CLINGENDAEL INTERNATIONAL ENERGY PROGRAMME | CIEP

MANAGING FUTURE SECURITY OF LOW CARBON HYDROGEN SUPPLY

UNDERSTANDING INTERNATIONAL VALUE CHAIN DEVELOPMENTS AND MARKET STRUCTURES REGARDING SECURITY OF SUPPLY

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July 2022

PREFACE

In many forward-looking sketches of market developments and the energy transition, the assumption is always that the open international markets will persist, and relations will be harmonious, while it is by no means clear that these globalised markets and international relations as we knew them until recently will continue in the future. The course of the energy transition and the development of energy markets may thus be different in the context of an alternative world order. This is the context of the project 'Hydrogen To Be' (H_2TB) concerning the geopolitics and geo-economics of hydrogen carrier imports and the impact on local economies and society in Northwest Europe. The H2TB project is commissioned by SmartPort. The Ministry of Economic Affairs and Climate through RVO commissioned CIEP to work on the Future Security of Supply of Hydrogen (carriers), which is both part of the H_2TB-project and a stand-alone contribution.

The current tense geopolitical relations are a stark reminder that the development of imported hydrogen carrier value chains may have to take place in less harmonious international political and economic circumstances than anticipated in many studies. From these less than harmonious circumstances arose the idea to compare the eventful rise of the international oil and gas value chains with the potential growth of international hydrogen carrier value chains over time. For the latter we used insights from the Dynamic Market Theory on how value chains and markets may develop and previous CIEP-studies on security of supply. Based on these insights, lessons regarding security of future hydrogen carriers supply may be drawn.

This work was inspired by discussions with colleagues at CIEP, Pier Stapersma, Jasper Meijering and Roelof Stam and colleagues in the H_2TB project, namely Wouter Jacobs and Amit Arkhipov Goyal of UPT-Erasmus University, Roel van Raak en Igno Notermans of DRIFT and Aad Correljé and Toyah Rodhouse of TBM, TU Delft. At the same time, Martha Huijsinga, intern at CIEP, was working on a master thesis on a similar subject, creating a fertile environment to explore, discuss and write on potential development paths and the implications for future security of supply policymaking. This exploration process is far from complete, and this paper is only a first attempt to understand the potential developments paths and the implications for policymaking. Moreover, we focussed here on security of supply policymaking, but also regulation of the future market requires far more study. The current energy crisis shows that also regulatory shortcomings played a role in the strategic dependency on supplies from Russia. Awareness of the fact that over time 'things' change, that the development phase of a value chain matters, and that the EU is not an island nor able to dictate all the terms in energy relations, may be helpful to dynamically manage future supply risks.

Coby van der Linde

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EXECUTIVE SUMMARY

The world international political and economic order is under increasing pressure. The rise of China has created more uncertainties about the future political and economic order in the world. More competition for natural and mineral resources and energy carriers, but also in markets and in the creation of new alliances, may influence the context in which international economic relations develop in the future. In many forward-looking sketches of market developments and the energy transition, the assumption is always that the open international markets will persist, and relations will be harmonious, while it is by no means clear that these globalised markets and international relations as we knew them until recently will continue in the future. The course of the energy transition and the development of energy markets may thus be different in the context of an alternative world order.

There are important lessons to be learned on security of supply from market developments and the evolving structure of the fossil fuel market (here oil and gas) for the low carbon energy and feedstock economy of the future. These lessons include the dynamics of market development, the organisational structure of the market (over time) and the type of market players. Towards maturity of the market, the need for regulatory authorities or governments to change from monitoring and nudging to regulation and maintaining security of supply increases. In low carbon hydrogen markets, it is also important to understand the logic of the different low carbon hydrogen carriers, their contribution to security of supply and, importantly, that low carbon hydrogen (carriers), together with electricity, may, in future, perform the same function in the energy economy as coal, hydro, oil, gas and nuclear do in the current system.

The level of government support, ownership, and market intervention for these various traditional energy carrier markets varies among fuels and countries, and it is likely that, although we currently bundle the different low carbon carriers under one label, these also require an approach that does justice to their respective value chains. The level of internationalisation of these value chains (bilateral viz. multilateral) also matters, as does the level of segmentation of international markets. Furthermore, governments should balance the development of domestic production and imported flows of low carbon hydrogen. From a security of supply perspective, development of domestic value chains in low carbon hydrogen creates (security of supply policy) comfort to import more H_2 carrier volumes. Here domestic can be understood as the Netherlands, North-West Europe and/or the EU.

Security of supply always implies a cost to society because policy measures nudge, steer, or command to hold additional stocks, to source from various geographies/markets instead of the cheapest supplier alone, in addition to all sorts of other measures to shape the market. In the Netherlands, the context of the EU and climate change policies are very important. The current size of the unabated hydrogen market in NW Europe ill compares to those in other parts of the EU, suggesting that a one size fits all approach of the EU may not work as easily as suggested in recent policy documents. Member states also need some space to work within their own resources and needs, especially in the early stages of value chain and market development.

Security of supply is a different issue in the various phases of value chain and market development. Broadly speaking, the concentration of the market in the introduction phase, will be followed by a period of de-concentration in the expansion phase. During the expansion phase newcomers will enter the market and vertical and horizontal integration of companies will decline when companies focus on a certain part of the value chain. In the mature phase of the market, concentration increases, and governments may regulate the market to ensure market competition. However, it would be wise to study the experience of the EU gas market regulation to learn from mistakes. The policy preoccupation to end or shorten long-term contracts and the lack of policies to diversify imported supplies may have created additional security of supply risks, because markets were geared towards short-term (cheapest) supplies. A more balanced view on market functioning, sensitivity to the phases of value chain and market development, and security of supply would be wise.

Another remarkable issue is that the EU looks at low carbon hydrogen only in a gaseous form, as can be deduced from the proposal for a new gas and hydrogen market directive. Such an approach is perhaps based on the preference for domestically produced electrolyser hydrogen but may affect imported low carbon hydrogen carriers like ammonia, methanol and LHOC, to enter the market and transport them inland in liquid form. If the gaseous approach persists, the EU Commission apparently assumes (in its proposed regulation) that all imported low carbon hydrogen carriers will be converted to a gaseous state at the point of entry into the EU market, most likely on the coast (like LNG terminals), and misses the possibility of low carbon liquid hydrogen carriers to be converted closer to inland demand. The proposed regulation could therefore end up regulating only a part of the low carbon hydrogen flows. This misunderstanding may seem like a detail, ahead of the first flows to arrive from abroad, but the current security of supply crisis may have made member states more aware of securing flows close to demand in their country and want to have the possibility to develop storage and conversion at home. The current proposals may end up stimulating low carbon hydrogen flows and transportation and storage modes outside the proposed regulated space to manage investment and demand uncertainties. This would fit companies that prefer to develop vertically integrated imported low carbon hydrogen flows, but maybe not the idea the EU Commission has about the emerging low carbon hydrogen market. In the introduction and early expansion phase, these two models of developing low carbon hydrogen value chains may compete.

A further important issue for security of supply monitoring is transparency, a broad low carbon industry and market knowledge in government and the public domain. This has become pertinent in the current energy crisis, when important information to understand first, second and third order effects of supply disruptions are publicly hard to come by or missing at the EU and/or member state level. Indeed, the EU still does not provide the level of transparency in oil and gas markets needed for proper monitoring and policymaking in liberalised markets. Transparency in the US, through the service of the energy information agency (EIA of the Ministry of Energy), is much better organised than in the EU. During disruptions they publish daily updates on available capacities on the website.

The lack of transparency makes it difficult to monitor market developments, develop publicly available analyses, and understand the impact of changes in demand and supply for market players and the government. Greater transparency of information in the short-term, and longer-term issues in security of delivery and supply should be promoted to facilitate investments and inform consumers. Not leaving knowledge to the market players and develop a sound knowledge base in society at large and in government institutions, is also crucial for a balanced and timely security of supply environment to come about. This knowledge should also be organised in the public administration. In addition to the knowledge base in ministries, a model like the one used for oil, where analysis of oil market developments is currently organised for the ministry in COVA (Centraal Orgaan Voorraadvorming Aardolieproducten), could help to shore up the knowledge base. In natural gas and electricity, this knowledge is currently also embedded in the two state-owned network companies (Gasunie and TenneT), but their brief on reporting on security of supply issues could be strengthened to include other parts of the value chain and look beyond the shorter-term security of supply. Moreover, information from these government institutions should be transparent and not used for political purposes.

