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Hydrogen for the Port of Rotterdam in an International Context *– a Plea for Leadership*

Key Messages

Low-carbon hydrogen, such as green and blue hydrogen, offers a unique and rare opportunity for the Port of Rotterdam to remain a globally important energy and chemistry hub in the future. However, the Port's industrial cluster does not currently seem to be convinced of the urgency of taking a prominent position in hydrogen developments. The cluster and the Port of Rotterdam Authority must show leadership if we are to successfully cope with the risks, uncertainties, and large investments that the hydrogen developments require.

Hydrogen imports are needed – Next to electrification, green hydrogen will become an important part of our future carbon-free energy system as an energy carrier and as a raw material for chemical production and zero-emission fuel. Still, locally produced green hydrogen does not offer any emission reduction in the short term, requires large investments and local production will not be enough. The Port of Rotterdam, the Netherlands, and Northwestern Europe will remain dependent on energy imports.

Global trade flows and associated geopolitical interests will continue to exist – In a global energy system in which hydrogen plays an important role, trade flows will emerge between regions with a surplus of renewable energy and those with a shortage, such as Northwest Europe with its energy-intensive industrial clusters. Trade routes will not be determined only by business cases but by geopolitical interests as well.

Energy imports remain necessary – It is a myth that a sustainable energy system in the Netherlands could become energy independent. Northwestern Europe has a joint task to decarbonize and simultaneously produce and import renewable energy.

Rotterdam has a unique and exceptional position for hydrogen – Rotterdam is currently a fossil superpower; low-carbon hydrogen offers the opportunity to maintain this dominant position as an energy and chemical cluster. In addition to a hydrogen production and user hub, Rotterdam's main potential is as an import and trade hub for low-carbon hydrogen due to its current strong position on a global level. The plans for blue hydrogen offer a unique bridging opportunity to reduce emissions in the short term.

However, it is far from certain that Rotterdam will acquire a dominant position in hydrogen – Rotterdam's current strong energy hub position does not mean that it is the only or most logical place for hydrogen developments. Hydrogen trading can bypass the Port by transporting it via pipelines, and large-scale production near the wind farms in the North Sea does not have to pass through the Port. Other clusters are involved in the "battle for hydrogen" as well, so it is far from certain that Rotterdam will become the hydrogen hub of Northwest Europe.

Leadership is necessary to cope with the risks, uncertainties, and large investments that hydrogen developments require. Low-carbon hydrogen should be seen as one of the few vital lifelines for the future of Rotterdam, where one runs the risk of being late if action is not taken proactively and cooperatively now. The Port of Rotterdam should take risky "regret" actions to develop the various hydrogen hub functions, even though Rotterdam will not become great in all of them. History shows that such leadership is within the DNA of the Port.

Leadership strategies

To create a breakthrough in hydrogen developments, we identify five main leadership strategies for the the Port cluster and the Port of Rotterdam Authority:

1. Simultaneously build up all four possible hydrogen hub functions for the Port now—user, production, import, and trading hub—to develop a position in hydrogen on a global level. For now, the focus should be on an import and production hub as these fit the current cluster well. This strategy implies investing in possible "regret" options that turn out to be unattractive or unprofitable over time when hydrogen developments take shape.
2. Financing low-carbon hydrogen should neither be based on CO_2-savings nor on technological innovations, but on the long-term value of investing now in upscaling technology and preparing infrastructure.
3. Proactively develop the trade and production of hydrogen elsewhere in the world, thereby making use of the knowledge and expertise Rotterdam already possesses. For example, Rotterdam has knowledge in the field of digitalization and sustainability of ports; in exchange for this knowledge, Rotterdam can gain access to green hydrogen in the regions and countries that will produce it. Global trade routes around hydrogen are emerging, and international cooperation with other regions is vital. This is urgent—the cards are now shuffled, and the hydrogen hub functions will soon be distributed.
4. Create "outside-the-box" demand for green hydrogen in niche markets where there is willingness to pay a premium. The next ten years will be crucial in developing the market for green hydrogen. Without an existing profitable revenue model, this is possible only through start-up subsidies from the government and pre-investments by companies. The Port could start by developing an ecosystem of hydrogen initiatives within the cluster, for example by involving the logistics chain, but also by building public infrastructure (for which the first steps are being taken).
5. Establish an iconic first import shipping route with green hydrogen in the short term to put Rotterdam on the map as an import and trade hub for hydrogen. The green spider project responds to this call by developing a green hydrogen chain from Portugal via the Port to Rotterdam's hinterland.

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Prologue

The transition-agenda *Hydrogen for the Port of Rotterdam in an International Context – A Plea for Leadership* was largely developed before the COVID-19 crisis appeared and its ripple effects became an economic crisis and a highly volatile, oversupplied energy market resulted.

However, this does not imply that this agenda has already become obsolete. If anything, current developments bring forward the future of our energy system. On the short term, an oversupply of fossil fuels on the world market will severely impact business cases for renewable energy and thus for green hydrogen. Also, investments in green energy will be lower in 2020 than in previous years (IEA Outlook). In the middle and long term, however, the current oversupply of fossil fuels might bring forward a hard correction in investment levels in fossil energy. Over the last decade, investments in green energy have grown exponentially while investments in fossil energy continued, including major sunk investments in large-scale infrastructures that will typically last decades before being written off the books. In these circumstances, even under continuous economic prosperity, a clash of investments was bound to happen. The current crisis will likely result in an unparalleled decline in fossil energy investments or even the reversal of investment decisions and hastening of the decommissioning of older, less competitive fossil plants and infrastructure, which will last longer than the direct pandemic crisis. In the middle and long term, this will create space in the energy markets for sustainable alternatives, which would have taken much longer to develop without a crisis.

In addition, an early advantage for green hydrogen production might be that, for both fossil and renewable electricity, prices have dropped dramatically, lowering, at least in absolute terms, the costs of green hydrogen production.

Therefore, the challenge is to bridge the short-term lack of investment and negative business cases for the longer term. This will undoubtedly require a deepening of short-term investments while markets will be hesitant to invest given the current levels of volatility, uncertainty, complexity, and ambiguity. The crisis, however, also unlocked a new belief in public investment to stimulate economic recovery and in the role of public parties to secure necessities, such as energy, in a volatile world. Although at the time of publication, fierce debates about the mechanisms at the European level in funding the economic recovery are ongoing, a movement toward scaling up economic recovery is clear. This is in line with the argument in this agenda to move beyond national energy system agendas to at least the level of connected European regions.

Hydrogen plays an important role in the currently proposed green deal as part of the EU recovery strategy. In the vast solar resources of hard-hit countries in the south, hydrogen could improve the trade balance of the south with continental Northwestern Europe's *energy sink*. Governments can make hydrogen part of the economic recovery through direct investments but also by ensuring that investments in other aspects of the economic recovery are conditional upon simultaneously greening our economy. Governments can also revise existing sustainability regulations, such as the Renewable Energy Directive, to allow the use of green hydrogen (certificates) to count toward compliance with such regulations.

It will require the leadership sought by this agenda to kick-start the role of green hydrogen in a sustainable energy system to both strengthen economic recovery and keep climate targets in reach. We hope this agenda contributes to a shared sense of urgency for such leadership.

↓ Photo by Mike van den Bosch on Unsplash / Colors modified

Chapter 1

Introduction – Toward breakthroughs for low-carbon hydrogen

Hydrogen is gaining increased attention from policymakers and industry leaders as a necessary element for a fully renewable energy system. It is also seen as an economic opportunity for greening existing industries and as a basis for entirely new ones, such as biobased industries. In the Dutch port of Rotterdam, this growing attention for hydrogen has led to activated and interested business and industries, policy collaborations, and other initiatives, but overall, a coherent perspective and a sense of urgency is lacking.

This document is the first step to that end and is the result of a "transition arena" consisting of dialog sessions with people from both industry and science with different perspectives (see also **Textbox 2**). The focus is on "green" hydrogen developments in connection to "blue," but as (many) other colors of low- to zero- carbon hydrogen exist and have comparable developments (see **Textbox 1**), we usually refer to "low-carbon" hydrogen. Parallel to and in connection with this process, the Port of Rotterdam has also released its vision on hydrogen, which resembles many of the ideas presented here[1].

Examples of other hydrogen-related activities within the Rotterdam cluster are the project H-vision for blue hydrogen (feasibility study)[2], green hydrogen production plants announced by BP-Nouryon[3] and Shell-Eneco[4] (feasibility study and tender proposal), and the construction of an openly accessible hydrogen pipeline in the cluster by the Port of Rotterdam and Gasunie[5]. In the north of the Netherlands, Shell, Gasunie, and Groningen Seaports have stated the ambition of realizing "Europe's largest green hydrogen project" by completing a wind park with a capacity of 3 (2030) to a of maximum 10 (2040) gigawatt in the North Sea to produce 0.8 Mt of green hydrogen[6].

On the policy side, the Dutch government announced significant innovation funding and, recently, their hydrogen vision, in which carbon-free hydrogen is an important element in a sustainable energy system[7]. It also highlights the strategic importance of Rotterdam as an international energy hub and the opportunities that hydrogen provides the Rotterdam cluster. These initiatives have arisen at the Dutch national level, but there have been similar developments by other regional (Zuid-Holland[8]), national (Germany[9]), European (Hydrogen Europe[10]) and international (International Energy Agency[11]) organizations. Despite these policies and innovation funding, financing hydrogen initiatives is easier said than done.

The Port of Rotterdam urgently needs to define its position in the hydrogen chain, as it risks losing its important mainport position for Northwest Europe. Much effort is needed to bring low-carbon and especially green hydrogen to scale in the coming years, where all parties need to work together to benefit from the potential hydrogen offers. Low-carbon hydrogen is one of the few chances for Rotterdam to gain a competitive edge in transforming its fossil commodity chemical industry (and build up a new green industry) and to preserve and strengthen Rotterdam's position as an import hub for Northwest Europe. A "wait-and-see" attitude is thus not an option.

The above-mentioned initiatives do show that in a relatively short timeframe, low-carbon hydrogen moved from a marginal niche strategy to a serious ambition of both governments and businesses. Several (pre-)feasibility studies and (pre-)coalition developments have been published. However, for the Port of Rotterdam to become a serious frontrunner in low-carbon hydrogen, these ambitions must be translated into concrete action. More investments beyond the current feasibility studies are required, and collaboration between a group of the willing and able is needed to develop this market for green hydrogen. In addition, green hydrogen is one of the very few chances for an alternative to the fossil energy import hub in Rotterdam.

Of course, developments in the Rotterdam cluster depend on developments in the international policy stage (e.g., carbon pricing). However, this should not lead to a waiting game in the Rotterdam cluster. The favorable conditions for the Port of Rotterdam to become a frontrunner in green hydrogen chains can (and must) be created largely in the scope of Northwestern Europe.

To understand these favorable conditions, we explore the future hydrogen chain at three levels: global, Northwest Europe, and the Rotterdam cluster of port and industry. To better understand the urgency for concrete action, the first half of this document will outline an integral analysis: The emerging global trade in sustainable energy carriers (**Chapter 2**); the future energy landscape in Northwest Europe, including the role of imports (**Chapter 3**); and the opportunities and challenges for Rotterdam to maintain its strong current position as energy (and related feedstock) hub in Northwest Europe's feedstock hub for transport and processing (**Chapter 4**). In the second half, we will address the leadership needed to maintain this position by striving for a frontrunner position in green hydrogen (**Chapter 5**), and we will translate this into an agenda for four challenges and breakthroughs for producing and importing green hydrogen in Rotterdam (**Chapters 6–9**).

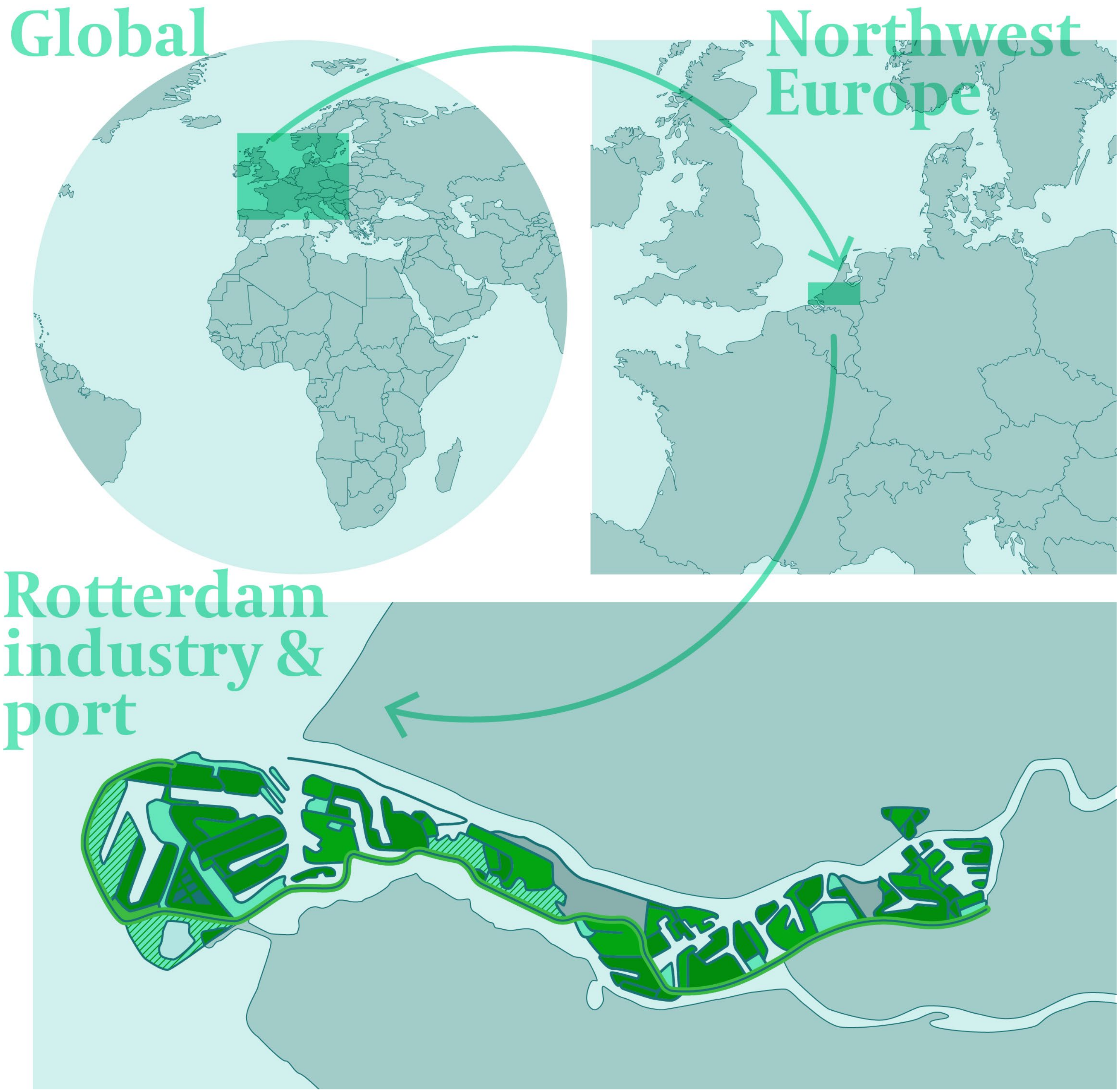

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Figure 1
Three levels of analysis: global, Northwest Europe, and the Rotterdam cluster of port and industry area.

Textbox 1

Colors of Hydrogen

Hydrogen is a colorless gas (or liquid), yet the process by which hydrogen is produced is often designated with a color. Although there can be small differences in impurities between gray, blue, and green, all hydrogen is essentially the same product regardless of "color." There are three main production methods:

Gray hydrogen – produced from natural gas, with CO_2 as a byproduct, typically through chemical processes such as "Steam Methane Reforming" (SMR) or "Autothermal Reforming" (ATR). Currently, most of the world's hydrogen is produced as grey hydrogen, from natural gas.

Blue hydrogen – similar production methods (both SMR and ATR are used) to gray hydrogen, but CO_2 is not released into the air but "captured" and stored (CCS) or used to make chemical products or grow plants (Carbon Capture Utilization [CCU]). When combined, CCS and CCU is often referred to as CCUS.

Green hydrogen – a very different production method in which green hydrogen is produced from water using electricity from renewable sources in a process called electrolysis, such as alkaline electrolysis or Proton Exchange Membrane electrolysis. Some hydrogen is already produced this way, for example, when producing small volumes/at remote locations, when coupled to hydropower plants, or as a byproduct of chlorine production.

Many other colors are used to refer to other production methods, although less often and less consistently, such as orange (produced in the Netherlands from local renewable energy sources), yellow (produced by solar, e.g., in the Sahara), brown (from biomass/biogas), golden (biomass with CSS, thus negative emissions), purple (nuclear), black (electrolysis from coal- and gas-fired powerplants), turquoise (produced by leading natural gas through a molten metal which releases hydrogen and solid carbon), and many more. These colors can be applied to physical flows of hydrogen, but through certification (guarantees of origin), the trade can also be separate from the physical flows (as with green electricity).

Textbox 2

Methodology

This document is the result of a "transition arena," a series of dialog sessions with people attending in a personal capacity from industry and science and with highly different perspectives. These sessions were fed by theory about transitions, analysis, and interviews done by DRIFT (Dutch Research Institute for Transitions, at Erasmus University), which also synthesized these dialogs into this document. This document is thus a prime example of the "co-production" of knowledge between science and practice.

