fixed rules. This model was also used for the Dutch Gas Exchange in the run-up to the actual market. This could be initiated quite soon based on the current hydrogen market, which has the characteristic that it is mainly grey hydrogen, with CO_2 emissions. In order to ensure confidence in the sustainability, it would be best to simultaneously start an index in CO_2-neutral hydrogen or an index for the Guarantees of Origin.

- **A market for a possible blending obligation**

The modalities of a possible national blending obligation are currently being studied. The exchange initiative could play a role in the transparent introduction of hydrogen for such a blending obligation. This does, however, depend on whether there will actually be such a blending obligation, what it will look like, whether it is considered an added value for a role on the exchange and what the market thinks of this.

[8] https://www.spglobal.com/platts/en/our-methodology/price-assessments/natural-gas/hydrogen-price-assessments
[9] For example, following this logic, the price of electricity could be deduced from the prices of the main fuels, gas and coal, plus the cost of the power stations. In practice, actual electricity prices are at best related to this, but they have their own dynamics and different prices resulting from surpluses and shortages in the electricity market itself. This will also be the case for hydrogen.

6. Summary and conclusions

Hydrogen is increasingly attracting interest as an important part of the energy transition. No greenhouse gas is released when hydrogen is used. Hydrogen is therefore regarded by many as a climate-neutral energy carrier for the future. The Climate Agreement therefore devotes a great deal of attention to hydrogen. Because of the position that hydrogen will occupy in the future and the many ways in which it can be produced and used, with a variety of producers and users, the development of the trade in hydrogen will become important.

This development offers a promising situation for a hydrogen exchange with added value for the economic optimisation process and for optimising the dynamic matching of supply and demand. This will reduce costs, especially if this is an exchange that works for all market participants across the network, without barriers.

In the final situation, this hydrogen exchange will have the following characteristics:

- *A spot market on the hydrogen backbone with sufficient diversity of players at a virtual trading point across the entire infrastructure that is also connected to foreign countries.*
- *Open access and network operation by an independent network operator, with a single access rate: parties pay this to operate across the entire network (preferably a 'postage stamp tariff').*
- *Markets for ancillary services, where market participants supply products to the network operator for the operation and quality assurance of the hydrogen network.*

However, this situation with a developed market with a backbone will only arise over time. During this start-up period, a provisional market can already be created that can be supported by an exchange or pre-exchange activities. If that is the case, the exchange can play a role in the development of the market and grow along with it. In this context, there are four possibilities:

- *Launching an exchange in the start-up period at an already completed or existing physical trading point (or points) for hydrogen if there is sufficient market diversity.*
- *Starting a trade in "Guarantees of Origin" of green or decarbonised hydrogen between such locations, including in the period prior to the backbone.*
- *The launch of a hydrogen price index based on a so-called "pricing panel" in which the various market participants are regularly consulted on the current trading price.*
- *The exchange as a market facilitator for a possible blending obligation.*

Such provisional exchange products are steppingstones for the market in the run-up to a full-fledged hydrogen trade. Together with the final perspective of the exchange trading on the backbone, this creates a development trajectory which allows the development of the hydrogen exchange to grow along.