In the future, with an important role for electricity and low carbon hydrogen, integrated knowledge of these various markets (including the variety of low carbon hydrogen carriers and their specific value chains) should be organised in government and in society at large. It is likely that a variety of non-governmental knowledge groups will also develop and contribute to an ongoing critical discussion on security of supply issues. All have a role to play. However, organising transparent information on flows and capacities is typically a task for the government, also because it helps levelling the playing field and provides vital information on the development of the low carbon value chains, how the sector functions and how market players interact from the perspective of security of supply. This will help both market functioning and timely policymaking in security of supply.

Transparency should be organised as well at the level of the EU and at the level of relevant markets and/or national markets, as be presented in an agreed uniform manner for analytical reasons. In the United States, energy is mainly a matter of the states and not the federal government, but the Department of Energy organises both information at the federal, the relevant market and the state level. The energy transition offers an opportunity for the EU and the member states to organise information early on and avoid the governance confusion prevailing in the past decades. For historical reasons, the International Energy Agency (IEA) has a strong position in information on the oil value chain, but it has also developed a strong information position on other international energy carriers. The EU collects information through Eurostat. The EU's main analytical information is derived from the PRIMES and additional models, which are neither open access, nor aimed at making information easily accessible for non-experts. Rather, the models serve to support the internal planning processes of the European Commission. Here, the shared responsibility for energy policymaking and the focus on climate change policies play an important role in the incomplete information position.

The information position of EU low carbon hydrogen players and governments should be improved drastically. The EU (Commission) could set up a new service like the US Energy Information Agency and collect and provide timely data sets and data analyses for member state governments and market players. It would also help if the EU breaks with the practise of 'no-access' modelling and replace that with open-access exercises. In this way, member states, regions, market players and other interested parties are informed about the assumptions and can replicate outcomes for their own analyses. At the same time, the information position of the IEA is growing rapidly in low carbon hydrogen and offers member states already more timely and open information. Also, the expertise of the IEA and their willingness to research issues at the request of member states positions the IEA positively, compared to the EU Commission. It is crucial for institutions to function well, so that their knowledge position is uncontested and politically neutral.

1 INTRODUCTION

The invasion by Russia of Ukraine on 24 February 2022 has created a renewed focus on security of supply of energy. European Union (EU) member states rediscovered the perils of import dependency and relying on only a few large suppliers for oil, oil products, natural gas and coal. This dependency slowly emerged in the past decades when international energy markets grew to include more countries, particularly China, and legacy infrastructures and efficiencies rationalised physical flows into more regional concentration. This market development was the result of the geopolitical and economic (liberal) order, fast growth of energy imports of China and the growing maturity of the fossil fuel energy markets.

DEPENDENCY ON RUSSIAN ENERGY IMPORTS

Russia is a large producer and exporter of coal, crude oil, oil products and natural gas. The EU member states were among the largest importers of Russian energy, in part because the existing infrastructure makes Russian supplies the cheapest source of supply, and in part because no other infrastructure to import is available (oil, gas). This is particularly the case for land-locked East-European member states which still rely on the infrastructure system established before the break-up of the Soviet Union and the Warsaw Pact/COMECON. West-European EU member states often imported energy from the Middle East and North Africa and over time developed their own onshore infrastructure network (oil products - NATO network) based on imports and domestic production (Netherlands, UK, Norway - oil and natural gas). Furthermore, coal is imported overseas from the US, South Africa, and Columbia, while East-European countries also import significant volumes of Russian coal. The Netherlands became an important entry point for crude oil for Germany (and coal) and Belgium, and within the three-country energy-intense industrial cluster, oil products and feedstocks are traded. Russian supplies were a substantial part of total supplies imported via Rotterdam. Rotterdam also developed into an important bunker market.

The imports of coal, crude oil, oil products and natural gas (and electricity) contribute to the energy supply of the EU. The Russian share of imports into the European Union (EU) has grown in the last decade, in part because of the eastern enlargement of the EU with previous member states of COMECON from 2004 onwards, and in part because of declining EU energy production. The decline in EU gas production coincided with the liberalisation of the EU energy markets (natural gas and electricity) in that same period, expediting a preference for the cheapest supplies available in international markets. The liberalisation drive was not accompanied by security of supply policies, such as diversification to geographic origin. The competitive position of energy intense industries required relatively cheap energy supplies to maintain their position in international markets. The expansion of shale oil and gas production in the US, substantially lowering energy and feedstock cost, further complicated the competitive position of the EU industry. In the period after the financial and economic crisis (2008/2009), international oil and natural gas markets were buyer's markets and further stimulated short-term contracting and geographic concentration of supplies in the EU.

Since the 2000s, world energy markets have become much more regionalised regarding physical flows, while internationalising in paper trade. The Middle East, an important supplier of oil and oil products to the EU, increasingly became the supplier of Asia in general and China in particular. The EU's turning away from imports from Iraq and Iran started in 1991, during the First Gulf War. The break-up of the Soviet Union and the subsequent economic downturn in the Eastern bloc led to a production surplus in Russia that found its way to Western Europe.[1] The imports from Russia have increased since then.

Just prior to the war in Ukraine, the share of imports from Russia in the EU were: 27% oil, 41% of natural gas and 47% of coal. According to the EU Commission[2]: "*The stability of the EU's energy supply may be threatened if a high proportion of imports are concentrated among relatively few external partners. In 2019, almost two thirds of the extra-EU's crude oil imports came from Russia (27 %), Iraq (9 %), Nigeria and Saudi Arabia (both 8 %) and Kazakhstan and Norway (both 7 %). A similar analysis shows that almost three quarters of the EU's imports of natural gas came from Russia (41 %), Norway (16 %), Algeria (8 %) and Qatar (5 %), while over three quarters of solid fuel (mostly coal) imports originated from Russia (47 %), the United States (18 %) and Australia (14 %). (…) In the EU in 2019, the dependency rate was equal to 61 %, which means that more than half of the EU's energy needs were met by net imports. This rate ranges from over 90 % in Malta, Luxembourg, and Cyprus to 5 % in Estonia. The dependency rate on energy imports has increased since 2000, when it was just 56 %.*"

1 Study on Energy Supply Security and Geopolitics, January 2004 (https://www.clingendaelenergy.com/inc/upload/files/Study_on_energy_supply_security_and_geopolitics.pdf)

2 https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-2c.html#carouselControls?lang=en

In the words of Daniel Yergin in a recent article in the *Wallstreet Journal* (6 July 2022): *"Russia's invasion of Ukraine turned a burgeoning energy and economic crisis into a geopolitical one, further driving up prices. For half a century Russia, and before that the Soviet Union, had trumpeted itself as a "reliable supplier" of oil and natural gas, especially to Europe. That idea was widely accepted in Europe on the premise that interdependence would benefit both sides through what the Germans called "change through trade." So confident in this relationship was Germany, for example, that it decided in 2011 to shut down its nuclear power industry—which produced a quarter of its electricity at the time—and let coal and Russian natural gas account for the shortfall (…). No country is making as rapid and determined a turnaround from dependence on Russian energy as Germany, which is undergoing what Chancellor Olaf Scholz calls the Zeitenwende, or turning point."*

The war in Ukraine radically changed the energy relation of EU member states with Russia. In designing its future energy carrier relations with exporting countries, the current experience may be just as formative for future security of supply policymaking as was the 1973 oil crisis.