The responsibility for this final document, including any errors or omissions, rests, however, solely with DRIFT, and the views expressed in this document do not necessarily reflect the views of the participants or the organizations for which they work. The project has been funded by The Port of Rotterdam Authority (Port of Rotterdam in this document), who also participated in the sessions, along with –

Elmer de Boer	Eneco
Silvan de Boer	Eneco
Robert Bouma	Commercial Manager Energy & New Business, Nouryon)
Hans Coenen	Director strategy & business development, Gasunie
Steven Engels	General manager Benelux, Ørsted
Leo Freriks	New Energy Business, Siemens Energy Nederland B.V.
Marcel van de Kar	Director New Energies, Vopak
Thijs ten Brinck	Wattisduurzaam.nl
Jan-Coen van Elburg	Rebel
Noé van Hulst	*on personal title*
John Kerkhoven	Partner, Kalavasta
Coby van der Linde	Director, Clingendael International Energy Programme [CIEP], professor Energy and geopolitics RUG

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Textbox 2

Methodology

Julius Smith	Head of Business Development, Ørsted
Prof. Dr. Henk Volberda	Professor of Strategy & Innovation, UvA Director of the Amsterdam Center for Business Innovation
Prof. Dr. Ad van Wijk	Professor of Future Energy Systems, TU Delft, Guest Professor Energy and Water – KWR Water Research Institute

In addition, international experts have been involved to validate and enrich the international perspective on Rotterdam through interviews and reviews. Some of their contributions are included in this document as written reflections (see page 12, 19 and 33.). These international experts include –

Muneki Adachi	Deputy Director at the Global Climate Bureau Ministry of the Environment in Japan & PhD Candidate, Nagoya University
Roy Green	Chair, Port of Newcastle, and Emeritus Professor, University of Technology Sydney
Paul Hodgson	General Manager, Innovation and Stakeholder Engagement (East Coast), National Energy Resources Australia
Stefan Lechtenböhmer	Director of Future Energy and Industry Systems, Wuppertal Institute & Adjunct Professor, Lund University

Lastly, the Wuppertal Institute provided additional knowledge about the emerging hydrogen economy and industry, especially in the German and international context, and has also reviewed the work of DRIFT. This agenda for low-carbon hydrogen aims to complement the Port of Rotterdam's H-vision for local blue hydrogen production, although some leadership challenges are shared between blue and green hydrogen.

On behalf of DRIFT the arena process has been facilitated and supported by:

Carien van der Have
Martin van de Lindt
Igno Notermans
Roel van Raak
Prof. dr. ir. Jan Rotmans

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Chapter 2

The emerging global green hydrogen economy

Current pressures on our global energy system, such as impending climate change, resource scarcity, and price volatility for fuels and energy carriers, steer us in the direction of a decarbonized future economy in which low-carbon hydrogen plays a significant role. Hydrogen is the most abundant element on Earth. It can be used as feedstock for important chemical industries, as an energy carrier, and as an emission-free fuel. When produced through water electrolysis powered by renewable energy, it is seen as key in enabling the energy transition and realizing a new, green economy. It offers a decarbonized alternative to natural gas and can be used in aviation, mobility, logistics, building heat and power, industry, electricity generation, and storage.

In a hydrogen world, the global energy trade will still exist...

In this future economy, low-carbon hydrogen trade networks will be present on a global level, comparable to the way fossil fuels are traded globally today. There will be regions with a surplus of cheap renewable energy because of available space combined with positive wind and solar conditions, such as, potentially, Australia, Northern Africa, Latin America, and the Middle East (see Figure 2 and Figure 3). Other regions, such as Japan, will trade with regions willing to pay for this energy, hydrogen production, and its transport because of regional energy scarcity, due to less favorable climatic conditions, density of population, and energy intensity of industry. Of course, the level of trade is also dependent on the need and (in)ability of the source region to distribute their (renewable) energy and for domestic use through national grids.

Blue hydrogen will also be part of this trade system, especially when the market for low-carbon hydrogen is not yet fully developed. With rising prices of CO_2 emissions, the price of blue hydrogen will be comparable to the prices of gray hydrogen, which eases the market entry[12]. In this case, locations with the possibility of using, for example, greenhouses, chemical production processes, and plastics or capturing CO_2 emissions from the production of hydrogen (CCS), supply hydrogen (or certificates to guarantee the origin of hydrogen).

...as will the geopolitics of energy

As with fossil fuels, the trade routes will be determined not only by natural, technical, and cost factors, but also by geopolitical factors. History shows that industrial transitions on a global scale can lead to a shift in power between regions and in the geographic focal points of hubs. Hydrogen supply will originate in countries with extensive renewable energy capacity that offer electricity for low prices. In addition, countries that have a dominant (fossil) energy exporting position and have favorable climatic conditions for renewable energy production (and the resources for such investments, e.g., Middle Eastern countries) may try to maintain this position through hydrogen export[13]. Many countries with excellent natural conditions and space availability often deal with political instability, either domestically or in neighboring countries whose territory must be crossed for access to the rest of the world.

Thus, the global transition to hydrogen might imply geopolitical risks because of new trade routes and supply dependencies of geopolitically unstable regions and countries (in North Africa, Middle East, and Latin America). Although what might happen in the future is speculative, our best guess is that the geopolitical risks regarding the hydrogen trade will at least be comparable with the geopolitical risks related to oil and coal trading. The very idea of becoming energy autonomous for the Netherlands or Northwestern Europe is illusory; the dependencies will be at least as large as the current dependencies on fossil fuels. In regions such as Northwest Europe, which will become a large importer of hydrogen (see Chapter 3), will need to be alert to the impact of geopolitics on their supply chains. One solution can be found in strengthening the resilience of supply chains by importing via multiple routes and from various suppliers.

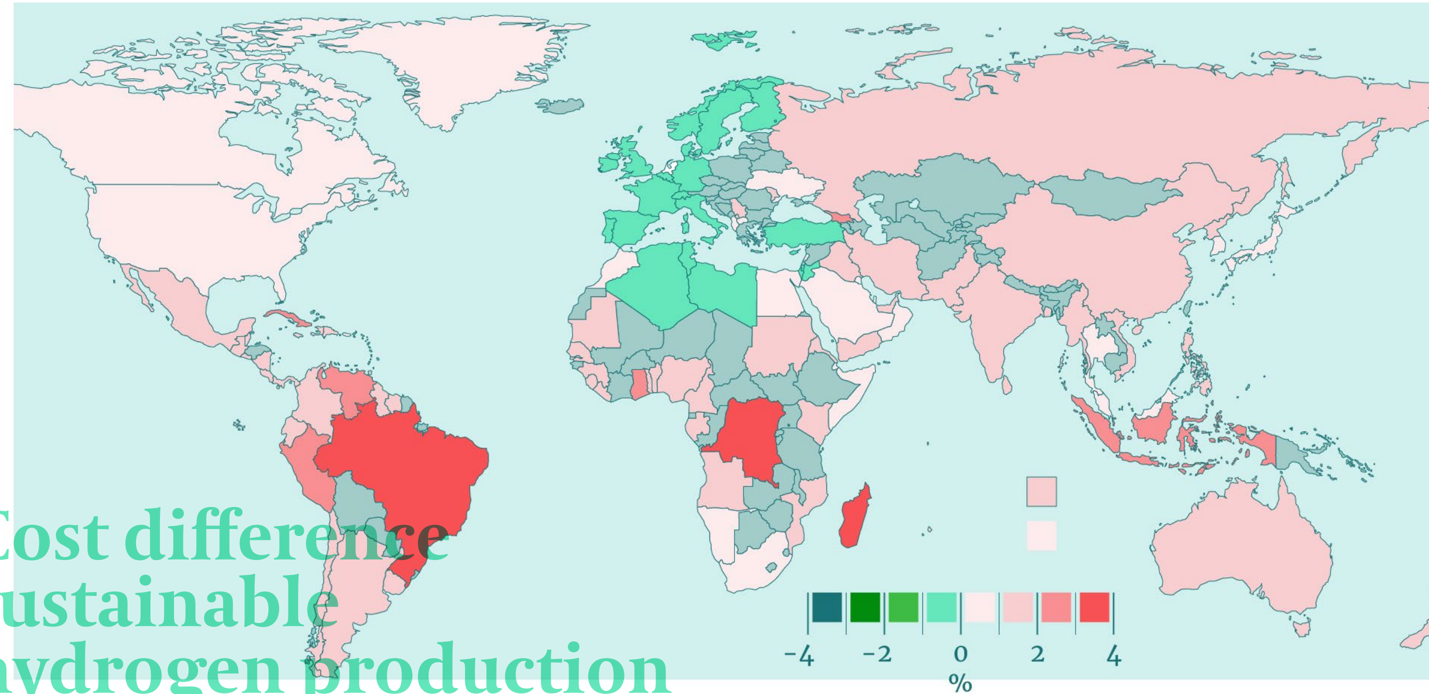

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Figure 2

Example visualization of the current difference in costs of producing green hydrogen locally in the Netherlands or in other countries and transporting hydrogen.
This is based on the HyChain II model. Please note this is an exploratory model and highly dependent on assumptions. One simplification is that the model assumes production in the geographic center of a country, so coastal production might be cheaper. For the visualization, the default values in the reference model were used, with a maximum pipeline transport of 3,500 km and a maximum inland transport to port of 500 km. Please note this visualization does not represent the availability of energy (or whether it is to be used locally or exported elsewhere for economic efficiency). The model represents current costs and prices. For more information and the model itself, see here.

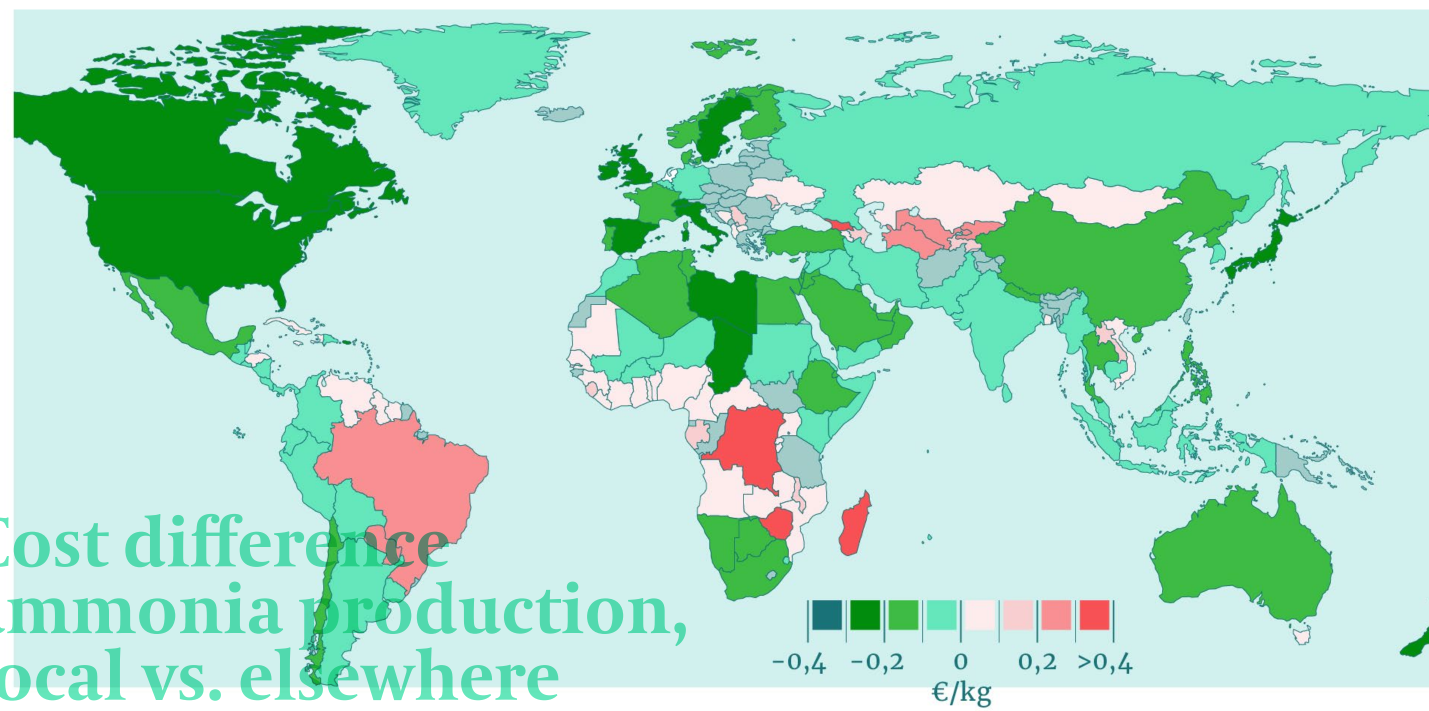

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Figure 3

Cost difference between producing ammonia locally in the Netherlands or producing green hydrogen elsewhere and, before transporting it, converting it to ammonia.
This is based on the same model as Figure 2, using the default parameters in the reference model.

Intercontinental transport costs are surmountable but lead to diverse forms of transport

The obvious argument against a global hydrogen trade is the availability of low-carbon hydrogen and the cost of transport.

Although renewable energy has become the lowest-cost source of new power generation in most parts of the world[14], little (less than 0.1% of global dedicated hydrogen production today comes from water electrolysis) renewable energy is used to produce hydrogen. Renewable electricity production can still be absorbed for direct use into national grids almost everywhere in the world, which does not stimulate trade in green hydrogen. However, at some point, the availability of space and the right climatic conditions will become more of a decisive factor than investment and transport costs. Areas such as Japan and Northwest Europe will simply run out of space for renewable energy production to meet their energy demand. Additionally, when the prices of renewable energy drop even further and the market for hydrogen scales up, the cost of hydrogen production through electrolysis, in comparison with hydrogen production from natural gas or coal, is no longer significant (e.g., IEA expects a price drop of 30% for producing Hydrogen from renewable energy[15]).

Still, the high transport costs – owing to the high costs of chemical conversion, liquefaction, or compression, compared to, for example, LNG, and especially oil (products) – will impact the way transport is organized; from source to user, supply chains will be formed that minimize costs. This will result in a diversification of the forms of transport. Where possible, pipelines will be used for transport or energy will simply be imported as electricity for direct use or near-user conversion into hydrogen up to 3000 km. Over longer distances, such as intercontinental transport, shipping will become the dominant transport mode by using the currently promising liquid organic hydrogen carriers (LOHCs), for example.

The end use will also determine in which form hydrogen is transported. For example, currently, almost half of global hydrogen usage is feedstock for ammonia production (fertilizer)[16]. Conversion at (or near) the location of green hydrogen production into the fertilizer precursor ammonia might be the most cost-effective option.
In comparison, for using hydrogen as fuel for mobility, fuel liquefaction might be the most cost-effective. In some (e.g., European) areas, policy makers consider to mix in hydrogen in natural gas infrastructures in order to easily scale up the demand for (low-carbon) hydrogen while using existing distribution systems. This is cost effective from the supply side, but as the proportion of hydrogen in the pipeline increases, the cost of modifying delivery systems will be passed to consumers.

Next to cost minimization, geopolitical and reliability considerations will determine modes of transport in general, trading longer transport distances for stable production locations, and the flexibility of shipping. At a more modest scale, this diversification also occurs in fossil gasses. For example, Europe is largely supplied through pipelines, but economic optimization (arbitrage between pipeline and LNG) and geopolitical independence still give LNG a significant complementary role in the energy system.

This differentiation in transport modes and routes will most likely also occur over time. In the early years, repurposed natural gas networks, new short-distance single-production facility pipelines, and small-scale shipping will be dominant. Later, a more dominant role will be fulfilled by new continental hydrogen infrastructural networks (which might include intercontinental connections, e.g., North Africa-Europe), which are optimized for changes in volume and locations of demand and supply (including ports) and no longer necessarily aligning with the old natural gas infrastructure.

Although renewable energy has become the lowest-cost source of new power, little renewable energy is used to produce hydrogen.

Expert Reflection 1

Hydrogen developments in Japan-Aichi

For Japan, which is poor in energy resources, hydrogen could be a key resource for ensuring energy security and preventing further climate change. Japan can use hydrogen, due to its storability, portability, and flexibility, to use abundant or unused (renewable) energy resources from overseas that it has so far failed to use, since Japan is an island nation. Non-renewable resources could be coupled with CCS, and its use could have significant positive effects in terms of Japan's efforts to mitigate climate change. Currently, Japan's main applications for hydrogen are fuel cells in mobility and fuel-cell CHP systems for residential usage (heating), although some industrial usage and hydrogen-electric power generation projects are being developed as well.

"Establishing a network among global frontrunners could be beneficial to all stakeholders"

↑
Muneki Adachi – **Deputy Director at the Global Climate Bureau, Ministry of the Environment (Japan) & PhD Candidate, Nagoya University Graduate School of Environmental Studies**

To seize the hydrogen opportunities, Japan established the Hydrogen Basic Strategy (2017) and Strategic Roadmap for Hydrogen and Fuel Cells (2019) to realize a hydrogen society. The Basic Strategy shows future visions for 2050 but also serves as an action plan for 2030. It sets the goal that Japan should reduce hydrogen costs to the same level of conventional energy sources (e.g., gasoline and LNG), and provides integrated policies across ministries ranging from hydrogen production, utilization, and regional cooperation to promoting citizen understanding. The Strategic Roadmap renewed this pathway by setting new targets, measures, and financial support on the development of imports, basic technologies, and cost reductions. For example, the target is to increase the amount of hydrogen imported to Japan from 0.2 thousand tons in 2019 to 300 thousand tons (0.3 Mtons) in 2030.