Opportunities for the Netherlands

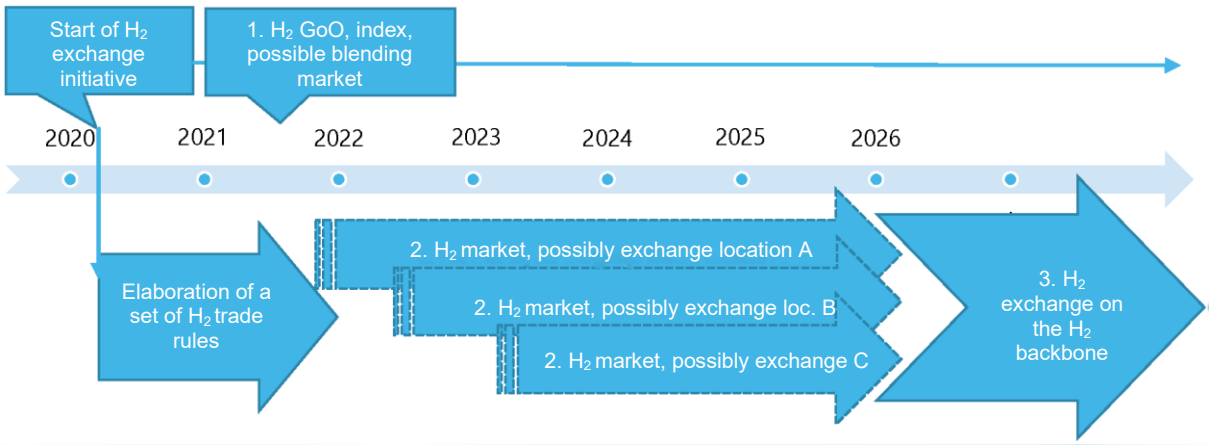
The Netherlands has a unique starting position due to its cost-efficient approach to sustainable energy, its location, which is perfect both for offshore wind and the landing of hydrogen imports, the role that Dutch industry plays in hydrogen, and, of course, the unique gas infrastructure that will be converted and used for the transport of hydrogen. The Netherlands also has a track record when it comes to energy exchanges: as the designer of the system of market coupling of the European electricity exchanges, and, of course, the creation of Europe's leading gas market at the TTF.

All in all, this means that the Netherlands has an excellent opportunity, which deserves to be developed.

In this regard, it is recommended to take an appropriate initiative. further. Such an initiative should be structural, aimed at the launch, development and expansion of the exchange initiative as it grows with the development of the Hydrogen Market as a whole. Three steps can be distinguished subsequently:

1. Forerunners of the exchange initiative also paving the way for the market: a system for guarantees of origin and the trade therein, including between possible locations, and, if possible, a price index for hydrogen and/or a market for a possible blending obligation.
2. Regional physical markets in the start-up phase based on the hydrogen infrastructure at one or more port locations or hydrogen carriers such as ammonia or LOHCs, whether in combination.
3. The final hydrogen market on the hydrogen "backbone" around a virtual trading point, over a network with a virtual hub with international connections to other countries.

This can be summarised in the following timeline (schematic, times are examples and depend on practical developments):



Initiative group

In order to set this up in a coherent manner and based on the experience from previous exchange initiatives, it would be best to set up an initiative group. It could be made up of circles of interested organisations, for example, those that have already been consulted in this study and/or possibly other interested parties, supplemented by representatives of the national government and others. The author of this study is also willing to take part in such an initiative group and, if necessary, to take the lead in it, in order to make positive use of the experience of previous energy exchange initiatives.

Such an initiative group would then deal with the main preconditions and condition-setting activities such as the initial design of a hydrogen price index and the criteria of a system of guarantees of origin. In addition, a set of trade-enhancing rules can be elaborated as advice to the emerging hydrogen networks locally and nationwide, in cooperation with the network owners and/or intended network operators.

This does not mean the initiative group will be ultimately responsible for the implementation or bear the main responsibility. Rather, it ensures that each, in its own role, takes account of the same principles in the common interest: the transition to climate-neutral hydrogen will benefit from good and liquid trading, and the hydrogen exchange is an important means of achieving this. Such an approach has already yielded positive results: at the start of the electricity and gas exchanges and also in the international context with European market coupling of the electricity markets. In this respect, the hydrogen exchange can draw on a wealth of experience.

Appendix: list of organisations consulted

Several people and organisations were interviewed during the study, for which we are grateful. These interviews have yielded valuable insights that have been incorporated into this report. The responsibility for the report lies with the author.

Essent

Gasunie

Gasterra

Vopak

Delft University of Technology

Groningen Seaports

Yara Sluiskil

Dow Benelux

Shell

Port of Rotterdam Authority

Port of Amsterdam

North Sea Port

Clingendael International Energy Programme