GLOBALISATION, LIBERALISATION, AND THE EU

The EU has become an energy-poor region in traditional fuels. The North Sea is now a mature oil and gas producing region, while also other European energy producing regions like Romania are mature or in decline. The oil crises in 1973/74 and 1978/79 made the West European countries aware that diversification of suppliers/supplying countries and the energy mix is important. The development of the North Sea energy resources dampened oil import dependency in the 1980s and 1990s, provided some assurance to have this domestic source and helped to manage market power of OPEC by pricing Brent just below its nearest OPEC crude competitor. Nevertheless, the oil price shocks also led to a period of depressed demand for oil which lasted until the mid-1990s, when oil prices declined (further) compared to personal (West European) income. The supply from Russia in the 1990s offered a timely alternative to supplies from politically instable countries in the Middle East (after the first Gulf War). The quality of oil from Iran and Iraq is close to that of Russia's Ural, requiring relatively few adjustments to refineries to maintain their conversion efficiency.

Liberalisation of the EU energy markets also played a role in increasing the EU import dependency on Russia. The EU liberalised the electricity and gas markets, created more interconnections and reverse flow options to exchange energy carriers, but failed to implement an accompanying security of supply policy to guarantee sufficient diversity of supplies. This was in part due to competency issues between the member states and the EU. The EU did try to develop the so-called Southern gas corridor to link Caspian Sea resources (Kazakhstan, Azerbaijan, Turkmenistan) to the EU and promoted LNG-import terminals. These efforts were only partially successful, and the liberalised market orientation continued to prefer the cheapest supplies.

The gas crises between Ukraine and Russia in 2005 and 2009 led to a diversification of pipeline routes, partly replacing flows through Ukraine. Nord Stream 1 and Turkstream were the result of this security of transit strategy on the part of Russia. The dependency of Russia on EU gas demand was substantial, and Nord Stream 1 was supposed to further reduce transit risks to its main markets. Opponents of the project argued that Russia could use the growing import dependency on Russian gas as a political weapon, while other EU countries saw Russia as a very dependable supplier.[3] Early in the war, Russia delivered the gas to customers on its long-term contracts using mainly Nord Stream 1 and the pipeline through Ukraine. From May 2022 onwards, Russia ordered payments for gas to be made in rubles accounts to circumvent the financial market sanctions, which resulted in early termination of contractual deliveries to companies that decided not comply. In May 2022, Poland, Bulgaria, and the Netherlands refused to pay in rubles for their long-term contracts (expiring in 2022), which led to an early termination of deliveries. Denmark also indicated that it would not pay in rubles for the 2 bcm per year contract running until 2030.[4] In June 2022, deliveries through Nord Stream 1 were substantially reduced, below contracted volumes, and the use of natural gas supplies as an economic weapon was a fact.

The war in Ukraine has fundamentally soured the energy relation between the EU and Russia. Sanctions on coal, and recently on oil and oil product imports from Russia, have already been agreed on, while a reduction of EU demand for Russian gas is actively pursued. The security of supply situation for oil, natural gas and coal remains precarious in the short-term. For oil, the EU has a strategic reserve, either as part of the EU regime, or on instigation of the International Energy Agency (IEA) or both. Contrary to this, EU member states have not agreed to maintain strategic coal or gas reserves. Finding alternative supplies in tight international markets may be difficult, while the expansion of renewable power production and developing new

3 Various articles: https://www.clingendaelenergy.com/inc/upload/files/HFD-20220105-0-025-003.pdf;
https://www.clingendaelenergy.com/inc/upload/files/NF-HFD-20211013-0-025-006.pdf;
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https://www.clingendaelenergy.com/inc/upload/files/HFD_20200910_0_025_004.pdf;
https://www.clingendaelenergy.com/inc/upload/files/vanderlinde_2_1_20_FD.pdf.

4 https://www.politico.eu/article/netherlands-and-denmark-gas-buyers-warn-of-russia-shutoff-kremlin-gazprom/

values chains, for instance in low carbon hydrogen, may take some time. The impact of the current energy crisis on the EU energy markets is therefore uncertain, because it is unclear how quickly alternative supplies can be made available, what the dislocation costs will be and whether, in the end, it is demand destruction in the EU and elsewhere that will rebalance international energy markets.

Apart from the impact of EU sanctions on Russian income from energy exports[5] and the (in)ability to source oil, gas, and coal from elsewhere, the lack of a security of supply policy in most EU member states (apart from protecting households and other vulnerable consumers) is an important lesson for the future, when low carbon hydrogen and circular carbon needs to be sourced outside the EU, and imported rare earths and minerals are needed for solar and wind production. The current EU security of supply policies appear to cover only shorter-term disruptions (technical, weather) and they do not cover the economic impact of closing industries and businesses on those same vulnerable consumers. A discussion on critical industries and their dependency on the complex mesh of the energy system in and between member states and how to secure energy supply, should be included in future discussions on the functioning of the energy system.

In 2019, at the start of the current term of the EU Commission, intentions to formulate a strategic industry policy were aired, to make sure that the EU will rely less on imported products and long supply lines. The Covid-19 pandemic uncovered more of these structural vulnerabilities. Dependency on China for resources and goods, but also on India for pharmaceuticals, exposed the dependency of the EU on many goods it no longer produces itself. In a world more divided, these structural dependencies can become politically more sensitive, like with energy. The looming food and energy crisis due to the Russia-Ukraine war is already invoking protectionist measures in various countries around the world. The process of retreating from globalisation, which started after the global financial and economic crisis, is further accelerating after two years of covid crisis and growing geopolitical standoffs. These developments may also impact imports of low carbon hydrogen and the ability to diversify.

5 Energy export income is a significant part of government income for Russia. Export taxes on oil and gas contribute most to fiscal income, but also dividends from state oil and gas and infrastructure companies are part of the energy income of the state. Imposing a tariff on Russian imports will not impact government income easily because the government takes a set amount. A tariff could change the competitiveness of Russian crudes and oil products compared to supplies from other countries. However, the current oil, gas and coal markets are very tight due to a period of low investments. Russian income from energy exports is increasing due to higher prices, despite lower volumes. https://www.clingendaelenergy.com/inc/upload/files/Sanctiebeleid-verdient-strategische-discussie.pdf

BALANCING ENERGY IMPORT DEPENDENCY AND DOMESTIC PRODUCTION

Energy relations with unsavoury regimes are not uncommon. For a long time, these relations were managed with a variety of measures and instruments. These ranged from the wider security umbrella of the US, IEA agreements, the EU's soft economic power, to the development of domestic energy production, like in the North Sea and elsewhere. The Netherlands, UK and Norway were important contributors to domestic production, contributing to the level of comfort with imports coming outside of the EU, while imports from other Organisation Economic Cooperation and Development (OECD) countries was also seen as an important contributor to this security of supply comfort. Discussing future energy trade relations should include the importance of domestic production as part and parcel of import and security of supply policies. Some argue that domestic supply may be more costly than imports, but the value in terms of security of supply is not considered in these more short-term oriented views. Moreover, the debate on costs of domestic production vis-à-vis imported low carbon flows is still undecided because not all costs are known, nor are all costs included. More importantly, no country will willingly engage in a low carbon hydrogen import strategy without developing a domestic production (and knowledge) base. The history of import dependency on coal, oil, and natural gas, and developing local alternatives, such as hydro, biomass or nuclear, shows that governments from different countries always prefer their own balance between domestic and imported energy sources or energy carriers for strategic and economic reasons. There is no reason to suppose that this will change in the future, even if the world would find its way to a multilateral harmonious international world order. Indeed, deciding on the energy mix of a member state is still considered a national prerequisite.

WORLD (DIS)ORDER

The world international political and economic order is under increasing pressure. The rise of China has created more uncertainties about the future political and economic order in the world. More competition for natural and mineral resources and energy carriers, but also in markets and in the creation of new alliances, may influence the context in which international economic relations develop in the future. In many forward-looking sketches of market developments and the energy transition, the assumption is always that the open international markets will persist and relations will be harmonious, while it is by no means clear that these globalised markets and international relations as we knew them until recently will continue in the future. The course of the energy transition and the development of energy markets may thus be different in the context of an alternative world order.