There are many regional projects promoting hydrogen across the nation, and a few projects also established a supply chain of green hydrogen. For instance, in 2018 the Aichi Low-Carbon Hydrogen Supply Chain consortium started in the Aichi Prefecture (capital: Nagoya, a.o. it houses the headquarters of Toyota Motor Corporation). The project adopts a unique scheme: biogas is generated by Chita-city and Tohogas from sewage sludge, which is transported via a gas pipeline to Toyota Motor Corporation where the hydrogen is produced, stored, and used by forklifts. Moreover, the Aichi local government established a certification system for green hydrogen and coordinated with businesses. Next to the project, the parties also established a vision on local low-carbon hydrogen supply chains for 2030.[1]

To reflect on the role of Rotterdam, I believe that it has a significant potential to develop as a production, usage, import, and trade hub. In particular, the role of blue hydrogen as a bridge from gray to Green is an important opportunity I would like to stress. In addition, the frontrunner strategy would make it easier to establish the position as a hydrogen hub. On the other hand, Rotterdam also seems to need to create a potential demand by diversifying the hydrogen usage not only in industry but also for residential use and transportation, for which examples from Japan might help. Lastly, with the aim of diffusing hydrogen society around the world, I think that sharing information and establishing a network among global frontrunner cities could be beneficial and reciprocal for all stakeholders, including those from Japan and, in particular, Aichi.

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1 More information on the project and vision can be found here.

Chapter 3

Emerging green hydrogen in Northwest Europe

The emerging green hydrogen market is of great interest for the Port of Rotterdam. Low-carbon hydrogen is currently seen as one of the key options to make the existing industry and shipping within the Port more sustainable, thus helping to achieve climate sustainability.

The port of Rotterdam is not alone in this challenge. As a large-scale production and trading hub and transit port to the hinterland, their strategies impact all of Northwest Europe. After all, Northwestern Europe is an area with many ports and cooperating industrial clusters in a relatively small geographical area. Although the Port of Rotterdam is regulated at the national and European levels, we focus on Northwest Europe because this area has a shared identity and common challenges.

Northwestern Europe faces a shared challenge

The countries in this area (Netherlands, Germany, Belgium, Luxembourg, and Denmark) share more than their European roots: They are connected to the same shipping routes (sea and inland shipping) and electricity and gas networks. They are positioned around the North Sea, which is seen as a shared wind energy supplying area and have a similar potential for solar energy due to moderate climate and spatial planning (densely populated, highly industrialized).

Northwest Europe has common challenges as well. Many nations are struggling to reach their binding EU targets for renewable energy, and they have no clear path at the system level to reach the 2050 goals of a fully sustainable energy system and industry and the other ambitions of the European "Green Deal"[17]. To reach this goal, the role of green hydrogen in the Northwest European energy system will be significant. Green hydrogen is not only a flexible and emission-free energy transport medium with various purposes, it is also a storage medium to balance out electricity grids powered by renewable energy sources.

Northwest Europe will stay dependent on energy imports

Northwest Europe is a densely populated and highly industrialized area where the energy demand is high despite limited availability of land and capacity for generating solar and wind power. For example, the capacity of the North Sea for wind parks is limited to the various additional functions of this area, including fishing, shipping routes, nature reserves, and military terrains, and allows only about 75 GW total wind energy capacity with current availability and planning, and about 180 GW if a much greater planning priority is given to wind energy (these numbers relate to the entire North Sea of the UK, Germany, and the Netherlands but excludes Belgium and Norway)[18].

It is unlikely that the full energy demand of Northwest Europe in the future can be sustainably supplied by local and regional renewable production, and it is unclear whether the supply is sufficiently stable, as the area is prone to the same risk of adverse weather conditions, so a large proportion of the energy—including green hydrogen—must be imported. To illustrate, Van Wijk and Wouters (2019) developed an energy scenario with extensive hydrogen imports from North Africa and estimated that roughly half of the total energy demand of the EU will be imported (including green hydrogen), which is similar to the level of energy dependence today[19].

There are a few other studies that estimate future energy dependence. An example is the three scenarios developed by Gasunie and Tennet in which the imports of hydrogen and methane result in import dependency ratios between 35% and 75%[20]. In scenarios developed by the EU, the dependence will be lower under the assumption that decarbonized energy carriers like hydrogen will all be produced within the EU, although at the moment this seems unlikely[21]. A quick explorative scenario scan for this document for the eventual sustainable energy system (for example around 2050) estimated the import dependency of Northwestern Europe (Denmark, Belgium, Luxembourg, Netherlands, and Germany) at between 20% and 60% (see Textbox 3) with optimistic assumptions about local renewable energy production. This ratio depends on the expected demand for hydrogen and the concessions that are made in favor of becoming more energy self-sufficient. For example, failure to use fields and other open spaces for energy generation leads to import dependency ratios of roughly 65%–75%.

For the Netherlands, it is highly unlikely that a climate-neutral energy system will be as self-sufficient as it was when domestic-sourced natural gas was part of the energy mix[22]. To illustrate, under all scenarios developed by Jepma, Spijker, and Hofman (2019), we will need to import at least half of our total energy needs[23]. However, the degree of self-sufficiency will also depend on the level of emission reduction targets, the degree to which we want to limit energy system costs, or rather prioritize self-sufficiency (see Textbox 3).

Local hydrogen production

In parallel to imports, some hydrogen will be produced locally in Northwest Europe and the Netherlands. One option is to produce green hydrogen with temporary surpluses of locally produced renewable electricity from "hydrogen islands" in the North Sea connected to wind farms or from internationally transported electricity. However, some applications need a constant, reliable supply of hydrogen (e.g., industry), and electrolyzer capacity is still quite expensive to install. Therefore, green hydrogen production could also be developed parallel to wind, where only a (small) baseload is used directly as electricity and the rest is dedicated for electrolysis. From a business case perspective, this could spread the risk and lower costs, although technically it could be preferred to divide these functions over different wind parks.

Local hydrogen production will also become much more important when energy independence and resilience of a system are considered. National or even European concerns for a sufficient amount of local production of hydrogen or stress tests of the robustness of our energy systems could enhance the demand for local and diversified sources of hydrogen production. Increasing the robustness of a system can be costly (but also necessary as backup, e.g. installing overcapacity) or will be at the expense of other functions (e.g., in the North Sea). Still, to realize the full potential of low-carbon hydrogen, hydrogen storage and other colors of hydrogen are important to consider.

Blue paves the way for green hydrogen production

In the future, the largest share of hydrogen will be green, but in the beginning, the larger share will be blue. Blue hydrogen can be used as an important stepping stone for the introduction of green hydrogen. In order to meet European climate goals by 2030[24], radical cuts in emissions are required. Blue hydrogen delivers a direct reduction of CO_2 emissions for hydrogen use and can be implemented relatively quickly for a price comparable to gray hydrogen. Because of availability and affordability, blue hydrogen can introduce low-carbon hydrogen as a favorable alternative to fossil resources (e.g., natural gas), scale up demand in new markets, accelerate the development of a hydrogen infrastructure, and accelerate a hydrogen trade system. Blue hydrogen is then the inevitable and necessary step toward green hydrogen. Blue hydrogen compensates for the impact of gray hydrogen through CCS. In the coming decades, this will be required in applications where the phase-out of fossil fuels is not yet complete. For example, some refineries will be needed by the chemical industry, but the large demand from the chemical, fertilizer, and synfuel industries cannot yet be fully covered by renewable electricity sources. This is another reason that blue hydrogen will be prioritized over green hydrogen at the start.
It should be noted that, from a transition perspective, blue hydrogen is seen as an incremental innovation, while CCS acts as an expensive "lock-in" of fossil resources in the energy system. Only when gray hydrogen is replaced would CO_2 emissions be lowered; otherwise, emissions would increase. Another remark in this discussion is that the price of green hydrogen would be comparable to gray or blue hydrogen when emitted CO_2 has a price (e.g., when a stronger EU Emission Trading System is developed)[25]. Still, the future is uncertain. A scenario where blue hydrogen is not necessary as a stepping stone is possible as well; for instance, when mega wind parks are realized relatively fast and large quantities of green hydrogen can be imported simultaneously.

Nonetheless, there is time pressure on delivering low-carbon alternatives for fossil fuels as natural gas. Green hydrogen has been considered for years, and current forecasts show how the development of green and blue should go hand in hand[26]. The share of green hydrogen will grow over time, while blue hydrogen investments will keep their value because the total demand for hydrogen will increase as it replaces fossil resources, such as natural gas[27]. However, to begin increasing the share of green hydrogen, action is needed today.

↓ Panorama – Waalhaven westzijde – Port of Rotterdam by Frans Berkelaar

Low-carbon hydrogen has the potential to replace one-third of current fossil fuel and feedstock use, but it requires public support

Hydrogen can be used in a wide range of energy applications. Technically, it is (or will be) possible for it to replace almost any existing energy carrier. Of course, this will also be determined by the applications that are most economically attractive. It is hard to predict which applications will be dominant once the hydrogen economy fully emerges, particularly given the uncertainties about alternatives (e.g., electrification for energy use and storage). However, typical (first) applications in Northwest Europe are expected to be the applications that cannot be powered by another sustainable power source, such as those that currently use (gray) hydrogen as feedstock and applications that are situated in industrial clusters (the short distance between production or Import sites makes supplying hydrogen through pipes easier). Examples include:

- **Feedstock** in refining and fertilizer production as current major hydrogen users and, in the future, many new major users that need hydrogen feedstock; for example, manufacturers of synthetic fuels, materials, etc., may emerge.
- As fuel for heavy, long-distance **transport**, such as long-haul trucking, inland water transport, and international shipping and aviation. Demand will grow when exemptions from CO_2 reduction agreements for international aviation and shipping end.
- As fuel for **high-temperature heating** in industry, especially for applications that require temperatures beyond what is easily feasible with electric heating. Second, brownfield applications for replacing natural gas burners for hydrogen burners in existing plants.
- As a **balance/buffer for the electricity system**, either in central or decentral systems, hydrogen buffers can provide electricity when weather conditions are unfavorable over a prolonged period for wind and solar by providing easily dispatched electricity.

These functions represent about 20% of the current final energy use in Northwest Europe (DRIFT's calculations are based on Eurostat statistics, 2018). Several other studies and estimates arrive at similar ranges[28]. Of course, this percentage will be higher if green hydrogen is also used in residential heating, light transport and mobility, or the large-scale CCU production of synthetic fuels and materials.

Some applications will take longer to introduce because they require radical changes in the energy system and public support in order to be implemented successfully. For example, introducing hydrogen mobility will need technical and behavioral adjustments that impact the consumer side (pump stations, etc.). Public support for these changes is crucial and can quickly affect policies. In the Netherlands, public discussions on the use of biomass as an energy source and on the use of natural gas from Dutch (Groningen) gas fields have caused a radical change in public opinion and policies.

Biobased and circular applications may dominate future feedstock use of hydrogen

In Northwestern Europe, circularity and biobased practices are important strategies to meet climate goals and to reduce economic vulnerabilities. Both circular and biobased strategies ask for a system that is fully powered by renewable energy and feedstock; green hydrogen makes this possible. Both strategies can enhance the development of hydrogen markets and influence the demand for green hydrogen.

For example, chemical industries are incorporating the principles of a circular and biobased economy by closing material loops: Discarded plastics are collected and recycled, bioplastics, and biofuels are produced in order to realize a system that is fully fueled by renewable sources. It will be a challenge for the chemical industry to find sustainably sourced carbon and hydrogen as feedstock for these processes. In some cases, biobased virgin or waste material will be the source of hydrogen, but in many cases these new processes will require significant amounts of green hydrogen from non-biological sources.

Simultaneously, refineries (representing a significant part of the current hydrogen demand) will have a less prominent market position and closing loops in "circular agriculture" might reduce fertilizer use (representing the other major current use of hydrogen as feedstock). Phasing out fossil fuels will reduce the demand for hydrogen from refineries or increase the demand for low-carbon alternatives.

These trends combined mean that green hydrogen may start as a way to reduce emissions from our current fossil and fertilizer industry, but over the years and decades, biobased and circular processes may very well become the dominant uses of green hydrogen as feedstock.

Technically it is (or will be) possible for hydrogen to replace almost any existing energy carrier.

Diversification in import and distribution networks

The demand for hydrogen will result in new transport networks through Northwest Europe. In order to import the required amount of energy, both hydrogen, electricity from renewable sources, and hydrogen bound to different substances will be imported. Electricity from various renewable sources will be imported over electricity grids from production locations outside Northwest Europe (NWE) in proximity with locations that require power in NWE. Hydrogen will be imported by ships and through pipelines from both South(eastern)-European borders, dependent on the distance and steadiness of supply. Import from offshore wind parks could also be transported via pipelines from dedicated hydrogen islands. Moreover, countries will select multiple supply routes in order to create a resilient network, not affected by geopolitical changes.

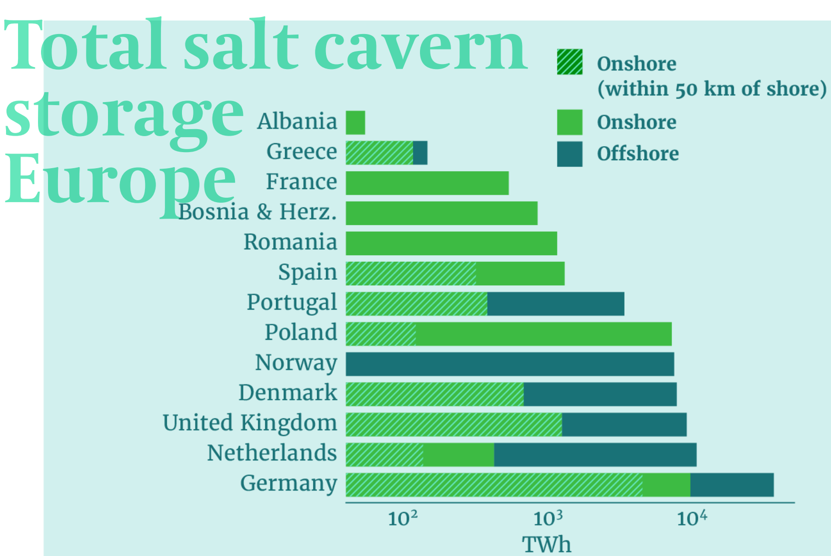
The distribution of hydrogen within Europe will depend on the specific demand of industries but also on regional differences of the source of electricity generation, the annual fluctuations in the weather, and storage capacity. Therefore, it is likely that different forms of hydrogen and hydrogen compounds will be used and transported through Northwest Europe—in a gaseous state, compressed, liquified, or bound in ammonia, methanol, and other substances.

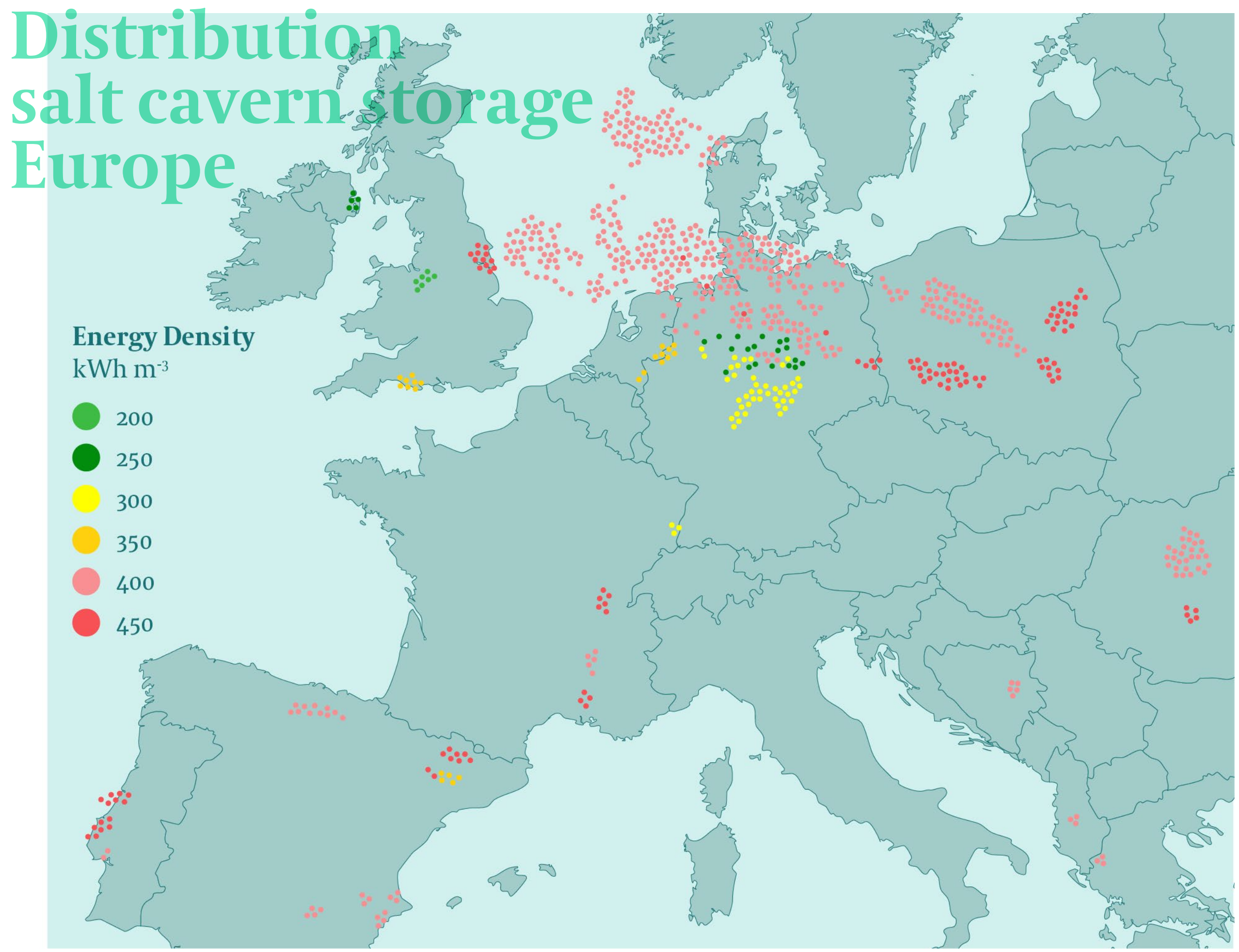
Both import and distribution have a temporal dimension: Even where pipelines are a more economical choice in the long run, the high initial investment required might mean those routes will be first served by ships, in the case of import, or by inland water transport or tank truck for distribution. In the long run, it makes more sense to develop (and/or repurpose) pipeline infrastructure, as it has a larger capacity to transport energy than the (current) electricity grid, for both imports and distribution. The first pipelines will probably reuse and optimize natural gas pipelines. The first steps have been taken by introducing an H_2 network in the Netherlands. When demand for green hydrogen increases, new pipelines will be constructed.