China's growing importance in energy markets reflects its rising geopolitical and geo-economic importance. The post-Cold-War idea that integrating the Chinese economy into the world system would turn the country into a so-called 'rule follower' has become more and more undone by China's mercantilism and the creation of alternative institutions that compete for influence and impact with existing UN institutions. In the past few years, conflicts between the West and China have been mounting over themes as climate, trade, currency policy and intellectual property rights, but also on geopolitical issues, and countries like Iran, North Korea, expansion in the South China Sea, the status of Taiwan and Hong Kong. The conflict over Ukraine between Russia and the West may be a harbinger of more disputes between powerful countries and their proxies. A systems-clash can no longer be ruled out between market-oriented and state-oriented political systems and their allies, nor a longer period of economic disintegration and dwindling cooperation. Important for this study on security of supply for low carbon hydrogen is that the premise of a globalised cooperative world is not set in stone, and that other world orders should be considered as part of the strategic thinking on security of supply. Apart from the international (economic) order, also the dynamic development of low carbon hydrogen life cycles and market structures should be considered to understand the various challenges security of supply policymaking must address at different moments in time.

States matter and markets cannot solve all strategic issues. The current period seems a period of redressing the balance between the state and the market in many countries. It is in these periods of structural change that new value chains are developed for strategic reasons, which create new realities and start new trends. In these periods of structural change, production costs seem to matter less than the cost of (political) dependency. The development of an energy system based on variable solar and wind, in combination with low carbon hydrogen may be stimulated by the geopolitical developments, because it may kill two birds with one stone: reduce the structural import dependency on (Russian) fossil fuels and lower CO_2 emissions. For sure, security of supply may prove to be a much stronger incentive to develop a new energy system based on a low carbon hydrogen and electricity backbone, than climate change alone. Moreover, it also helps forging new energy trade relations that may be deemed safer in the current period of uncertainty.

THIS STUDY

This study looks at past experiences with security of supply in oil and natural gas and, in part based on these experiences, looks at the expected risks in security of supply for the different stages of market development of low carbon hydrogen, to ascertain how and when to employ the available instruments in the policy toolbox. Security of supply must also be seen in the geopolitical context and is a much more dynamic issue than sometimes assumed. For instance, the role of markets and governments in security of supply is related to ownership structures, while the regulatory context is also important.[6]

6 Although we do not cover regulations specifically in this study, a lot of policymaking is hindered by derived principles and criteria related to a certain view on the internal market, which neither matches the market realities of today nor the needs of new value chains. Also, the ideological approach to energy transition where everything is measured against a 2050 standard and not sensitive for progress in steps also hinders value chain development. This approach hinders pragmatic solutions and strategic policymaking. In Hydrogen development the Inflation Reduction Act (IRA) in the US a more pragmatic approach may very well organise stiff competition for investors in the EU. The impact of regulation on new value chain development warrants a separate study.

2 DEVELOPMENT OF IMPORTED LOW CARBON HYDROGEN CARRIERS

Currently a variety of stakeholders is working on the development of imported hydrogen (carrier) value chains. The potential producers of low carbon (electrolysis and gases with carbon capture and storage, CCS) are as well countries with which the Netherlands already has an energy relationship (oil, gas and coal producing countries), as countries with which a new energy (carrier) relationship will have to be developed. These latter countries have a large potential in producing solar and/or wind energy and in converting the electricity into hydrogen for export. Moreover, also companies involved in developing low carbon hydrogen are diverse in terms of the current sector in which they have their core business and in terms of size.

HYDROGEN PROSPECTS IN NORTH-WEST EUROPE

Current hydrogen production in the region is mainly concentrated in and among industrial clusters in the Netherlands, Belgium, Northern France and Germany. Hydrogen is predominantly made from natural gas and waste gases. It is an industrial gas and is treated as such in EU trade policy (import tariff). Hydrogen is both an energy carrier and feedstock for the chemical industry (in the current organic chemical sector and in future circular chemistry). Hydrogen is used in the refining of crude oils and oil products, in petrochemical industries, and in the production of second-generation biofuels and bio-naphtha. New hydrogen production in the region will be based on electricity generated by offshore wind and solar. Although the offshore wind potential in the North Sea is large, and some countries will be able to export their surplus electricity or low carbon hydrogen to neighbouring countries (Denmark, Norway), the expectation is that the countries around the North Sea[7] will not become self-sufficient and will have to import additional hydrogen from elsewhere. Particularly demand in Germany will have to rely on imports, but also the Netherlands and Belgium, assuming the continued existence of their current industrial base, will need to import low carbon hydrogen carriers.

HYDROGEN MODES OF TRANSPORTATION AND TRADE FLOWS

When importing hydrogen from elsewhere, either from outside or from within the EU (without the interconnections in place), the different modes of transportation (pipeline, ship) and different hydrogen carriers (ammonia, LHOC, methanol or Liquid Hydrogen) will have to be considered when looking at value chain and market

7 https://www.clingendaelenergy.com/publications/publication/hydrogen-in-north-western-europe-a-vision-towards-2030

development in the context of security of supply. This is due to the dedicated assets needed to bring the hydrogen (carrier) from elsewhere to the NW European market. These assets may differ among EU member states, depending on their preferred supply routes and low carbon hydrogen carriers, but they could also strategically position a certain mode of transportation and carrier compared to the other options. Moreover, the choice for a certain type of carrier may influence the development on where to convert and/or store hydrogen. If available, hydrogen can be transported through refurbished gas pipelines, as shown in a study by the European TSOs (see figure 1).

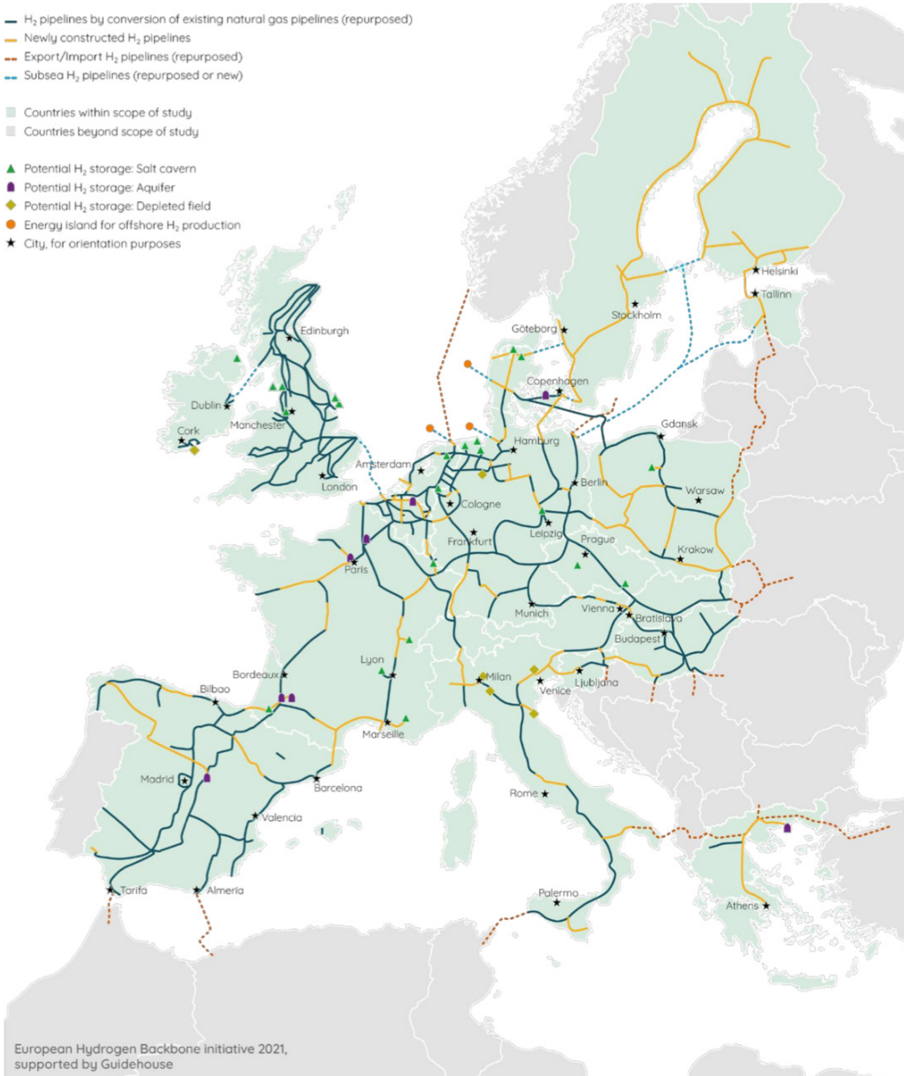

FIGURE 1 REFURBISHED AND NEW PIPELINES TO CREATE A PAN-EUROPEAN HYDROGEN NETWORK

SOURCE: EXTENDING THE EUROPEAN HYDROGEN BACKBONE, APRIL 2021. (HTTPS://GASFORCLIMATE2050.EU/WP-CONTENT/UPLOADS/2021/04/EUROPEAN-HYDROGEN-BACKBONE-2021-WEBINAR-SLIDEDECK.PDF)

The same may apply to oil and oil product pipelines. The latter may benefit the development of liquid hydrogen carriers, particularly LOHC. Another complication for the development of the hydrogen economy is that parallel to a hydrogen network, a (circular) carbon network must be realised to produce chemical products, of which many are used in daily life. The logic of the North-West European energy and chemical clusters in western Germany, Belgium and the Netherlands may change because of the choice of the transportation mode and hydrogen carrier. Such a development is not unlike the change of location of modern steel factories to the coast (when inland shipping was not available), when it was cheaper to ship coal overseas than to produce it in mature inland coal production regions.

GASSES AND LIQUIDS INFRASTRUCTURES AND LOCATIONAL QUESTIONS

The choice for a certain low carbon hydrogen carrier and transportation system may also influence the location of conversion facilities. Near the coast, when transformed into a gaseous state feeding into a refurbished/new gaseous network, or near the demand centers, when transported in LHOC, ammonia or methanol, or both, depending on the safety of transporting these carriers. The development of break-bulk systems may be important to determine which value chains can be developed, and also whether they can service smaller demand centers too. It is also possible that various hydrogen carrier value chains will be developed alongside each other, and that a more dominant form will appear only later. As history tells, this may technically not be most effective option, but rather the economically and societal best option.

DISTINCT DEVELOPMENT MODELS IN DIFFERENT INDUSTRIES

In July 2021, the Netherlands has decided to refurbish part of the natural gas infrastructure into a hydrogen system (Hyway27) connecting the industrial clusters within the country and to Germany. At the same time, a new pipeline bundle is developed from Rotterdam to the Ruhr-area in Germany and Chemelot in Limburg. This so-called Delta corridor is planned to also carry low carbon hydrogen to these inland industrial regions, and includes a CO_2 return pipeline, and some chemical pipelines. It is still unclear whether the hydrogen will be transported in gaseous form (and off-ship converted in Rotterdam), or that a pipeline will (also) bring ammonia (or LOHC) to the inland industrial clusters (and build or refurbish a pipeline for a return of toluene if shipping or other modes of transportation are too cumbersome). The proposed regulatory model seems to aim at gaseous low carbon hydrogen only, while low carbon hydrogen flows developed in a vertically integrated value chain may be transported unconverted to the market for inland storage and conversion. These two models may compete in the early stages of development.

The development of various low carbon hydrogen carriers may depend on various factors:

a. the (early) regulatory arrangements of the government;
b. the speed of domestic developments to produce electrolyser hydrogen promoting gaseous transportation to the market;
c. the ability to converge the value chain development models akin to the 'oil industry' with that of the 'gas industry'[8];
d. the security of supply needs of Germany;
e. the ability and/or wish to store hydrogen carriers near demand centers and/or the landing points of offshore wind for conversion into electrolysis hydrogen; and
f. the geopolitical context.

It is possible that the infrastructure in the early phases of development is less homogeneous than in later stages of market development. The same applies to storage. Storage is important for security of supply, and system flexibility and stability in an energy system where variable production plays an increasingly important role. Both storage and imports of hydrogen carriers can play an important role in providing security of supply, system stability and flexibility. The economics and ease of transportation and storage may be an important factor in the full value chain development of one or two types of hydrogen carriers. The ease of non-converted hydrogen carrier use in for instance seaborne shipping or (dispatchable) power generation is equally important.

8 We will discuss the various development models of the value chain further on in this report.

3 ENERGY POLICYMAKING

Security of supply[9] is one of the priorities in the energy policy of a country, in addition to affordability and acceptability. The latter priority is often also referred to as 'clean', but it is to be expected that with the advancement of new energy technologies, such as solar and wind at an industrial scale, new 'externalities' may emerge that will require additional policymaking. Land and coast/sea use, for instance, will increase and may create local or other dislocations and cultural issues that cannot be easily foreseen now, but will require additional policymaking to make them acceptable. If no new externalities appear, and 'clean' as in lower CO_2 or other greenhouse gas emissions still applies, the traditional tension between the three priorities of energy policy may wane over time. However, new externalities related to new energy technologies will undoubtedly materialise and require additional policymaking.

The three priorities of energy policymaking are often presented as a trilemma (see figure 2), because it is difficult to achieve all three of them at the same time. At best, only two of the three can be combined in policymaking. For instance, if coal is cheaper than other sources of power, it may help affordability, but not the environment/CO_2 emissions and therefore acceptability. Also, the limitation to burn coal in power stations may help CO_2 emission reduction, but also limits the options to diversify in power production as regards to source, or as regards to geographic origin when there are only a few suppliers.

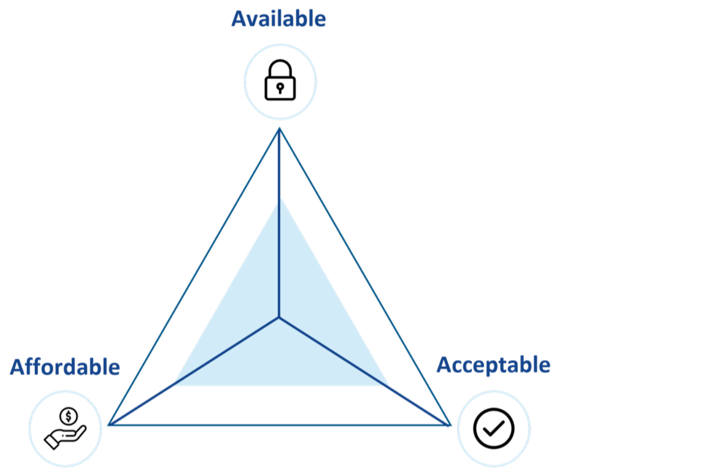

FIGURE 2 ENERGY POLICY TRILEMMA

9 This work draws on insights developed in various CIEP-studies on security of supply policy in oil and gas (2004, 2011, 2012, 2014 2015, 2016, 2017, 2018, 2019, 2020 and 2021) and earlier work of Van der Linde on the dynamic market theory and the oil value chain (1991, 2000).

Currently, all three priorities of energy policy appear at stake. The tight markets in oil, natural gas and coal, due to low investments in previous years, and a rapid increase in energy demand at the end of the covid-19 pandemic induced lockdowns, has turned the buyer's market into a seller's market. The subsequent higher energy prices are already a test to affordability. Moreover, the substantial dependency on Russian energy supplies and the total collapse of the energy relation is a major challenge to security of supply.[10]

Investments in solar and wind did reduce the role of fossil fuels in power generation. However, because of the variability in the solar and wind power generation, fossil fuel dispatchable power generation is still necessary to match demand and supply. Heating and mobility still largely rely on oil and gas. In the medium to longer-term, the contribution of biofuels, solar, wind geothermal, and low carbon hydrogen will help mitigate the fossil fuel import dependence, and the current crisis may expedite part of the EU Fit-for-55 programme. Nevertheless, new strategic dependencies may occur when developing these new value chains.[11] The current energy crisis increases the need to speed up the contribution of domestic and imported low carbon energy production to reduce current demand for coal, oil, and natural gas. Since building new value chains takes time, serious short- and medium-term issues with security of supply will challenge governments to address both these shorter-term problems and keep on building a new energy and resource system.