Lastly, the network developments are also likely to be influenced by the natural storage capacity for hydrogen present in Northwest Europe in the form of salt caverns, especially when hydrogen is playing a dominant role as a battery or buffer in the overall energy system. Storage in salt caverns is abundantly available in Northwest Europe, thereby strengthening its potential as a central function of the hydrogen distribution network. Figure 4 below describes the technical potential of storage capacity in salt caverns, where social and ecological limitations, but also empty natural gas fields for storage, are not yet considered.

↓→

Figure 4
The technical potential of salt cavern storage capacity in Europe[29]





Textbox 3

Is Northwest European external dependence unavoidable?

In this document, we argue that we should face the implications of NWE remaining a net energy importer and the urgency and opportunities for green hydrogen this provides. This was the strong consensus in the group that participated in the "transition arena." In support of these discussions, DRIFT has also made some rudimentary explorative calculations for NWE. These calculations are based on the Eurostat current final energy use data, factoring in changes in efficiency of energy use. From these, we conclude that it is indeed likely that NWE will remain a significant importer. Nevertheless, there is an alternative, unlikely but plausible, scenario in which NWE sacrifices a significant amount of its grassland for solar (and wind) farms. But even in this scenario, there is the necessity for a "two track" approach for the Port of Rotterdam, in which it also takes "regret" measures in case NWE does provide strong opportunities for local production and use of hydrogen along the North Sea coast.

We assume a completely sustainable (non-nuclear, fossil free) and significantly lower final energy use in 2050, from about 16,000 petajoules to 8,000 petajoules. This is partially because of energy saving measures, such as insulation, and cascading (e.g., heat networks), but mainly because non-fossil final energy use will be more efficient; should energy efficiency agenda's fail, final demand may be around 10,000 PJ.

Likely scenario – at least 30% of energy is imported, 40% of final energy use is hydrogen

In this scenario, better natural conditions and cheaper land on other continents will allow overseas production of green hydrogen to outcompete the growth of renewable energy production in NWE, despite the costs of liquifying and transporting hydrogen. There will still be massive Northwest European production of renewable energy by stretching the use of the North Sea (pushing out other functions) to a maximum, using virtually every roof available for solar power. Still, this production will fall far short of Northwest European energy needs. There will be no significant transfer by hydrogen pipelines from North Africa through South Europe to the region because of a lack of European cooperation and Northwest European worries over the geopolitical stability of that region.

Instead, NWE imports at least 2,000 petajoules per year by ship from regions such as the Middle East, Latin America, and Australia. If energy savings are not realized and less space is available for wind energy, this import can reach 7,000 petajoules and energy dependency can become around 70%, and hydrogen's market share in final demand might also become 70%. In NWE, electricity prices will be high because local production is scarce and the centralized conversion of hydrogen back into electricity is expensive. In the more extreme import situations, hydrogen applications are often favored over electrical applications, even if not as efficient. Hydrogen is used as the main fuel in many types of transport (direct or processed into synthetic fuels), other mobile applications, high-temperature heating, and, to some extent, for low-temperature heating. The existing natural gas transport and distribution networks will be repurposed and transformed into a fine-meshed hydrogen (or methanized hydrogen) network. Storage will be liquid storage (or still bound to the hydrogen carrier) in ports for strategic reasons. NWE has a strong regional collaboration, led by Germany, to establish and reinforce stable trade relations with many countries. Individual high-volume users of hydrogen and hydrogen retailers will also, through long-term contracts, aim to increase price stability.

Other directions that are less likely but plausible

There are other directions possible in these scenarios. A geopolitical awakening of NWE and a strong desire to be self-sufficient lead to – unlikely but not completely implausible – sacrifices of other policy aims that allow self-sufficiency, such sacrifices include –

- **Sacrificing green space and free trade:** including sacrificing the goal of preserving green/agricultural space. The North Sea's dominant function becomes energy production, pushing out other functions. A significant part of Northwest European grassland →

Textbox 3

Is Northwest European external dependence unavoidable?

is converted into solar (and wind) farms. It should, however, be noted that a largely electrical and solar driven energy supply would also require extreme balancing solutions that will likely require local hydrogen as an energy buffer, unless there are major advances in battery technology. This again might make hydrogen applications more attractive. In such a scenario, massive subsidies, trade tariffs, or other import barriers may be needed to prevent energy (such as hydrogen) from elsewhere from simply out-competing domestic production.

- **Sacrificing car/plane mobility:** Aggressive, extreme policies toward energy savings, including deeply renovating/rebuilding Europe's entire building stock, large heating grids to reuse all remaining high-temperature heat, shifting to less energy-intensive mobility (train instead of flying, biking/walking instead of driving, more local material loops), reducing high-temperature industry (e.g., switching to microbiological production of chemicals).
- **Sacrificing bans on nuclear energy, especially the explicit German ban (2022) and Belgian ban (2025):** Not in the calculations, but also technically possible—a large nuclear industry providing the energy for electricity/hydrogen production (and mining the uranium in, for example, eastern Germany, if energy independence is desired).

If electricity is less scarce, no high-volume imports through the shipping of green hydrogen are developed, except as intermediate products, such as ammonia for fertilizer. Northwestern Europe is largely electrified and has made extreme investments in upgrades to its electricity network. Still, hydrogen plays a much larger role in the 2050 energy economy than it did in 2020. Hydrogen may still be used for more limited functions as feedstock, heavy transport and high-temperature heating, and there are both central and decentral fuel cells and hydrogen-fueled conventional power plants to balance the hydrogen net when needed. This hydrogen is produced under normal circumstances where concentrations of renewable energy are highest, e.g., around the North Sea or in North Sea energy islands. Part of the production is directed toward storage in caverns. When the weather is unfavorable for the production of renewable electricity, electrolyzers are taken offline and hydrogen is supplied from storage, and some hydrogen is also converted to electricity. The North Sea coast, especially its industrial ports, become prime locations for both converting electricity into green hydrogen and for high-volume green hydrogen production. This green hydrogen is also distributed and produced in the hinterland – not in a fine-mazed distribution network; only an industrial backbone (also serving gas stations for transport) is developed, partially from repurposed high-volume natural gas pipelines. The natural gas distribution networks are dismantled and maintenance and investments are redirected toward electrical grids.

↑ Euromax terminal – Yangtzekanaal – Port of Rotterdam by Frans Berkelaar is licensed under CC BY 2.0 / Colors modified from original

Expert Reflection 2

Hydrogen developments in Newcastle, Australia

"Hydrogen could play a key role in unlocking the renewable resource potential"

Australia is a global energy powerhouse, exporting more than two-thirds of its annual energy resource production. But despite the huge potential of renewables in the country, Australia leads the world in penetration of rooftop solar, for example, (principally for domestic electricity generation), the intermittent and place-based nature of solar energy provides limits to the growth of Australia's renewables. Hydrogen could play a key role in unlocking the renewable resource potential and decarbonizing fossil fuels and related sectors. For example, the interest in hydrogen as an energy vector has surged again over the past two years due to strong market signals from Australia's existing energy export destinations, particularly Japan and South Korea.

Commissioned by the Council of Australian Governments' (COAG) Energy Council, Australia's National Hydrogen Strategy was released in November 2019, setting a vision for a clean, innovative, safe, and competitive hydrogen industry that benefits all Australians[2]. It aims to position the Australian industry as a major player by 2030, and most Australian states and territories have also released hydrogen strategies and plans. NERA, Australia's key industry growth center for the energy resources sector, is leading the establishment of a national hydrogen industry cluster while Australia's national science agency, CSIRO, is establishing a national hydrogen mission. The hydrogen ambitions include a target of reducing electrolytic hydrogen production costs in Australia to less than 2.0 AUD/kg H_2 (approx. €1.2) and are backed by significant funding, including AUD300m from the Clean Energy Finance Corporation. Currently, hydrogen projects in the country are spread across various potential uses, and there are a number of publicly announced hydrogen developments in Australia, covering brown, blue, and green hydrogen and green ammonia[3]. As Australia is the largest exporter of LNG and a significant producer of ammonia from natural gas, blue hydrogen is seen as an important opportunity. One of the largest projects currently underway is the Hydrogen Export Supply Chain project, a world-first trial to demonstrate the safe and efficient transport of liquefied hydrogen (produced from brown coal) to Japan.

↑ ***Paul Hodgson*** **– General Manager, Innovation, and Stakeholder Engagement (East Coast), National Energy Resources Australia.**

2 As input to the National Hydrogen Strategy, Deloitte Australia prepared "Australian and Global Hydrogen Demand Growth Scenario Analysis" (Deloitte, 2019).

3 The Australian Renewable Energy Agency has provided co-funding to the majority of projects so far, you can find an overview of initiatives here.

→

"The Port of Rotterdam would benefit from becoming a hydrogen import hub as part of its own energy port ambition."

The challenge of transforming a system reliant on fossil fuels and activating the potential offered by hydrogen is highlighted by the developments of the Port of Newcastle, located just north of Sydney. Currently, the Port is the largest coal port worldwide, by shipping around 160 million tons per year of primarily thermal coal for the power stations of Asia. It is now engaged in a process of diversification and decarbonization, which has two main elements. First, the Port will reinvent itself as an "energy port," with an emphasis on hydrogen production and export. In the short term, this may require the use of domestic gas, but in the longer term, the objective is a renewables-driven hydrogen ecosystem, which would contribute to the growth of advanced manufacturing as well as to the prospect of a competitive export hub of hydrogen. Second, the Port is also committed to a AUD 2 billion investment in establishing a fully automated, large-scale container terminal, both to diversify its own business and to facilitate the economic transition of the whole Hunter Valley region.

In this context, some complementarity may be noted between the plans of the Port of Newcastle and those of the Port of Rotterdam, which would benefit from becoming a hydrogen import hub as part of its own energy port ambition. It provides an important opportunity for the Ports of Rotterdam and Newcastle to work toward a global hydrogen ports alliance. In the end, everything will depend on the commercial viability of these related and potentially synergistic propositions, and, as in the case of renewable energy more broadly, viability will in turn depend on the production and delivery of hydrogen at scale.

↑ ***Roy Green* – Chair, Port of Newcastle, and Emeritus Professor, University of Technology Sydney.**

Chapter 4

Urgency for the Rotterdam Port cluster

Rotterdam is currently the leading energy cluster in Northwest Europe and has great potential to replace the current high volumes of gray hydrogen via blue hydrogen with green hydrogen. According to the Port's hydrogen vision, the total potential flow of hydrogen via the Port could be as large as 20 Mtons, of which the largest share is for export (7 Mtons is for domestic demand). However, this is not just a substitution of one feedstock source for the other. The emergence of low-carbon hydrogen, and more broadly, a renewable energy economy, provides the Port with important opportunities but also creates several threats.

The Port of Rotterdam is also the main port and the fossil fuel leader of Northwest Europe. More than half of the total throughput of Rotterdam consists of fossil fuel resources (52%: coal, crude oil, mineral oil products, and LNG)[30], more than most of the other major ports in the le Havre-Hamburg range, and two-thirds of the economic added value in industry is from the fossil fuel industry. This strong fossil fuel position has made Rotterdam the successful and efficient industrial cluster it is today, but it also creates a serious challenge in reducing CO_2 emissions – currently nearly one-fifth of the total Dutch emissions.

If the Port of Rotterdam wants to maintain this dominant position in the long run, it needs to quickly move beyond the fossil fuel chimneys and pipelines of today and search for alternatives. Green hydrogen is such an alternative and has the benefit of fitting well with the position of Rotterdam in both chemicals and energy, as hydrogen is expected to play an important role in exactly these sectors. However, Rotterdam is not the sole and most obvious place to develop green and blue hydrogen.

Rotterdam's strengths

Like the whole energy system, Rotterdam faces the challenge of decarbonizing rapidly over the next thirty years. The current strength of the Rotterdam cluster as a powerful (fossil) energy and container hub could be deployed to play a leading role in developing hydrogen before its power diminishes. Because the Port is internationally renowned and connected, it has the potential to launch and/or develop hydrogen production and trade in coalitions with companies and countries globally.

Zooming in to Rotterdam, the cluster has a good starting point regionally. First, the already existing hydrogen market around Rotterdam is extensive. In 2019, 121 PJ of predominantly gray hydrogen was supplied by the Rotterdam-Zeeland based industry (nearly 70% of the total Dutch supply)[31]. Also, Rotterdam has a comparative advantage in handling large quantities of liquid bulk, and its infrastructure, which is able to receive, process, and transfer fossil fuels, could be used to handle large volumes of green hydrogen and related products as well[32].

Third, the location on the windy North Sea provides access to large volumes of renewable energy. In the coming years (2021–2022), the Port of Rotterdam will be connected to a 1.4 GW wind park (Hollandse Kust Zuid)[33]. The North Sea also provides access to other offshore infrastructure, such as potentially reusable production platforms. Rotterdam is the starting point of an extensive pipeline infrastructure connected to Belgium, Germany, Luxembourg, and France. This includes two private hydrogen pipelines from Air Products and Air Liquide all the way up to Dunkirk (dotted red line, see Figure 5). The key for the infrastructure is the realization of a dedicated "hydrogen backbone" around 2030 by Gasunie through the Netherlands, mainly repurposing the existing natural gas network.

A key opportunity for the Rotterdam cluster is to use blue hydrogen as a stepping stone for the development of green hydrogen. The Port cluster already develops meaningful plans for blue hydrogen through the projects Porthos and H-vision, although a clear connection with green hydrogen is still missing. Such a connection is important for blue hydrogen in order to avoid a lock-in on fossils.

Although blue hydrogen seems to be only an incremental step away from gray hydrogen, it is a crucial and logical chance to ensure the availability of considerable quantities of low-carbon hydrogen. It allows the Port to reduce its emissions while maintaining the dominant energy hub function. The current energy-intensive activities supply a concentration of CO_2, and the proximity of potential storage fields makes the Port an ideal place for storing it. The availability of CO_2 also provides the additional opportunity for the chemical industry to develop new (sustainable) products like building materials, polymers, and fuels[34]. So next to carbon capture and storage, it also provides the chance to use carbon in industry.

As it is not expected that large volumes of green hydrogen can be produced in the short run before 2030[35] – if due only to the limited availability of renewable electricity in the Netherlands[36] – blue hydrogen is a necessary intermediate step to decarbonize current hydrogen usage to further develop a hydrogen infrastructure and possibly develop new hydrogen applications. Green hydrogen should be developed simultaneously; the value chains of green and blue could even enhance each other by reducing risks or securing a constant supply, although this requires coordination[37].

Lastly, the potential demand for hydrogen around Rotterdam through new hydrogen applications is substantial[38]. Green hydrogen could (partially) take over current functions of the Port, such as bunkering fuels for (inland) shipping and aviation. Rotterdam is one of the top three bunker ports of the world, with 11 million m3 of fuel being delivered to ships each year, and it is connected to the CEPS/NPS aviation fuel network through which major airports throughout Northwest Europe can be reached (see Figure 5). Green hydrogen could additionally be used for high-temperature processes and feedstock in new chemical industries, such as in waste to chemistry processes, biobased materials, or in the utilization of captured CO_2.

Challenges for Rotterdam

Despite the current strengths of the Rotterdam Port cluster, five issues threaten the position of Rotterdam as a favorable location for green hydrogen developments. First, Rotterdam is dependent on international shipping routes for hydrogen in the long run. When production volumes increase, it will make more sense to transport hydrogen via pipelines within Europe or even from North Africa[39]. Rotterdam is only a logical place for import and trade when hydrogen will be shipped (intercontinentally). Of course, if Rotterdam is not the point of import into Northwest Europe, green hydrogen that enters from elsewhere can still be used for greening the industry located in the Port.

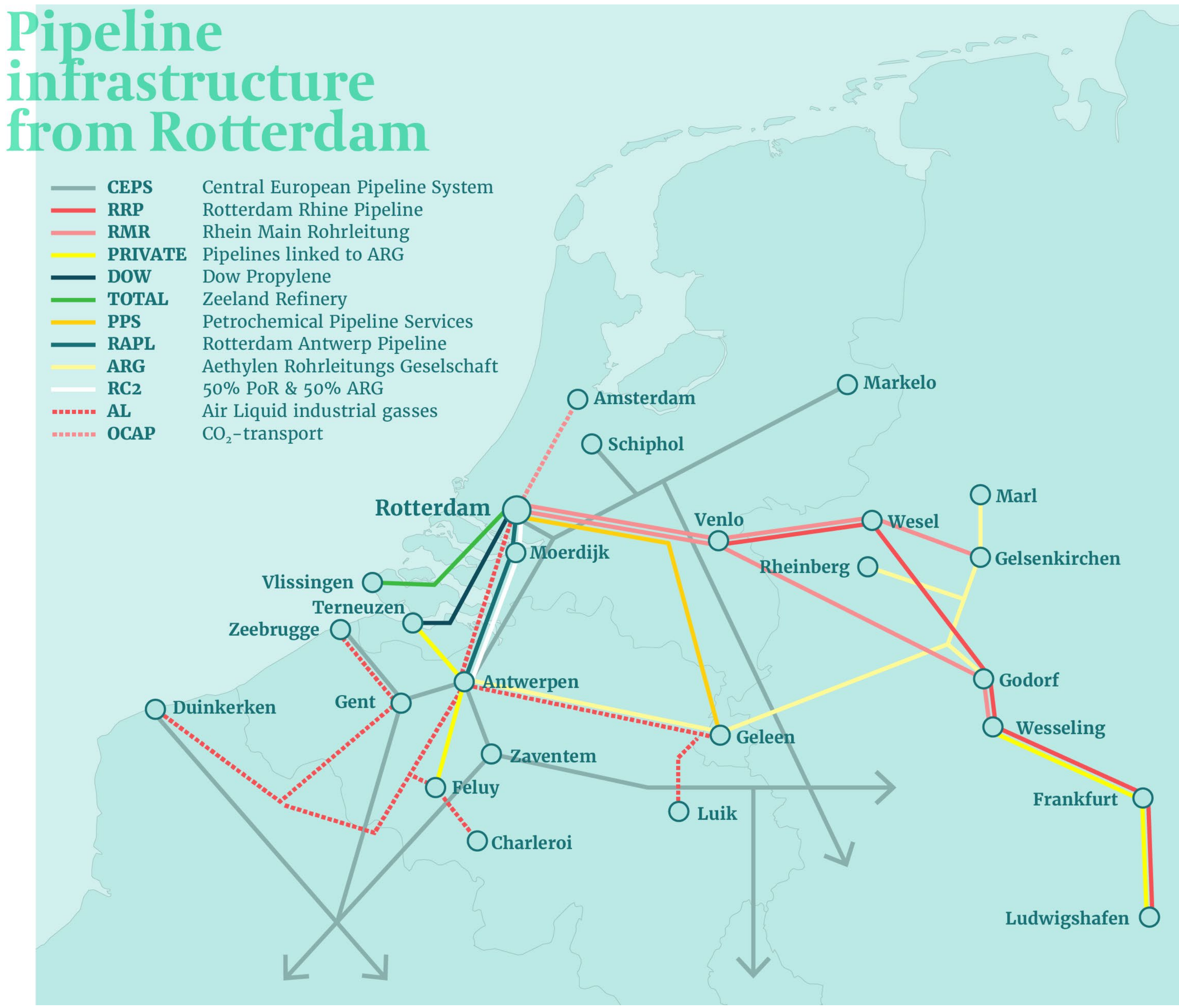


Figure 5
Pipeline infrastructure from Rotterdam for the transport of oil (products) and gasses[40].

Textbox 4

Four hydrogen hub functions for the Port of Rotterdam

To seize the hydrogen opportunities, four (combinations of) hub functions arise for the Port of Rotterdam –

1 **Usage hub** – where (imported) low-carbon hydrogen is used to replace gray hydrogen, to make synthetic fuels, for high-temperature heating, or for new sustainable chemical industries. The current functions of the Port to bunker fuels and add value to large quantities of fuels will be retained. Crucial for this function will be a reliable supply of green hydrogen, regardless of its place of origin.

2 **Production hub** – where low-carbon hydrogen is produced to supply the potentially large user base. Blue functions as a bridge between the current fossil industry and a full green future, but it does require a speedy implementation of a CCS project. Green hydrogen would need a connection to offshore wind farms, possibly dedicated ones, to ensure a constant supply of green electricity. Centralized green hydrogen production is most likely within the Port because of the limited space available to provide electricity to decentralized locations. Production is important, but unlikely to match the needs for local usage and inland distribution. The Port Authority, for example, estimates local production might be only 10% of the needs of the cluster and its hinterland (Table 6, 2020 Hydrogen Vision PoR).

3 **Import hub** – where green hydrogen is imported via ships and transported to users in the Port and to the hinterland. The hydrogen is possibly converted from/to other hydrogen-related products (ammonia, methanol, etc.) in an intermediate step. The current function of bunkering fuels will be retained as well. The import hub would require a demand for green hydrogen in the Port and the hinterland, a good connection (infrastructure) to the hinterland, and the development of international chains and shipping routes. It could also involve active development of production elsewhere and to gain excess to low-carbon hydrogen in exchange for knowledge on digitalization and sustainability (see also Chapter 7). In addition, Rotterdam could be the place where hydrogen produced on the North Sea makes landfall.

4 **Trading hub** – where the hydrogen market trade is organized, concentrated, and which serves as a main price and benchmark. It requires infrastructure for transport and storage and substantial amounts of hydrogen. Such a trading hub depends on the combined development of usage, production, and import hub functions.

For Rotterdam, the best strategy in this phase of the energy transition is to invest in all four hub functions. This also means investing in regret options that turn out to be less attractive when selection is needed. Naturally, the usage and import hubs fit well with the current Rotterdam cluster, although developing the usage hub is easier on the short term and needed to become an import hub; it is also less distinctive. Moreover, the production function could provide a key opportunity in the form of blue hydrogen and this function is especially interesting now due to the announcement of NortH2 in Groningen, potentially the largest green hydrogen project in Europe. Over time, a division of the different hub functions in a collaborative network of Dutch or Northwest European port-industrial clusters could emerge.

The second issue is the continuation of the strong hub model for global energy flows. The current petrochemical cluster arose out of the advantages of proximity to industrial partners and a recognition of Rotterdam as a geographically well located, but also politically neutral and stable location in a (then) unifying European market. Some of these factors will hold for a green hydrogen economy, but others are less certain. A possible alternative future is a decentralized system of smaller hydrogen hubs, in which Rotterdam still has these advantages but is just one of the hubs. For example, a low temperature, low pressure (biobased) chemical industry can develop more decentral. Also, Northwest European countries could prefer to develop and control their own points of import into the area (for of geopolitical reasons; see next point).

Third, the amount of (geo)political power play associated with developments in the (global) energy market is underestimated in the Netherlands and the Port of Rotterdam. Developing international shipping routes and becoming a dominant hub require building international coalitions. The Netherlands and the EU do not yet have a (geo)political energy agenda regarding hydrogen that could support these strategic interests of Rotterdam. For example, energy dependency does not play a role in current energy debates. In contrast, for many other countries, economics is politics. For example, China is trying to become more dominant in the ports of Southern Europe. For them, economics is politics not just business.

Fourth, Rotterdam may also not be the ideal place for large-scale hydrogen production and storage. When wind farms are increasingly developed away from the shore into the North Sea, these remote locations will be closer to other regions, for example Groningen, for their power cables to make landfall. Furthermore, Rotterdam is well connected to the current gas infrastructure, but is not as central as, for example, North Netherlands/North Germany, where a dominant north-south natural gas network originates and extends into Europe. Rotterdam also does not have access to large salt caverns in contrast to, for example, Groningen or Hamburg[41]. Although Rotterdam has some connections to natural gas production pipelines into the North Sea, most existing pipelines that could be repurposed make landfall in the province of North Holland.

Lastly, the "societal license to operate" of the cluster in the energy transition is much more fragile compared to other (national) clusters. This could hamper the capacity to invest and attract subsidies for green hydrogen. The pressure to reduce carbon emissions or to take bold steps away from fossil fuels can intensify quickly and unpredictably. A recent example of such a swift buildup of pressure is the decision to stop extracting natural gas in Groningen and the response to develop the NorthH2 project there. The window of opportunity to transform the current fossil fuel cluster, then, might be much more limited than generally thought.

First a multi-track approach, develop focus later

As will be discussed in the next chapter, the best strategy for Rotterdam now will be to invest in all four future energy hubs: usage, production, import, and trading. From earlier transitions, we learned that early in the transition, it is important to keep options open and also invest in regret options, as uncertainty makes it impossible to pick winners early on. As the transition progresses, however, hard choices will need to be made. These choices are about which hub functions Rotterdam develops opportunities to really establish a strong position over time, but also about what in the end will be most important for the Port of Rotterdam. For example, does the Port prefer to guarantee green hydrogen supply to industry above all, even if this means supporting another location to produce this green hydrogen? These questions might become more pressing on the short term if a joint Northwest European strategy is to be pursued (see Chapter 7).

Textbox 5

SWOT of Rotterdam's position to develop low-carbon hydrogen

Strengths	Weaknesses
→ International leading position as energy and container hub, with strong ecosystem including global (petro)chemical leaders, including specific advantages in fuels such as LNG and oil products terminals, processing, storage, and trade.	→ Balancing a triple track strategy – current fossil fuel (gray), blue, and green routes.
→ Infrastructure to accommodate large-scale shipping and industry, including international natural gas (LNG), (petro) chemical and private hydrogen pipeline infrastructure.	→ Existing hydrogen users (and the cluster in general) operate in highly price-competitive and fossil markets, with sunk investments in gray production and private pipelines.
→ Large already existing and large potential market for hydrogen in the cluster.	→ Lack of large-scale underground hydrogen storage options nearby.
→ Synergies from developing blue hydrogen parallel to green (infrastructure, oxygen, value chains) and from CC(U)S in general.	→ Dependent on shipping routes and more centralized development for the import of hydrogen, weak geographic position for long-distance intercontinental pipeline transport.
→ Competitive "soft" conditions, such as nearby (energy-chemical) knowledge, research, and workforce, political stability, etc.	→ The Netherlands is not a geopolitical "power player" in global politics and the energy economy.

Opportunities	Threats
→ Proximity and connection to the North Sea, including landfall[42] points with existing and future offshore wind farms.	→ Many other landfall points are possible for electricity and/or hydrogen from the North Sea, especially in the long run.
→ Infrastructure developments in the Netherlands (creation hydrogen "backbone") and existing natural gas network that can be used for distributing and sourcing hydrogen.	→ Rotterdam competitive edge as current fuel hub, but other regions have other competitive edges such as Groningen (position in natural gas network), Antwerp (position in chemical networks), etc., so Rotterdam's edge may not be a decisive competitive edge
→ A hinterland with a large existing and large potential hydrogen demand and a sustainability-conscious hinterland.	→ "Invisible" investments in hydrogen due to competitive reasons hamper collaboration in the cluster, but also ensure developments elsewhere are underestimated.
→ Option for a diversified strategy with multiple hubs that can be developed: usage, production, import, and trading hubs.	→ Geopolitical considerations in Rotterdam's current and potential hinterland (e.g., wish to have own terminals/conversion parks).
→ Potential incentives from different government levels with ambitious climate goals (EU, national, etc.).	→ A fragile "societal license to operate" could hamper hydrogen developments.

Chapter 5

Rotterdam's window of opportunity to become a first mover

In the previous chapters, we outlined Rotterdam's opportunities to become a green hydrogen hub in an international context. However, there is also a time dimension to this opportunity. From historical transitions, we know that new industries do not necessarily settle at the same location as others. And existing industry often struggles, or often even fails, to transform themselves to keep up with the transition.

In addition, as we outlined in the previous chapters, location is determined not only by logistic and geographic advantages but also by geopolitics. For example, the current petrochemical cluster was established in an era of strong belief in opening the borders and international trade, at least in the Western world (see also **Textbox 7**). In the current era, geopolitics between, but also within, economic, and political blocs might lead to highly different outcomes being unfavorable for the Rotterdam cluster.

From past transitions and from Rotterdam's port and industrial history, we can also learn about the importance of frontrunning. Although transition dynamics can be whimsical, and moving first is not without risk, it often establishes a decisive competitive advantage in becoming a dominant hub. Rotterdam has proven this point throughout its history by showing leadership and in being a first mover in deep water ports, direct transshipment, establishing a fossil fuel industry and logistics hub, and investing in Europe's first large-scale container terminal (see also **Textbox 7**, **Textbox 8**, and **Textbox 9** in the following chapters).

If we consider the current hydrogen developments in this light, Rotterdam faces the serious risk of missing the opportunity to become a frontrunner. Although the current pace of developments is substantial, it is largely before final investment decision, in some cases in the phase of feasibility studies, in other cases closer to a decision with the first major indicative final investment decisions moments next year. Regardless of how understandable the hesitation for large investments under uncertainty is, the window of opportunity for a leading role is closing fast. What is lacking is a sense of urgency.

This sense of urgency appears not to be widely shared in the Rotterdam cluster. The current cluster has a strong tendency toward efficiency, optimization, and incremental change, which is logical when focusing on keeping the status quo (see also **Textbox 6**). However, becoming a frontrunner in low-carbon hydrogen requires leadership and the development of a smart, multifold strategy. We identify four principles for this leadership in taking a frontrunner position for the Rotterdam cluster:

Nice to have → Need to have
Low-carbon hydrogen should be seen as one of the few lifelines for Rotterdam to remain an energy (carrier) hub at the current scale—a lifeline Rotterdam cannot afford to miss.

Wait-and-see → Proactive
It requires a shift in focus from the risk of jumping too early to the risk of jumping too late.

No regret → Regret
Being proactive and taking risks also imply going for both public, private, and public-private investments under uncertainty, as no risk-free "no-regret" scenario exists.

Each for himself → In cooperation
In the current highly competitive culture, there is much hesitation to share and widely collaborate between industrial partners; however, to create the right conditions the focus should shift to a joint challenge to create societal support and policy conditions together.

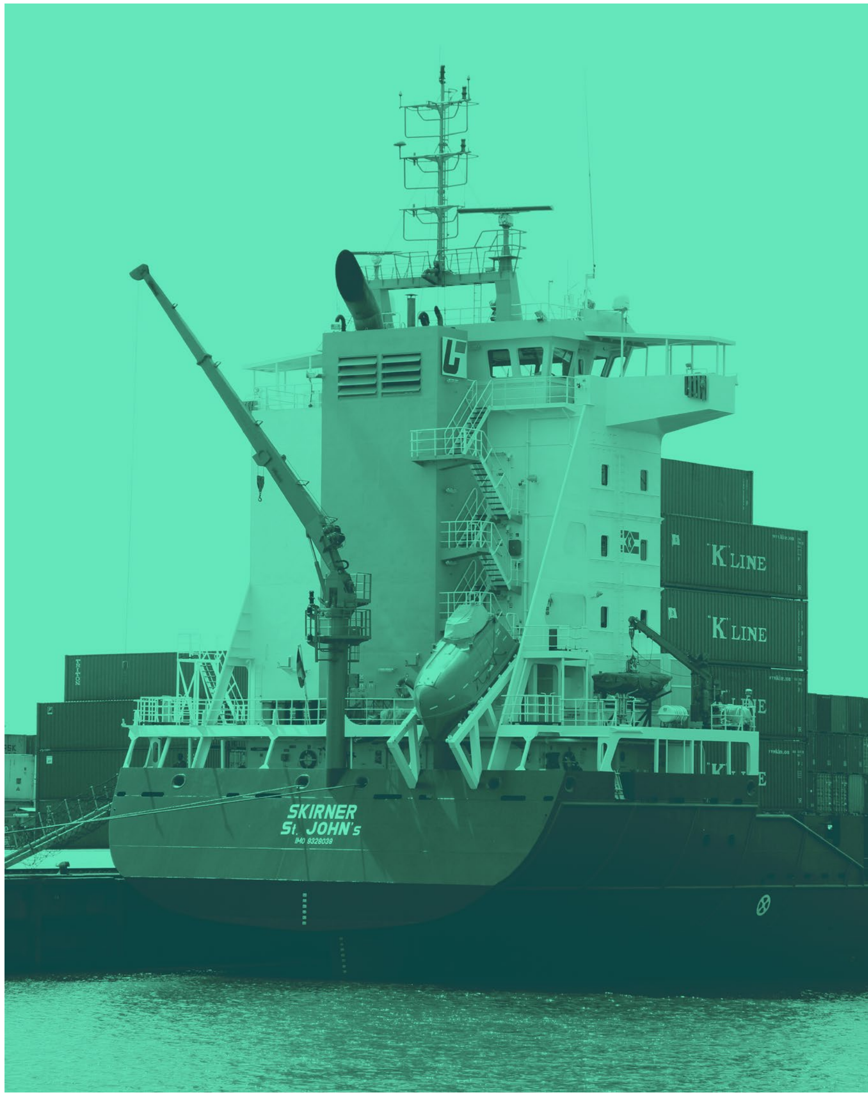
In the following chapters, we will apply these general leadership principles to four potential breakthroughs: **1** reorienting existing subsidy frames into a "transition proposition" from industry to government and society; **2** scaling up national strategies to at least a Northwest European regional strategy, addressing the necessity of importing energy [carriers]; **3** creating green hydrogen markets and infrastructure into the hinterland; and **4** being a first mover in a European green hydrogen shipping route.