The current energy crisis has both short-term and medium to long-term security of supply dimensions now that the energy relation with Russia is disturbed for a longer period. For industry an important source of relatively cheap natural gas may no longer be available and dramatically change their competitive position when they must rely on more expensive Liquefied Natural Gas (LNG). The same applies to other internationally competing sectors in the EU. The share of fossil fuels in total primary energy consumption is still very large, despite the growth in renewable electricity production.

The crisis could imply an abrupt change to more costly energy (carriers) for industry (and power) and fast-forward them into a more radical path towards energy transition, without the benefit of international competitors going through the same process at the same time. This could seriously impact the competitiveness of EU industry and could cause a restructuring of EU industries producing for world markets and perhaps incite a reorientation on EU markets. This may also change the potential demand of industry for low carbon hydrogen. Industry is an important factor in potential low carbon hydrogen demand, as they need the large volumes to

10 https://www.clingendaelenergy.com/inc/upload/files/Sanctiebeleid-verdient-strategische-discussie.pdf

11 Volkskrant, Groene energie maakt China Oppermachtig: 'Alsof we cocaïne verruilen voor heroïne', 14 mei 2022

replace current feedstocks and energy use. The large volumes create the potential for the development of these new values chains (domestic and imported).

The Netherlands is aiming to develop an electricity and hydrogen backbone to supply the new energy and feedstock system. The Netherlands (and NW Europe) is not expected to become completely self-sufficient, despite the substantial potential for offshore wind in the North Sea, expected regional trade with other countries around the North Sea, plans to convert some domestic power into hydrogen produced via electrolysis, and plans to convert industrial waste gases into low carbon hydrogen with CCS.[12] Hydrogen imports will be necessary to fulfill the expected demand in a future low carbon energy and feedstock system. This is particularly the case when economic specialisation in previous decades, which was based on strategic choices in a different geopolitical environment with a less open international trade system, is reversed, and the EU-countries are stimulated to opt for reshoring process industries to reduce strategic dependency on crucial commodities and commodity processing.

Currently, security of supply is very much focused on fossil fuel producing countries, also because sufficient processing capacity is still available in the EU. However, when we look at the resources needed for an energy system based on renewable technology, such as solar and wind, the dependency on China's processing industry may become a strategic bottleneck (see Figure 3) to develop the imported hydrogen value chains without entering into new strategic dependencies.

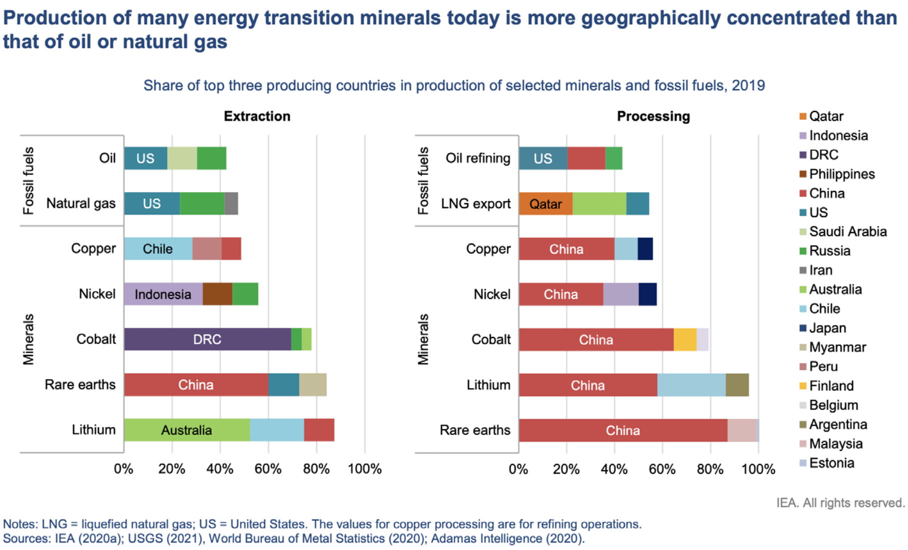

FIGURE 3 THE CONCENTRATION OF MINERAL PRODUCTION AND PROCESSING
SOURCE: THE ROLE OF CRITICAL MINERALS IN CLEAN ENERGY TRANSITION, IEA, MAY 2021.

12 EU indicated that about 40 GW needs to be imported in the EU in 2030. Germany already indicated that they need to import 1 Mton per year in 2030. https://nationaalwaterstofprogramma.nl/file/download/830f9c4c-c2f2-47c5-b6f2-0fd6b86d58ac/20210422-csww-inbreng-subgroep-import-export.pdf

In the recent IEA report *Securing Clean Energy Technology Supply Chains* (July 2022) the issue of future security of supply is addressed. Figure 4 shows a cut-out of figure 2 of this report, showing the value chain for low carbon hydrogen. From these value chains it becomes clear that minerals, processing and manufacturing play an important role. This is different from current fossil fuel security of supply where securing the flow is important (because we do have processing facilities close to the market: refineries, gas terminals). For the clean energy technologies, not only securing the minerals, but also processing and manufacturing them need to be developed. In addition, also construction matters. On page 9-11, the report states in short that: "clean energy technology is fundamentally changing the nature of energy security. (…) Low emission hydrogen and its derivatives (including ammonia) and bioenergy/biofuels, may face similar energy security challenges to traditional fuels. By contrast, a shortage or spike in the price of a raw material of component required for producing batteries and solar panels will primarily affect the roll-out and availability of new capacity additions."

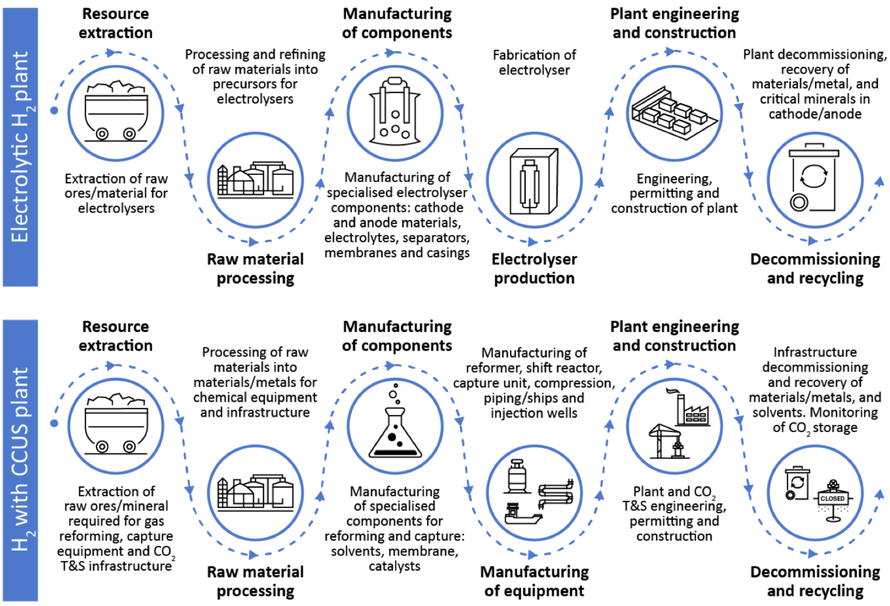

FIGURE 4 LOW CARBON HYDROGEN VALUE CHAINS

Another issue in developing the value chains for imported hydrogen carriers is the capital expenditure that needs to be invested in the new trading partners. In an uncertain world, investors may be reluctant to outlay large (dedicated) capital investments in countries where it is unclear if and how the investors can collect their return on capital. If the risk premium becomes too high, investments may not materialise or not without some solid government guarantees of importing states. These guarantees could be political or economic.

An analytical framework for security of supply should enable tracking the evolution of import dependency of low carbon hydrogen as regards geographic origin and contractual format of low carbon trade flows, market developments, market structure, the type of market players and trade relationships. Tracking these developments informs the government on how to manage dependencies. This framework is not fundamentally different from that for coal, oil and natural gas, or other resources, except for including certain characteristics of the low carbon hydrogen value chain. It is important to invest in government knowledge in value chain development in order to be able to manage security of supply in various phases of this development. Such a framework is in accordance with the framework developed by the IEA in the July 2022 report on Securing Clean Energy Technology Supply Chains, where in table 3, page 16-17 a similar list of criteria and factors to consider is presented. Together with the logic of the dynamic market approach of developing new value chains and markets, this should provide a handle on how to monitor and collect information on security of supply in low carbon hydrogen.