Textbox 6

Institutional & psychological barriers

Emblematic for the discourse in government and industry about making the transition to low-carbon hydrogen is the focus on technological and economic barriers that need to be overcome. However, even – or perhaps especially – in the highly competitive physical industry, the institutional, psychological, collaborative hurdles and similar barriers are also impediments that need to be tackled but are often overlooked. Among others, the barriers for the Rotterdam cluster to become a frontrunner in the green hydrogen economy are –

- the current paradigm of a competitive advantage of the cluster through an utmost process of optimization. In markets, competition can take various forms. The current Rotterdam chemical cluster is largely oriented to compete on process efficiency and reliability. However, the focus now should be on collaboration and building hydrogen chains together on an international level. Competition still exists, especially on a global level, but to make Rotterdam a dominant hydrogen hub, a joint effort is needed.
- the current paradigm of competing individual sustainable energy sources, for example, on price or for subsidies, instead of complementing the nature of different sustainable energy sources/carriers at a systems level.
- the current paradigm of the government and financial instruments to focus on technological innovation instead of a focus on upscaling – governments tend to invest in developing technology, whereas green hydrogen requires investment in upscaling and price reduction.
- the current paradigm of a competitive advantage through obfuscation: in this highly competitive industry, investments are kept secret as long as possible, which hampers joint action and also provides the mental space to underestimate hydrogen developments in other clusters. The sense of urgency could be increased by greater transparency, a common vision, and goal setting by the government or Port Authority.
- the current paradigm of self-sufficiency and national energy systems, instead of inevitable import and an interwoven Northwest European energy system.
- the current paradigm of competition and that Rotterdam will be unchallenged as the largest port in Europe, instead of collaboration (to develop hydrogen) between port and industrial clusters in the Le Havre-Hamburg range.



↑ Haven van Rotterdam by Bert Knot / Colors modified from original

Chapter 6

Reorient subsidy instruments into a transition proposition from society, government, & industry

The challenge: A need for public funding, but a politically difficult message, requiring a broadly supported societal deal

For all parties, it is clear that without any form of government support or intervention, the low-carbon hydrogen economy is unfeasible, not only because fossil fuel alternatives are currently outcompeting low-carbon hydrogen but also because green hydrogen is not competitive with, for example, the direct use of renewable electricity in the national grid (most of the time under present conditions). Hence, a call for government intervention is needed, especially because hydrogen will become an essential balancing mechanism and energy import carrier for the overall energy system.

Although from an economic and systems perspective the arguments for immediate strong action are compelling, from a political perspective this will be a very challenging message. Amongst the barriers to move from economic rationale to the political creation of broad societal support are:

1 **The system price** – Costs for hydrogen and a hydrogen infrastructure may reflect a "system price"—the price for balancing the energy system of a whole region. At the moment, virtually all subsidies of renewables or other CO_2 reducing measures aim at optimal solutions for only part of the energy system. It will be a difficult message that the initially high subsidies for hydrogen will not benefit only the direct users of hydrogen, but also everybody benefiting from a balanced energy system as a whole.

2 **No immediate CO_2 savings for green hydrogen** – Paradoxically, while hydrogen is a crucial element for a long-term CO_2-neutral future, in the near future there will be no CO2 reduction or even, depending on the method of calculation, a negative effect. In earlier cases of introducing renewable technology, the CO_2 savings have been immediate, even if modest and against very high costs. For imported green hydrogen, there might be direct CO_2 savings elsewhere (but this does depend on whether overseas-produced renewable electricity, if not used for hydrogen, will be fed into a local electricity grid).

3 **Funding future energy dependency and international chains** – Whereas many other developments that are being subsidized have an implicit or explicit promise of energy independence in them, the future of hydrogen may very well be in international chains as a necessary complement to the limited potential for energy production in Northwest Europe itself. This means that directly or indirectly, public money will be invested in production elsewhere. By itself such a spillover effect is not new, e.g., many other energy subsidies have benefited foreign industry producing the necessary equipment, varying from windmills to solar panels and household boilers. But investing in infrastructure and production facilities outside national borders is new.

4 **Subsidizing upscaling** – Although more fundamental R&D activities certainly play a part in upscaling low-carbon hydrogen, much of the investment falls between the R&D phase and the phase of subsidizing the "most bang for the buck" (e.g., CO_2 avoided per euro). This by itself is not new and can be considered part of the well-known "valley of death" in technology innovation (the phase between R&D and profitable commercial operation). Earlier subsidies have bridged this valley for the upscaling and thus optimize and cost reduction of offshore wind production.

5 **Subsidizing first-mover advantage and lock-in prevention** – lastly, and more overarching, from the previous four points, it is tempting to adopt a "wait-and-see" approach to the large-scale funding of hydrogen. In the long term, however, this may worsen these barriers; if a first-mover advantage is lost, it is very well possible that public support is still necessary but will even less likely lead to investment within domestic borders and less autonomy in choices of the future energy system. Also, waiting too long can lead to the need in some cases to make two transitions instead of one transitions. For example, electrification might in the short term be cheaper for many applications that can use both hydrogen or electricity as final energy carriers. But this can also lead to a costly new lock-in, where there are more electricity applications, as renewable electricity will be available in Northwest Europe.

These communication barriers do not mean subsidizing low-carbon (or the import of) hydrogen is a flawed idea. It does mean there is a need for subsidizing, or otherwise funding the difference between market price and production costs, that is very different from what we have experienced in the last few decades. Thus, at the very least, we need a very different message. Such a message also needs to include attention to other benefits then sustainability alone and must be coupled to economic opportunity and job creation. Moreover, such funding must address the entire (inter)national chain to be successful, as funding single links (e.g. activity of one company) does not necessarily add up to a business case that is positive for all participants in the chain.

This is a challenge that cannot be underestimated because reliable, stable public support will be needed for many years, or even decades, far beyond a single political term at any level of government. More is thus required than a one-off political success, and more is required than only a communication strategy. Although a strong joint industrywide proposal or signal would certainly help.

Strategies toward novel financing

How to overcome these challenges in financing the transition toward low-carbon hydrogen has been discussed several times in the "arena group," providing input to this document. From these various dialogs, multiple possible strategies (and combinations thereof) emerged, going beyond communication strategy without clear consensus in this phase. These possibilities are as follows –

1 **Certification and trade-ability** – Make the sharing of both costs and benefits go beyond the places where hydrogen is produced (or imported) and used. For example, if a certain industry agrees (or is regulated to) replace a certain percentage of gray hydrogen, for low-carbon hydrogen, industrial clusters with surpluses of renewable hydrogen can trade with clusters with shortages without the need to physically transport the hydrogen. Also, a certification and change in European regulation that allows using green hydrogen in refining, to offset lowering the number of biofuels mixed into fossil fuels (the RED directive), could be a novel approach to fund green hydrogen. Besides adapting existing obligations to use renewables to allow for low-carbon hydrogen, a new obligation for renewable shares could also be introduced once certification is in place, for example, an obligation for major users of hydrogen for a certain percentage of low-carbon hydrogen of their total hydrogen demand.

2 **Internationalize financing** – If hydrogen chains and the benefits of investing in green hydrogen become international, a logical implication might be to also form international coalitions of both government and industry to fund such investments.

3 **Public investments result in public ownership** – Current sustainable energy production subsidy has a division of roles in which, greatly simplified, industry bears much of the risk to make investments, and governments guarantee they will cover the gap between sustainable production costs and market prices, and, in some cases, some infrastructure is publicly provided. Depending on the willingness of business and government to invest, but also societal preferences, these roles could be altered. For example, instead of guaranteeing a subsidy for produced energy, governments could also co-invest by becoming a shareholder or setting up investment funds.

4 **Societal benefit (and cost sharing)** – There are other ways in which the benefits could be shared with society. One approach might be to share at least part of the imported or produced low-carbon hydrogen beyond industrial clusters. This can be done in two ways. In an early phase, the use of low-carbon hydrogen in relatively new but highly societally visible applications, such as passenger and transport vehicles, can be facilitated, which would also convey information about highly decentralized electricity buffering. A more conventional approach could be to mix hydrogen into domestic natural gas distribution networks. Mixing in hydrogen would allow the spreading of costs, either through regulation or consumer choice, where many consumers pay a small premium instead of concentrating costs with energy-intensive industry and the very concentrated associated subsidies. Of course, this would need to be traded off against the possibly overall higher costs and fewer benefits at a systems level of mixing in high value hydrogen into regular gas grid.

5 **Industrial end users sharing in final costs** – On the other hand, a breakthrough could be found in the thinking of current industrial hydrogen consumers as operating in a highly competitive international market with small margins and thus being unable to pay a premium price for low-carbon hydrogen (compared to the gray hydrogen cost). Not only would a small premium improve the business case and thus lessen the need for public support, but this would also be of great symbolic value. If this is not feasible for the current major users of hydrogen, niche or new industrial users of hydrogen could be sought.

6 **Joint proposal to government** – Industry can also step up in another way. Many individuals and small coalitions already give important signals with (pre) feasibility studies on the willingness to undertake and invest in projects, but there are very few to no industrywide joint signals, especially about financial conditions. A sector-based or chain-based proposal is needed for green hydrogen. This culture of individual action and joint ventures, including secrecy in early phases, is understandable due to the business strategies in the chemical industry that were employed very successfully in the highly competitive past in a growth market. However, if these small coalitions do not have enough momentum to make "grand deals" with the government, it can delay actual investments for years and thereby severely weaken the potential of building a hydrogen ecosystem. The other risk is a "wait-and-see" strategy from both sides. Industry as a whole leaves the responsibility to take initiative in a financial arrangement largely with the government, or expects to shop between the offers of different governments, and influences the government on a more individual basis. But from the others side governments are cautious about financial and political risks in the absence of a strong joint industry proposal and will also not take the initiative.

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Paths toward funding

From these strategies and their combinations, different ways to accelerate the transition toward low-carbon hydrogen can be identified and become part of a strong signal proposition toward the government. Of course, there are paths that do not lead to acceleration. If both government and industry do not step up, the most plausible scenario is "wait and see," where the Netherlands and Northwest Europe leave the initiative to frontrunner markets until the international market has made electrolyzers and green hydrogen prices competitive, there is plentiful renewable electricity in the national grid and elsewhere, and global shipping routes at competitive prices have emerged. There are two paths that would avoid the pitfall of minimalizing direct public costs but (likely) missing climate targets and losing the chance of gaining the long-term economic benefits of a frontrunner position in hydrogen.

A path close to current funding and earlier experience (SDE++ special category)

Offshore wind is a clear example of years of relatively stable public support leading to a front runner role in developing wind farms at sea for our region. Eventually, this public support allowed upscaling, which dramatically lowered costs to the point where little public support is still needed. This might provide a basis for fast tracking of the funding of low-carbon hydrogen. Especially for blue hydrogen, where public support has a direct CO_2 reduction effect, this might be the obvious route. For green hydrogen, this is also a possibility, but it would require a dramatic reframing of the scope of the current SDE++ funding scheme of the Dutch government—a reframing from financing CO_2 reduction to (also) funding technology upscaling. At the very least, this would require (imported) green hydrogen to be an exception category within the larger SDE++ framework. This exception to the general SDE++ framework may also make it a quick but vulnerable path to funding.

A more novel path: An (inter)national public–private partnership

An alternative path for government would be to play a much more active and flexible role as upfront investors through, for example, a public investment fund or a joint public-private investment fund. What would set this investment fund apart from other investment funds would be the willingness, especially early in the transition, to, in many cases, lose the original investment (as technologies are not yet competitive).

Such investment funds might also have much more flexibility to arrange tailormade funding schemes for specific challenges in the transition to low-carbon hydrogen, ranging from R&D grants to equity participations and loans.

Of course, such a funding mechanism would significantly increase the risk sharing of government with private parties, but in return, governments will also share in the benefits—a large or even controlling share in our future energy system—generated by those projects that eventually become commercial. The public interest could also be served by requiring any resulting IP and other know-how to be made widely available for licensing at reasonable prices.

Another possibility would be to "upscale" this public-private mechanism to the international level, given the at least regional nature of a future energy and feedstock system. For example, if Rotterdam profited from becoming a hydrogen import port, Germany would profit from using the hydrogen and supplying the electrolyzers, and a third country would profit from locally producing this hydrogen, the three countries could come to a common financing scheme. This kind of ad hoc funding could grow into a more institutionalized joint financing, for example, a large international investment and grant fund, or such a platform could be established immediately. This would also allow coordinating different funding mechanisms for different countries. For example, if hydrogen (or electricity) is produced in the south of Europe and used in the north of Europe, southern funding could rely more on economic support from the EU and northern funding more on national funding. This may also create the volumes of public investment needed.

Chapter 7

Face the need for energy imports, & actively develop hydrogen trade relations

The challenge: The Port of Rotterdam as an import hub

It is highly unlikely that the total future energy demand will be sourced only locally or regionally, as outlined in Chapter 2 and Chapter 3. The importance of hydrogen imports is also recognized in the recent hydrogen vision of the Dutch government and the Port of Rotterdam itself. It emphasizes the strategic importance of hydrogen for the Port of Rotterdam as a hub in the global energy system and the potential for the Netherlands to become a hydrogen supplier for neighboring countries.

Next to the importance of being a first mover in establishing this role as a hydrogen hub (see Chapter 9), in the long run, a secure supply of imported hydrogen is needed to become a large user, import, and trading hub. However, Rotterdam faces several local and global challenges. Locally, the challenge is to find support for this pathway as it potentially competes with local Dutch hydrogen production based on renewables and developing blue hydrogen (Porthos). However, these can also be considered complementary developments for a resilient energy system. Although not exclusive to becoming an import hub, the challenge will also be to find demand for low-carbon hydrogen in the cluster or in the hinterland, despite the current dominance of gray hydrogen production and infrastructure.

On the global level, Rotterdam faces even more pressing issues. First, it is far from certain that hydrogen will be a globally traded commodity and in what form it will be traded (liquified, ammonia, LOHC, etc.). It is also possible that trade will be developed only within regions mostly via pipelines, or, just like the LNG market, it might also take decades before a global hydrogen market is developed. And even when trade is developed, Rotterdam might not be much better positioned than other ports in Northwestern Europe. For example, interregional trade could be done via small ships – for which the Port has no advantage – and further distributed via regional pipelines to its users.

Moreover, the energy transition could redraw the geopolitical map and transform global power relations drastically when fossil fuel trade flows change[43]. In this new era, sustainable energy flows such as hydrogen may become the arena of geopolitical powers. Energy and oil developments have dominated geopolitics for years, and for the future carbon-free energy trade, this will not be any different. Import dependencies will need to be managed through diplomacy. Bilateral deals where common interests, such as stability and security, are made to shape the energy agenda and trade routes.

As hydrogen can be produced by various renewable (solar, wind, hydro) and non-renewable resources (coal, oil, gas), important dependencies might shift or even be reduced. Countries with multiple options to produce hydrogen—with access to both renewables, non-renewables (gas) and CCS—will play a decisive role in the development of hydrogen. Still, ultimately, for low-carbon hydrogen trade factors, such as the availability of renewable sources and CCS solutions, international trade agreements and corrective tariffs of the EU on carbon emitting hydrogen will impact the way roles are distributed.

This raises questions for Rotterdam/the Netherlands and also for Europe. How can a diversified network of supply lines be established? From which regions could you become dependent, and with which regions or countries should you want to cooperate? Such considerations have been important to establish the Port of Rotterdam we know today but will be important for the change of fossil fuels to renewables as well. Two schools of thought seem to exist here: Either hydrogen will liberate us from the current fossil energy dependencies, or such a scenario is undesirable, as it will weaken the stability of some countries or even regions.

Either way, the dominant thinking in Rotterdam and the Netherlands seems to be that investment decisions are largely based on viable business cases and not (long-term) political arguments. For example, a “new” power like China invests in South European ports, including Piraeus, as part of its political agenda to gain influence and power in its trade with Europe. But other European ports will try to import hydrogen for reasons other than business cases, such as national interests backed by hydrogen strategies. Thus, Rotterdam as a “logical” or “cost-efficient” location might simply not be enough in a new era of strong geopolitical tensions around global sustainable energy flows.

Leadership: Developing trade relations and a geopolitical agenda for Rotterdam as a hydrogen hub

Leadership is required to face these global and geopolitical challenges while simultaneously undergoing the energy transition locally in Rotterdam. The strategy is not to wait for other countries to generate a large amount of renewable energy, produce hydrogen, and then start thinking about smart ways to ship it. Rotterdam should actively develop trade and production of hydrogen abroad simultaneously, thereby using, but also developing, the strength and knowledge of the cluster. It should play a leading role in the development of hydrogen globally and locally.

The proactive and simultaneous development of hydrogen production in sourcing countries and its trade will be a regret strategy that partially tackles the previously discussed risks on a global level. Notably, it helps to tackle the risk of a slow or even absent supply of low-carbon hydrogen production beyond national capacity, and it increases the chances of hydrogen being shipped to Rotterdam and not to other places. In developing such trade relations, Rotterdam (and the Netherlands) has much to offer – it has extensive knowledge and expertise in developing maritime and port infrastructure, especially in response to challenges like digitalization, digital security, sustainability, climate change, water issues and energy transition. In time, the cluster could also export knowledge on developing blue and green hydrogen chains or could learn from its involvement in developing these chains abroad.