The current situation of energy dependency on Russia shows that open international markets are not a guarantee for security of supply, and that investing in and maintaining competences in certain value chains is crucial. The promotion of solar and wind, for instance, is not (yet) considering questions about the strategic dependencies on Chinese production, and therefore an example of the incompleteness of our thinking on strategic dependencies and security of supply. Another challenge will be to manage both old and new dependencies in the period of transition. The assumption that countries can gradually reduce consumption on the fossil system and switch to the other system, does injustice to the economics of investment and supply (in both old and new energy technologies). The likelihood of mismatches in supply and demand will increase in the coming years, apart from geopolitical conflicts and less ability to access resources and market. This may affect affordability and acceptance, particularly when monetary policies are out of sync with economic developments (in parts of the EU).

SECURITY OF SUPPLY POLICY

Security of supply includes both short-term and longer-term supply issues.[13] The IEA definition of security of supply, which we will apply here, is: (…) 'the uninterrupted availability of energy sources at an affordable price. Energy security has many aspects: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. On the other

13 In Dutch, the word 'leveringszekerheid' applies to the day-to-day security of supply (short-term) and 'voorzieningszekerheid' to the medium- and longer-term issues and often leads to linguistic misunderstandings.

hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance. (…) Disruptions in energy systems have the potential to cause severe impacts, thereby limiting economic and societal development. As such, modern energy systems need to be able to withstand shocks from a wide range of sources, including natural disasters, geopolitical conflicts, and new and emerging threats related to the ongoing digitalisation of energy systems.'[14]

Disruptions, or a shortfall of supply, can be a result of both supply and capacity issues (see Figure 5). To guarantee that firm demand can be met, infrastructure to transport hydrogen (carriers) from the production site to the end-user, and the availability of supply volumes, are vital. Regarding potential disruptions in supply capacity, it is important that transit risks in pipeline transportation and chokepoints in sea transport are included. The risk and impact of a disruption or shortfall in supply, which the market cannot or not easily accommodate, are part of the security of supply risks and should be mitigated, if possible, by policymaking.[15] In this study we will also distinguish the security of supply risks in the various stages of development of the low carbon hydrogen value chain and the development stage of the (international) market. To analyse these stages of development we will use the dynamic market theory as guidance. Moreover, we will also begin to explore the various companies that are (potentially) interested in developing a (international) low carbon value chain. Some companies have a lot of experience in organising international energy value chains, while others rely on contracting out part(s) of the value chain. Based on their core competencies and capacities, we will try to understand their contribution to the robustness of the supply and capacity developments. We will discuss this later.

SECURITY OF SUPPLY FRAMEWORK

Based on the security of supply framework of D.J. de Jong (CIEP 2012, 2014), there are three types of security of supply (capacity and supply): operational, strategic, and long-term (see figure 5). **Operational adequacy** implies that there is sufficient hydrogen capacity and available supply to meet both daily demand and peak demand (e.g., during a severe winter or peak demand season). **Strategic robustness** addresses the ability of the system to serve firm demand in case of a disruption. It indicates potential vulnerabilities and the level of resilience of the

14 https://www.iea.org/areas-of-work/ensuring-energy-security

15 https://www.clingendaelenergy.com/inc/upload/files/NF-HFD-20211013-0-025-006.pdf and https://www.clingendaelenergy.com/publications/publication/prospects-for-sustainable-diversification-of-the-eus-gas-supply

system (flexibility), in case of a defined loss of infrastructure or a sudden interruption of supply due to, for example, (geo) political, technical, domestic, or external issues. **Long-term availability** focuses on satisfying long-term projected demand and includes appropriate political and economic relations and a healthy investment climate to mobilise timely investments in supplies and (infrastructure) capacities.[16]

	Operational	Strategic	Long-term
Capacity	Capacity to process (or import) and transport hydrogen to meet defined peak daily demand	Processing (or import) and network supply capacity sufficient to meet peak firm demand in the event of defined loss of infrastructure	Processing and network expansion designed to meet the anticipated demand growth
Supply	Supply available to meet both the defined daily demand and to supply during a severe period/winter	Ability to meet firm demand in the event of a severe disruption to the principal supply source	Supply available to cover future projected demand

Security of supply low carbon hydrogen

FIGURE 5 SECURITY OF SUPPLY FRAMEWORK

SOURCE: BASED ON EARLIER STUDIES ON SECURITY OF SUPPLY (CIEP, 2012 AND 2014)

Security of supply is not only a government issue, but often a combination of coordinated interventions between governments and market players. The coordinated efforts in the oil crises of 1973/74 relocated flows of oil to both adhere to the embargo of the Arab producing countries (OAPEC), and supply the embargoed countries (US, Netherlands, Portugal, and Denmark) from elsewhere to mitigate the impact. In gas, the ability to supply tsunami-stricken Japan also relied on the flexibility of both producers and market players.

In the current energy crisis (2022), the coordination efforts must not only focus on issues in one energy carrier (oil, gas, coal/electricity production), but on all energy sources. The energy system has become a lot more complex and interwoven in the last couple of years due to efficiency drives, energy transition measures and IT-solutions. This has complicated coordination, because the second and third order effects of disruptions are much more unclear and involve many more players. This complexity could have surfaced if energy sector participants had been privy to the discussions in the run up to sanctions on oil and coal.

16 See also CIEP, 2004; and also Arianna Checchi, Arno Behrens, Christian Egenhofer, Long-term Energy Security Risks for Europe: A Sector-specific Approach, CEPS Working Paper, 2009.

This interplay between governments and companies seems to be absent or slow in ramping up in the current energy crisis, despite the already substantial re-location costs of the energy related sanctions on Russia and the counter sanctions.[17] In various communications[18] references are made to: ‘the market can solve a lot of the dislocation costs and import oil and gas from elsewhere’, without discussing this in depth with the main market participants (apart from demanding OPEC to produce more). This is troubling from a security of supply perspective, because coordination can be an important crisis instrument in security of supply policymaking.

Obviously, the 1970s are not comparable to the 2020s in terms of geopolitics, contractual relations and market structure. In the 1970s, governments and companies only had to organise dislocations in oil, which was complicated enough, but in 2022, the dislocations span all fossil fuels, without a publicly available, deep analyses of the first, second and third order effects of the sanctions on energy. The short-term orientation of current EU (fossil) energy markets in contracting energy flows and the willingness to give up the sanctity of (long-term) contracts may reverberate in future energy (and low carbon hydrogen carrier) markets. An often-forgotten dimension of security of supply is the reliability of demand. Although the logic of the sanctions may be clear to the West, some current and potential producers and exporters may take a dim view of demand reliability in the EU.

The ability to accommodate disruptions depends on the flexibility of the energy and resource system but also on the producers’ ability to increase supply when needed, i.e., having spare capacity or strategic reserves to compensate for production losses elsewhere. Another option to mitigate a supply disruption is for the energy system to be able to rely on dual-firing capacity, allowing for a quick change in fuel for a certain amount of time. Moreover, the duration of the disruption and the ability to mitigate the worst effects also play an important role. Apart from disruption risks in producing countries, supply disruptions can occur because of technical failures (e.g., infant industry trouble, mechanical malfunctioning, or IT infrastructure defects), accidents (e.g., explosion, fire, or leak), or a disaster (e.g., piracy, extreme weather conditions or terrorist attacks). The incidence of technical failures and accidents are

17 The EU has produced its REPowerEU plan (where the sanctity of energy contracts is at least questioned/placed under pressure), but failed to deliver an impact study of the proposed sanctions and set up a coordination mechanism to manage the supply shock (May 2022). Individual member states also were somewhat slow to coordinate with the market participants, perhaps expecting that the conflict would be short lived.

18 Sweder van Wijnbergen, https://www.nporadio1.nl/podcasts/de-jortcast/67635/425-zonder-olie-is-rusland-tweederde-van-nederland-met-olie-15-keer; Peter van Bergeijk: https://www.nporadio1.nl/podcasts/de-jortcast/69423/438-stop-poetins-rollende-roebel

more frequent than those caused by geopolitical disputes, but the impact of a geopolitical motivated disruption is usually larger and longer in duration.