Additionally, Rotterdam could use its current strong international (trade) network to establish these hydrogen trade relations of tomorrow. Current fossil fuel trade routes could be replaced by hydrogen trade routes, as hydrogen offers a diversification path in the future to, for example, countries in the Middle East, although this maintains current trade dependencies. The first step could be the production of blue hydrogen through excessive gas reserves, parallel, and learning from/for blue developments in Rotterdam. In the second phase, when the renewable energy potential is realized (e.g., solar in deserts), vast amounts of green hydrogen could be produced. Partnering countries are those with similar development potential, such as Kuwait but also countries like Norway. Thus, developing hydrogen trade relations starts with active engagement in the development of hydrogen infrastructure and production.

However, actively being involved in developing trade also implies being involved in geopolitical powerplay around sustainable energy flows, and Rotterdam needs to be prepared for this. European ports are the same dot on the global map, and the large Port cluster in Rotterdam is only part of a small country. Without leadership, the different European ports and industrial clusters will respond individually to the pressure from global players and compete to become the regional leader for hydrogen, backed by their protectionist governments.

Rotterdam is likely to be much better off if the pressure from other global players can be channeled into a regional Northwest European collaboration. This will require leadership of the Port of Rotterdam – first, in setting the agenda and establishing a strong vision for the region and establishing strategic collaborations with other ports and industrial clusters. Such an agenda should do justice to the interwovenness of the region's current energy system, the shared need for sustainable energy imports and could help overcome the (domestic) hesitation for greenlow-carbon hydrogen imports due to its high costs. From an energy system perspective, the costs of importing hydrogen from outside the region (and most likely outside Europe) should be compared primarily to the costs of alternatives to import sustainable energy rather than the costs of producing local variable renewable energy.

Such a vision and collaboration should initially invest in all options, including options that might later turn out to be "regret" options: blue local production, green local production, import by pipe (from the North Sea) and by ship (intercontinental). In due time, however, a more collaborative approach might also require specialization between hubs in the region, including painful acceptance that Rotterdam might not fulfill each of the four hub functions. Building on its current strengths, Rotterdam may need to prioritize intercontinental import trade routes and the local use of hydrogen over local production under collaboration. Establishing the first hydrogen trade route/coalition could be key for this (see also Chapter 9).

Collaboration thus helps to deal with geopolitical pressures, but it could also support the role of Rotterdam as leader and booster of the transition and, in the end, as the logical hydrogen trading hub in the region or even the world. A feasible strategy would be to establish a port alliance for low-carbon hydrogen for institutional collaboration. In this alliance, European ports collaborate to establish shipping routes but may also include Southern European importation of hydrogen via pipelines from North Africa. Moreover, such an alliance should also include other global hydrogen players to learn from and develop the global hydrogen trade, such as countries in North Africa, the Middle East, or even Japan and Australia. The Port Authority can use the lessons and relationships from earlier initiatives in its collaboration and consultation with other overseas ports for such a process.

A more collaborative approach also requires specialization between hubs in the region

Textbox 7

Historical lessons from the establishment of a post-war chemical cluster in Rotterdam

In retrospect, Rotterdam, at the mouth of the Rhine, as the "main port" for the industrial heartland of Germany (Ruhr area) might seem to be the logical and obvious choice for establishing the current (petro)chemical cluster. However, directly after the Second World War, this was far from obvious, and it required a strong leadership role from the Dutch government to heavily invest in a paradigm shift in the chemical industry for the Netherlands.

The chemical industry was by itself not new for the Netherlands. However, most of the chemical industry, especially most employment in it, was relatively small scale and focused on inorganic chemistry. Moreover, even the organic chemical industry was traditionally "carbochemical": most chemical "building blocks" for organic chemistry were produced from coal, not oil. Even though (a predecessor of) Shell had been a frontrunner in pushing oil from fuel to the production of chemical building blocks, this was still a relatively new process. Coal was also available in the Netherlands, and the coal industry was already moving toward producing chemicals from coal. With Indonesia's independence, oil was no longer available in the Dutch realm. Especially for a better trade balance, using local resources was also very advantageous.

After the war, the government decided to radically break with past strengths and characteristics. From a long-term vision, the government made focused investments and other efforts into large-scale oil-based international chemical industry. This long-term vision sacrificed short-term employment and the rebuilding of small-scale domestic chemistry for attracting international companies. Oil was seen as the dominant energy carrier of the future (until the oil crisis). The Netherlands, and especially Rotterdam, had excellent long-term perspectives as a hub in global oil flows. This was not only a matter of geography, but also a reputation of a well-educated multilingual workforce, and with the prospect of a more united Europe (in 1951 the ECSC, the predecessor of the EU was founded), the Netherlands was also considered an ideal, neutral gateway into Europe.

Government efforts to attract foreign multinational companies to the Netherlands with subsidies, facilities, and very proactive lobbying of foreign companies were quite successful. Eventually, also fulfilled was the promise that, more than the old small-scale chemical industry ever could, a capital intensive, large-scale foreign "basic chemistry" industry would create much more indirect employment through services and a more advanced chemical industry attracted to the availability of refineries. These new foreign multinationals were also quite open to trade chemicals and energy between them, leading to a unique petrochemical ecosystem (whereas the incumbent chemical industry was much more hesitant to collaborate). This success story demonstrates the importance of leadership in industrial transitions to overcome resistance from incumbent interests and old paradigms.

This textbox is based mostly on *A.A.A. de la Bruhèze, H.W. Lintsen, Arie Rip, J.W. Schot, 2000, Techniek in Nederland in de twintigste eeuw – Deel 2 Chemie.*

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Expert Reflection 3

Hydrogen in Northwest Europe from a German Perspective

The role of hydrogen as an energy carrier and as a chemical component has already been widely discussed for more than two decades in Germany. Although hydrogen plays a relevant role in almost all available ambitious climate protection scenarios for Germany, views and positions still differ considerably regarding exactly how much hydrogen will be needed in the future and where and from what sources the hydrogen will or should be produced. For example, there is discussion on the ambition of total electrolyzer capacity installed by 2030 (3–5 GW or 10 GW). Also, the role that non-green hydrogen (blue/purple) should play in the early phase of hydrogen adoption is strongly contested. These different views and positions are also the reason why the National Hydrogen Strategy continues to be the subject of intense debate within the German government and between stakeholders.

> "Hydrogen production and industrial demand will be concentrated in the north and west of the country."

↑
Stefan Lechtenböhmer – Director of Future Energy and Industry Systems at the Wuppertal Institute & Adjunct Professor of Environment and Energy Systems at Lund University.

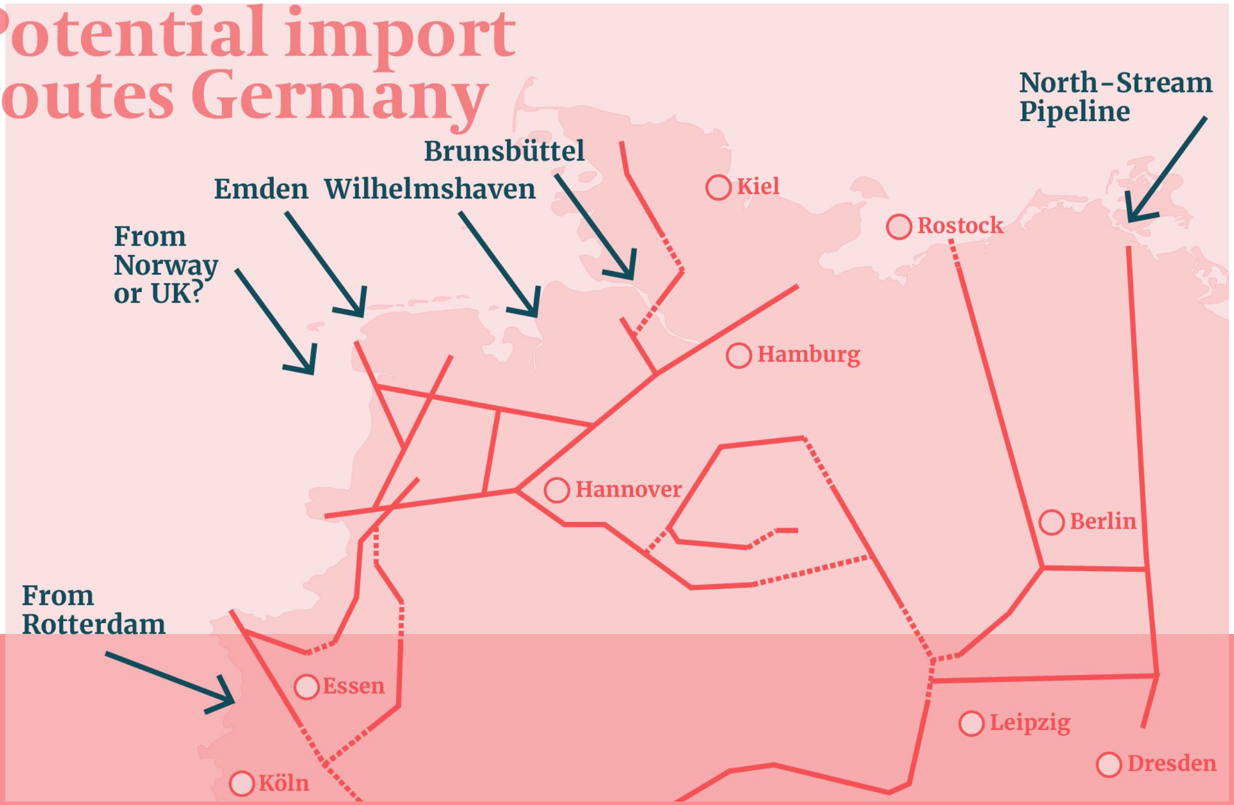
There seems to be broad agreement, however, that it is important for Germany to create a domestic market for electrolyzer technology that is large enough for German companies to be able to obtain a leading international role in manufacturing. Also, a compromise has been reached on the issue of where to use hydrogen: Applications that are already close to market and those that cannot be (fully) decarbonized through other means, as well as parts of transport will be favored. Hydrogen use for heating in buildings may follow 'in the long term'. Production and, particularly, industrial demand will be much more concentrated in the north and the west of the country. Many of the announced hydrogen projects are also situated within a 50-km corridor along the Dutch border. For the next few years, it seems probable that the speed of industrial demand ramp-up will be decisive in determining the amount of hydrogen that will be used in Germany.

Where the hydrogen could come from

Due to limited domestic potential for renewable electricity generation, an increasing number of voices and studies point toward the need to import a significant share of Germany's future hydrogen needs. Potential sources for blue hydrogen could be the Netherlands, Norway, and Russia, all of them well connected by strong pipeline infrastructures. Green hydrogen could be imported from many regions, but in particular the North Sea and countries in the Middle East and Northern Africa are often cited. For example, recently an industry alliance "Desertec 3.0" has formed to explore the potential import of green hydrogen from Morocco.

Hydrogen that is imported via ships could potentially enter the gas system via a number of ports, ranging from Emden and Wilhelmshaven in the west (both well located in →

Potential import routes Germany



←
Figure 6
Potential import routes of hydrogen and distribution via a future hydrogen gas grid in the northern part of Germany.

terms of pipeline and storage infrastructure) to Hamburg and Brunsbüttel in the north, which could serve regional industrial clusters. Wilhelmshaven and Brunsbüttel have the greatest water depths and already have operating or planned LNG terminals. However, imports via pipeline from Rotterdam or other Dutch ports are also conceivable, with Rotterdam being geographically the closest to the potential demand cluster in the Rhine-Ruhr region.

Strategic entry points for Rotterdam

Although some fog is lifting over Germany's future hydrogen plans, many possobilities are still quite open and not many shovels have so far been put into the ground. For Rotterdam, this means that key projects of the German hydrogen future still need strong partners – a situation that might offer good entry points for future collaboration. Technically, it seems obvious to Rotterdam to expand the pipeline connection with the Rhine-Ruhr region, either strengthening the direct route or using the already strong connection via Groningen. Creating a pipeline connection is probably an important prerequisite for an extended hydrogen exchange with Germany and could mutually reinforce other hydrogen developments.

An early entry point for Rotterdam could be the provision of blue hydrogen produced in Rotterdam, despite existing reservations by some German stakeholders. Norwegian and some Russian players are currently trying to develop a blue hydrogen trade, but they are faced with the disadvantage of significantly larger distances. For green hydrogen, two routes exist. First, overseas acquisition of green hydrogen would need strong and experienced partners like Rotterdam in setting up transport and value chains. This route would be particularly attractive if the overseas production sites were to become important electrolyzer markets for German technology providers. Second, green hydrogen from the North Sea area requires the development of hydrogen production and logistics. But here Rotterdam players probably face strong competition from Germany and other North Sea countries. Lastly, Rotterdam could also play an important role as import and production location on the side of hydrogen use. Although still very uncertain, it may well be that synthetic fuels and synthetic chemical feedstock made from green hydrogen will become an important part of greenhouse gas mitigation in, for example, the transport sector and chemical industry, thereby benefiting from the already existing hydrocarbon-pipeline connections.

Given these diverse potential entry points to the German hydrogen market for Rotterdam, it seems clear that existing strategic cooperation with German players should be expanded. For this, the planned hydrogen IPCEI (Important Projects of Common European Interest) would be a good crystallization point. The German government is planning to take a leading role in this IPCEI and will probably put a strong focus on the northern and western part of the country, from where collaboration with the Netherlands and Rotterdam seems natural. Therefore, many of the options discussed above could be welcomed and realized under this framework.

Chapter 8

Create demand outside the box

The challenge: The Rotterdam petrochemical market has no place for green hydrogen

A third challenge in realizing a green hydrogen economy is the apparent lack of demand. Potential producers do not yet see a market for green hydrogen because, pricewise, it cannot compete with current alternatives. Low-hanging fruits are primarily sought in replacing gray hydrogen markets in the petrochemical sector, both as product and fuel.

Green hydrogen is more costly to produce than gray hydrogen. Companies that already use (gray) hydrogen within the Port cluster today, such as refineries and fertilizer producers, are not easily convinced to go for green. The current petrochemical market is driven by small margins on bulk production and sales. In addition, the benefits of investing in greener products are not (yet) of interest in this business-to-business market. Both elements reduce the likelihood of making a business case for green hydrogen.

Leadership: Proactively create markets outside the current context

Leadership makes a difference. Instead of waiting for markets to arise, a proactive and entrepreneurial attitude is required – new markets can be created by collaboration with promising partners outside of the usual context. Leadership means proactively identifying promising markets and developing products and supply chains in collaboration with these potential customers. Leadership means looking for promising niche markets where the benefit of greener fuels is valued and where higher margins are affordable. Leadership means investing in multiple potential markets parallelly to spread opportunities and to scale up the volume of green hydrogen demand by combining smaller demands first.

These principles can be translated into concrete strategies. On the one hand, new markets can be found outside the Rotterdam area and in niche markets, and on the other, within the Rotterdam area, new ways of working can be implemented.

Approaching new markets – Leadership is demonstrated by looking for new and promising markets for green hydrogen outside the scope of the Rotterdam Area. The current position of Rotterdam, as an important supplier for the German hinterland, gives access to a large and diverse network of businesses. Among these businesses and their networks will be potential customers of green hydrogen. These can be companies that already use (gray) hydrogen but are mainly niche businesses. In a developing market, the type of infrastructure, fuel types, and market dynamics are still open to suggestions and experiments. Companies that have an interest in emission-free raw materials or fuels and have a business model that allows for a higher market price of green hydrogen are the most promising. By proactively promoting low-carbon hydrogen to these new markets, demand can be developed. One such example could be hydrogen-fueled (inspection-) drones[44].

The Port as business partner/co-developer – Leadership is shown when potential customers are proactively approached as partners. By developing a product and supply chain as a partnership, risks are shared by delivering certainty based on a shared future vision. Certainty of an expected demand, on the one hand, and of a made-to-measure supply on the other.

This approach has previously shown its benefits. When the Port of Rotterdam made the transition from a harbor based on manual labor into a mechanized transit port, the promise of becoming more efficient and being able to scale up transit volumes was a shared interest of the Port, the Rotterdam municipality, and businesses (see **Textbox 8**). This led to the introduction of mechanized loading systems based on shared investments and the commitment of these three parties.

One promising example of co-development today is for the Port of Rotterdam to invest in hydrogen infrastructure. In collaboration with committed users and with governmental support, existing pipelines can be bought and adjusted in order to transport hydrogen from sources to users. Together with stakeholders of, e.g., new mega wind parks at sea, the Port can designate areas for electrolyzes and/or landing sites for energy and hydrogen from sea. Additionally, the Port can invest in hydrogen-fueled ships (e.g., via the Future of Shipping Projects) and trucks to enable transport over longer distances.

This is how leadership is shown, by breaking through the waiting game of who steps in first by delivering an infrastructure together with governmental support and businesses. By making this infrastructure available, other industries are stimulated and more likely to follow the Port's lead[4].

4 The firsts steps are already being taken today. Shell and Port of Rotterdam are planning to invest in hydrogen production and pipelines. See here.

Benefits for hydrogen experiments – Leadership is shown when creating small breakthrough coalitions for hydrogen innovations within the Port of Rotterdam area to create demand.

When there are local parties with an interest in using green hydrogen, the market should be actively stimulated by creating the right preconditions. The Port can take the lead in creating a local hydrogen ecosystem where experimentation, production, and applications of hydrogen are being developed. This includes designating actual space for experimentation with hydrogen production and use, giving priority to hydrogen-related innovations in niches, and for example, asking local industries to consider using green hydrogen.

Current examples include the RH2INE Project, where a climate-neutral corridor between Rotterdam and Genoa is realized, based on hydrogen-fueled road, water, and rail transport.

Textbox 8

Historical lessons from becoming a mechanized transit port

At the end of the nineteenth century, the Port of Rotterdam invested in the mechanization of transfer practices. During this time, several practices show us how leadership makes a difference when facing an uncertain demand.

Changing perspectives

Ir. De Jongh, founder of the “Dienst Gemeente Werken”, is the visionary engineer who foresaw Rotterdam becoming a large-scale transit port. This future vision opposed the prevailing image of Rotterdam as a social trade hub for the elite and was met with resistance. Nevertheless, Ir. De Jongh radically argued that global developments (industrialization, steamships, etc.) asked for changes and introduced multiple radical improvements in the layout of the port area (Maasbekken, Rijnhaven, and Waalhaven were realized), which enabled inland vessels to quickly transfer their goods to seagoing vessels without using docks.

Facing shared risks together

An important step in the mechanization of transfer within the Port of Rotterdam was the introduction of grain elevators in the first two decades of the twentieth century. These systems were so efficient that they drastically reduced the number of jobs needed. This development was heavily protested by dockworkers in violent strikes.

In 1911, there were already some twenty grain elevators in the Port of Rotterdam, the result of a bitter battle between the workers and the various companies involved in grain transshipment, such as shipbrokers, factors, and shipping companies. The workers’ resistance had united the employers (in society to Exploitation of Floating Elevators), and together, they had overcome this resistance by mechanizing quickly and extensively. In 1911, grain transshipment was almost fully mechanized in Rotterdam, unlike in Antwerp, for example.

This textbox is based mostly on *H.W. Lintsen, J.W. Schot, 2002, Techniek in Nederland in de twintigste eeuw – Deel 5 Transport, Communicatie*

Chapter 9

Rotterdam as first mover in establishing hydrogen trade routes

The challenge: Staying relevant as an energy hub in a changing energy system

In Chapter 7, we discussed the leadership of the Port to build an international position as hydrogen import and trade hub. Here, we discuss how this ambition could be supported on the short run by being the first to establish a hydrogen trade route/coalition. Recently, the project "green spider" could provide such an opportunity by importing green hydrogen based on solar energy from Portugal[45].

Rotterdam is currently seen as an excellent hub for the energy and petrochemical trade and transshipment for Northwest Europe. It will be a challenge to maintain this role in a climate-neutral energy system. Other ports in the area, such as Groningen, Antwerp, and Hamburg, are actively researching the opportunities of green hydrogen as well. Second, because of the large-scale petrochemical industry present, Rotterdam is at risk of being considered a port bound solely to fossil fuels, a position that has no place in a climate-neutral future energy market. If the Port of Rotterdam believes green hydrogen will be key to maintaining a strong position in the Northwest European energy system, action is required today.
We see in historical examples that being a first mover in new markets has many advantages. Being the first production hub is uncertain because more hubs are working on these developments, and first investments are already announced. Being the first usage hub is possible because of the large industrial cluster where hydrogen can be used as feedstock, but only when a steady supply of green hydrogen can be ensured.

Leadership: Be a first mover in establishing a first green hydrogen carrier shipping route

As stated before, leadership requires a shift in focus from the risk of jumping too early to the risk of jumping too late. Being first mover in becoming an import hub is a challenge that fits with Rotterdam's identity and strengths as a transshipment port. Rotterdam as the first dot on the map importing green hydrogen could act as a flywheel to attract and develop other hydrogen trade-related projects in Europe and beyond, but this is essential to become a trading hub as well. In other words, the potential as an iconic or showcasing project is extensive. It also provides an opportunity to develop a trade-relational and knowledge advantage over competitors, to learn from the experiment on an operational level (e.g., how to transform the GATE terminal or build an additional import terminal?) and to establish Rotterdam as an international reference price for hydrogen. However, the value of the first-mover advantage and the right timing for such a move have not yet been determined. The main disadvantages of being a first mover are the high costs, as a solid business case is probably lacking, but also relevant is the uncertainty of the extent to which it would attract other collaborations. The challenge in achieving this position as the first import hub lies in the complexity of identifying the right partners, timing, and trading route.

True leadership of the Port in this pioneering initiative is crucial to overcome this complexity of possible supply routes and the large number of possibilities and uncertainties. Rotterdam will need to shift from "everyone for themselves" to "create the right conditions together." Leadership will share the narrative that convinces market parties to form a coalition, together turning Rotterdam into an import hub and beginning to develop hydrogen import terminals. As this coalition will be experimenting and taking risks, a high level of trust needs to be built. A long-term vision and commitment from market parties to be in the coalition for the long term helps to create this trust but also establishes a mindset of learning. The advantage of the Port over other parties is that it has a different risk profile and therefore could play a key closing role in financing the endeavor.

Concrete measures for such a coalition should include the following –

- → Financial Green Deal green hydrogen from a system perspective
- → Investing in blue hydrogen as a prelude to green hydrogen
- → Investing in various hydrogen hubs, with an emphasis on import and trade
- → Building a Northwest European green hydrogen network
- → Investing in new European and intercontinental trade routes
- → Developing trade relationships by linking import and production hubs
- → Lobbying for one joint Northwest European hydrogen policy

Leadership is required to show that idling until the business case becomes positive will certainly mean losing the first-mover benefit and that the risk of this loss does not compare to the risks related to participating in this coalition today. The Port of Rotterdam needs to show the extent to which it is truly committed to achieving this role as the first import hub of green hydrogen.

Textbox 9

Historical lessons from first-mover advantage in Europe for Rotterdam becoming a container hub

History shows us that leadership and a first-mover advantage were decisive factors in the Port of Rotterdam's success. When making the transition to a container hub, determined investing in niche developments, despite resistance, and strong encouragement of businesses to form a coalition led Rotterdam to become the first large-scale container hub.

Rotterdam was never a staple port and became specialized in direct, fast transshipment from seagoing ships to inland waterway, rail, and, later, truck transport (see Textbox 8). In the 1950s and 1960s, the need for container-based transport for "break bulk" (dry goods that cannot be handled as bulk goods such as grain or coal) became obvious. Ship tonnage increased dramatically, leading to ships spending more and more of their time in port to be manually loaded and unloaded. Railways already used standardized "transport boxes" as a clear example for the way forward. However, ship operators, stevedore companies, and other parties involved were very hesitant to invest because of lock-in in the current system. Any container system works only (or best) if the same standards are used over its whole journey. Although ship operators suffered from long loading and unloading times, they were reluctant to give up any space in their existing ships where containers would inevitably leave more dead spaces in the ships' holds. From this perspective, it is also understandable that early innovation in the Rotterdam port focused on using containers internally within the port to more efficiently shift cargo around within the port. "Roll-on, roll-off" solutions, where cargo trucks drive on to the cargo ship, were introduced for short routes. The container revolution started in the United States, with a pivotal role for the Sea-Land company, which demonstrated on short routes that throughput could be increased 30–40% with the same fleet of ships.

In Rotterdam, the CEO of the Port Authority, Posthuma, became interested in this new technology, made several visits to ports in the US, and arranged for the first containership to visit Rotterdam. Most stevedoring companies did not share the Port Authority's enthusiasm, given the very high investments needed. In contrast to earlier innovation in new cranes or similar equipment, a container terminal required an entirely new infrastructure. Rotterdam's previous strength had been direct transshipment from one ship to the other, whereas containers were transshipped indirectly. Two more innovative stevedoring companies (Thomson and Quick Dispatch), which had previously experimented with internal container systems, were interested. They announced a joint venture for a container terminal. Some remaining stevedore companies, now nervous to miss out, also announced a competing joint venture. The Port Authority, however, reasoned that because scale was such a necessity for success, they should all cooperate in one joint terminal. Although unclear, if true, the anecdotical story is that Posthuma gathered the decision makers of all stevedore companies in one room and threatened to keep them there until they agreed. This resulted in the joint ECT terminal. This terminal provided an unprecedented scale, which, along with other developments, was ridiculed by claiming those in the port were infected by "containeritus." However, this combination of scale, early mover advantage, as well as a culture of innovation and investment despite risks, gave ECT, and thus Rotterdam, a very strong position in the market. Another advantage was that labor unions shared the vision and considered containers a way to reduce the physical burden on workers. Conversely, in other ports, containerization was met with grim resistance from unions.

Of course, Rotterdam's geographic position would probably always have led to some container activity, but it may very well be that once the container market grew, and there was a shake-out in which some container terminals grew in strong hubs and other marginalized (or remained) to serve feeder lines, the early advantage of Rotterdam was decisive.

This textbox is based mostly on *Chemie A.A.A. de la Bruhèze, H.W. Lintsen, Arie Rip, J.W. Schot, 2000, Techniek in Nederland in de twintigste eeuw—Deel 5 Transport*. See for the evolution of container shipping network and hub formation: Ducruet, César & Notteboom, Theo. (2012). The worldwide maritime network of container shipping: Spatial structure and regional dynamics. GaWC Research Bulletin. 12.

Epilogue

In this final chapter, the floor goes to the participants of the arena sessions that led to this agenda. These experts from science, government, and business have shaped and strengthened the content of this report by openly discussing their perceptions of hydrogen development, reflecting on the role of the Port of Rotterdam and actively participating in the project by sharing their ideas, network, and knowledge. They will also be important to bring the message of this agenda forward. We want to thank you all sincerely.

In this arena project, the role of the Port of Rotterdam in current and future hydrogen developments was the central subject. This process led to a plea for leadership. Time is running out, and green hydrogen seems to be the only option for the Port of Rotterdam to remain the important hub it is today. We considered the position, opportunities, and risks for Rotterdam from a global, Northwest European, and local perspective and reflected on the leadership shown in the Port's historical transitions. We came to principles such as diversification, collaboration, and proactivity. Leadership is defined as an attitude where no-regret measures are replaced with regret measures, such as investing in multiple solutions simultaneously, even if there is resistance. A focus on the risk of entering the market too early should shift to a focus on the risk of being too late. Leadership is not about innovating autonomously but should be about working toward transition collaboratively.

These principles of leadership led to a concrete strategy for the leadership needs for the Port of Rotterdam –

- Financial Green Deal—green hydrogen from a system perspective
- Investing in blue hydrogen as a prelude to green hydrogen
- Investing in various hydrogen hubs, with an emphasis on import and trade
- Building a Northwest European green hydrogen network
- Investing in new European and Intercontinental trade routes
- Developing trade relationships by linking import and production hubs
- Working on one joint Northwest European hydrogen policy

The outlines of the first steps are already defined: The development of hydrogen production facilities, a hydrogen backbone, and a hydrogen corridor to link Rotterdam with the German hinterland are put on the agenda for the short term[5].

5 See here.

In these last pages, all participants share their reflections on the arena process that has led to this report and their ideas about what should be prioritized today.

"The sessions provided Eneco the opportunity to give input on the vision formation of the Port of Rotterdam on hydrogen; it also sharpened our vision. The Port of Rotterdam can create an important new ecosystem for industrial companies to make their processes or feedstocks more sustainable. There is a clear interest for Eneco, as well, by creating partnerships with such parties interested in the use of green hydrogen directly coupled to our renewable assets, which lead to green and low-cost hydrogen."

– **Silvan de Boer & Elmer de Boer**
Eneco

"An interesting trajectory with good insights from different perspectives. For me, hydrogen plays a pivotal role in the energy transition, transforming the world of the molecule from a fossil origin to circular and biobased. Developing the different tracks was valuable and inspires me personally to intensify my efforts to accelerate and scale the green hydrogen and circular chemistry projects Nouryon has globally and for Rotterdam specifically."

– **Robert Bouma**
Commercial Manager Energy & New Business, Nouryon

"To successfully develop the 'hydrogen economy,' leadership across the entire chain is required (production / import, transport / distribution, market). As an infrastructure company, Gasunie works with the Port of Rotterdam Authority on the development of the regional hydrogen backbone, the connecting link between supply and demand. We want to make the final investment decision for this in 2021."

– **Hans Coenen**
Director strategy & Business Development, Gasunie

"The most valuable lesson I learned through this process is the absolute magnitude of decarbonization by linking Offshore Wind and Hydrogen in the Rotterdam Harbor region. We need to allow ourselves to think big in order to decarbonize our industry at affordable cost to keep competitive industry in the Netherlands."

– **Steven Engels**
General Manager Benelux, Ørsted

"Green hydrogen plays a key role in a sustainable and integrated energy system. This report underlines that the Port of Rotterdam ecosystem can be a first mover, if we act now. Siemens Energy is committed to work in partnership to realize the first industrial scale electrolysis project in the Netherlands."

– **Leo Freriks**
New Energy Business, Siemens Energy Nederland B.V.

"As a provider of vital infrastructure in today's energy systems, I see a clear role for Vopak to facilitate the transition to new low-carbon product flows. I believe that hydrogen will play an important role in these new energy systems, and the import of hydrogen in the Port of Rotterdam will be a logical step forward. This could be hydrogen as a liquid at -253 °C or by using a carrier (LOHC) or as clean feedstock like green ammonia. During the arena sessions and through this study, we show how we can work together in developing these opportunities."

– **Marcel van de Kar**
Director New Energies, Vopak

"Unlike most climate investments, the scaling of green hydrogen isn't as straightforward as 'build as much as possible, as fast as possible.' Rotterdam may eventually thrive in the hydrogen economy, but the Port and its pioneering partners must carefully balance pace and prudence in order to get there."

– **Thijs ten Brinck**
WattisDuurzaam.nl

"The most important thing in this arena project has been that different views of the role and implementation of hydrogen have emerged, while no attempt has been made to reach a weak compromise on the perspective for action. It has been made clear that the past of the Port is characterized by courage and turning points of innovators. Waiting is not an option, as you would then become the port of the past, a tourist attraction. So, the message is to start now with smart public / private investment in technological development and system change, electrification, and the arrival of green hydrogen to be the port of the future in NW Europe."

– **Jan-Coen van Elburg**
Rebel

"This report is one of the few to review clean hydrogen in the perspective of the global hydrogen market that is emerging. Clean hydrogen is not a silver bullet but the missing link in the energy transition. The Netherlands is well positioned to become a frontrunner in building a European clean hydrogen market. We will see both domestic production of green hydrogen (from wind offshore) as well as imports going forward. The Port of Rotterdam has a unique opportunity to become a key import hub for clean hydrogen in Europe if it plays its cards well."

– **Noé van Hulst**
(on personal title)

"It is time for action instead of words, time is running out for the Port because the opportunities can also be exploited elsewhere in Europe. As Kalavasta, we will continue to look for opportunities at the 'edges' of the energy transition, so that a healthy climate-neutral, circular industry is just as collectively conceivable as the idea that petrol and diesel cars are replaced by electric cars. And if we can imagine something collectively, we can also realize it quickly!"

– **John Kerkhoven**
Partner, Kalavasta

"This project was interesting because it brought together different stakeholders and various areas of expertise. This led to rich discussions and insights, as reflected in the report. Although hydrogen is far from a new technology, the coming innovation in production, conversion, and consumption is truly exciting because hydrogen, among other clean gasses, can help build a new energy system backbone and innovate feedstocks. Rotterdam and other industrial clusters and ports want to be at the forefront of this new development and help develop regional and international collaboration."

– **Coby van der Linde**
Director, CIEP, Professor, Energy and Geopolitics, Rijksuniversiteit Groningen

"The Maasvlakte 2GW conversion park currently being developed has the potential of becoming a showcase of how to drive costs significantly towards competitive Renewable H_2 levels: Scale is crucial for costs levels. The combination of large H_2 consumption, infrastructure all the way to the Rhein area, and sites for Offshore Wind sound like a solid recipe for the Port of the future."

– **Julius Smith**
Head of Business Development, Ørsted

"Hydrogen offers great opportunities for making our economy more sustainable while partially retaining our energy distribution and infrastructure. The Port of Rotterdam can thereby become an important hub for hydrogen import, storage, and trade. However, this energy transition to hydrogen will not only require technological innovations but, above all, social innovation from the existing players in the petrochemical cluster; leadership, a long-term vision and co-creation with new chain partners."

– **Prof. Dr. Henk W. Volberda**
Professor of Strategy & Innovation, UvA
Director of the Amsterdam Center for Business Innovation

"Hydrogen for the Port of Rotterdam is crucial both for decarbonizing the industry in the Rotterdam area and for the economic development of the Port, especially to serve the hinterland with carbon-free fuels, chemicals, and products. This report clearly shows that North West Europa needs to import energy, which needs to be future carbon-free energy. Hydrogen and hydrogen-based fuels or chemicals will be this import energy that can be transported and stored in large quantities. The report shows also that we need to be proactive in developing import facilities together with low-carbon and green hydrogen production abroad."

– **Prof. Dr. Ad van Wijk**
Professor Future Energy Systems, Department Process & Energy, Faculty of Mechanical, Maritime and Materials Engineering, TU Delft
Guest Professor Energy and Water, KWR Water Research Institute

"Today, hydrogen is an important energy carrier. In a clean and sustainable energy system, the role of hydrogen as an energy carrier and feedstock will be even more important. The arena sessions have revealed different paths to develop the importance of clean hydrogen with respect to the role Rotterdam plays in the energy and feedstock system of the wider region, both national and international. Yet, with the words of Einstein in mind, *"A vision without realization is a hallucination."* We must start acting to realize the vision. The good news is, we have started. On behalf of the Port of Rotterdam, I would like to thank all participants of the arena sessions for their contributions, and I would like to ask them for their support in the upcoming period; together we can release the potential of clean hydrogen."

– **Nico van Dooren**
Director New Business Development
Havenbedrijf Rotterdam N.V.

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