Traditional instruments of security of supply are typically:

- strategic stocks (oil)
- diversification to source (type of fossil fuel; for hydrogen the type of carrier)
- diversification to geographic origin (the exporting country)
- flexibility (such as fuel switching capabilities)
- energy efficiency
- demand management
- maintaining good (political and trade) relations (EU and per member state)
- energy diplomacy (for instance collaborating with other net-importing countries, such as in IEA, IRENA, IEF or the EU) to promote long-term security of supply, or in case of net-exporting countries (OPEC, GECF, IEF) to promote security of demand.

In general, security of supply is part of the wider trade, foreign and security policies of states. The level of security of supply is also influenced by the market structure (i.e. the level of vertical and horizontal integration), access to resources and markets, contractual relations, concentration and type of ownership and regulation of resources, conversion, and transportation.[19] Many of these traditional instruments of security of supply policies can also be applied to imported low carbon hydrogen, of course taking the characteristics of the energy carrier into account.

BUILDING ON PAST EXPERIENCES IN SECURITY OF SUPPLY

Security of supply policy matured due to the oil crises in 1973/74 and 1978/79.[20] Before that, countries relied on oil supply organised by large international oil companies and limited strategic reserves (created after the closure of the Suez Canal in 1967, when Middle Eastern supplies had to be re-routed around the Cape Good Hope). These vertically integrated companies originated in the US and Europe and brought oil from foreign oil fields (mainly Middle East, Venezuela, North Africa, and Indonesia) to markets, often to their own processing plants or they delivered under long-term contracts to other (processing) companies. Deliveries of 'crude long' international oil companies to 'crude short' ones under long-term contracts, was the method used to balance the market, while the companies also collaborated in the

19 Study on Security of Supply, CIEP, 2004.

20 Coby van der Linde, Dynamic International Oil Markets, Kluwer, Dordrecht, 1991 en Bassam Fattouh en Coby van der Linde, Twenty Years of Producer-Consumer Dialogue in a Changing World, IEF, 2011, https://www.clingendaelenergy.com/publications/publication/ief-twenty-years-of-producer-consumer-dialogue.

Middle East consortia, where they nominated the production ceilings the market could absorb on a yearly basis.[21] Conspicuously absent from these consortia were the Independent American Oil companies who became exporters to Europe when they managed to develop oil fields in North Africa, and the French and Italian oil companies (predecessors of what is now Total Energies and ENI), and of course, companies from any other country. It was these independent oil companies that were pressured to raise oil prices in the early 1970s, which resulted in the Tripoli and Teheran agreements, just prior to the oil crisis. These independents could not organise alternative flows, and the big oil companies declined to help (or thought they could not help due to US competition law)[22]. As a result, they could be pressured by the producing countries to agree to their demands. The lesson here is, that in periods of structural change, it is important to know the organisation of the value chain and the relative strengths and weaknesses of the market players to understand the security of supply risks.

OIL

In November 1974, based on a decision at the Washington Conference in February 1974, the International Energy Agency was founded with as its main task to manage oil security of supply (strategic stocks, demand management and collaboration). [23] In the course of time, the IEA has expanded its work to all energy sources, energy value chains and the energy transition. However, the IEA only has special authority regarding security of oil supply, laid down in the International Energy Programme (IEP; November 1974). In 1974 the foundation for EU security of supply was created. In December 1974 the member states agreed to develop a common energy policy. Nevertheless, legally speaking, the oil policy of the IEA prevails over that of the EU, because it existed before EU policy.

In NW Europe domestic coal and natural gas production provided security of supply for a long time. North Sea oil and gas production (UK, Norway, the Netherlands), onshore gas production in the Netherlands, gas production in Italy, and coal and lignite production in Germany. In the 1970s, some countries added nuclear energy to their energy mix to reduce the dependency on imported energy (mainly to reduce the use of fuel oil for power generation).

Import dependency of oil became problematic because of geopolitical and economic conflicts in the period of decolonialisation and the (re)organisation and ownership

21 see van der Linde, 1991. Dan Yergin, The Prize, Simon & Schuster, December 1990.

22 Armand Hammer (with Neil Lyndon), Armand Hammer: Witness to History, Coronet Books, Hodder and Stoughton, 1987.

23 https://www.iea.org/reports/the-history-of-the-international-energy-agency-the-first-20-years

over local oil production (in producing countries) and the rewards these countries received. In 1960, the oil exporting countries organised themselves in the Organisation of Petroleum Exporting Countries (OPEC) in Bagdad, after several years of campaigning by Venezuela to oppose the dominance of the international oil companies (the so-called Seven Sisters). OPEC tried to improve (and stabilise) their income from oil. At the same time, in the 1960s, there was a movement to build processing industries (refining and petrochemicals) closer to the market, because demand for a variety of oil products rose, and it was cheaper to transport as crude than as separate products. Furthermore, it reduced the risk of exposure to nationalisation of capex, which had increased with decolonialisation.[24] After 1973, oil production and refineries in producing countries were indeed nationalised, and production and exports came in the hands of newly established national oil companies in producing countries. Some consuming countries created (or expanded) their state-owned companies to secure supplies (France, Spain, Portugal, UK, Italy). After the second oil crisis in 1978/1979, the long-term contracts between the national oil companies and the international oil companies were also terminated. From then on, short-term oil trade prevailed. This was a period of vast changes in the structure of the oil market.

The current energy crisis forces EU-based companies to sell their Russian assets, because of sanction policies directed at Russia. This may have a similar impact on the structure of the market. Russian companies, Chinese state-owned companies, and other Asian companies are the only likely buyers of the Russian assets of Western oil companies, thus expanding their ownership of energy and resources. For several years now, there is a trend that the ownership of oil, natural gas, and mineral resources which are important for the energy transition, is becoming more concentrated and in the hands of state companies, supported by mostly nationalist/autocratic regimes.

NATURAL GAS

In natural gas, long dominated by long-term-contracts and regional markets, liberalisation of the market first began in the US and later also in the EU. Increasingly, long-term contracts (in gas they could be up to 30 years), became shorter, more flexible or were replaced in part by short-term trade. The liberalisation was helped by the emergence of more Liquefied Natural Gas (LNG) that could be transported competitively in larger ships and over longer distances than in the decades before. This unlocked gas reserves had previously been stranded (for instance in Qatar and Australia). These developments in oil and gas happened alongside a growing

24 Van der Linde, Dynamic Oil Markets, 1991.

availability of oil and gas from more producers finding more diverse markets.[25] The current energy crisis may also change the structure of natural gas markets.

In short, the development of the oil and gas trade was characterised by growing volumes and growing demand in world markets and a diversifying group of buyers and sellers. Despite the expansion of LNG in the past two decades and the accompanying growth in terminal capacity in the EU, security of natural gas supply remained worrisome because the concentration of pipeline supplies (in the north and east mainly Norway and Russia, and in the south Algeria and to a lesser extent Azerbaijan), and the competition for LNG with Asian countries (mainly China, Japan, and South Korea) is substantial. The liberalisation of the EU natural gas market and the development of hub pricing (without accompanying security of supply provisions on diversity of supply), primed the market for the cheapest supplies. This was especially pertinent in the during the buyer's market between 2014 and 2021.

SECURITY OF SUPPLY: ABOUT UNSHARED RISKS AND COMPETENCE BATTLES

Market regulations regarding security of supply have been much less structured for gas than for oil (which is coordinated by the IEA). Although the EU made some progress to protect households, member states had difficulty to come to an agreement on how best to increase security of natural gas supply. The legacy of the East-European countries and their connection to the oil and gas pipeline systems - and the electric power system too - originating in Russia, played an important role in their positioning in the routing of gas pipelines. Since the eastern enlargement in 2004, the discussion on security of supply and security of gas transit was centred mainly on dependency on Russian supplies. Strangely enough, this discussion in the EU was focused only on natural gas and not on a similar dependency on Russian oil pipelines and coal imports. Historical grievances among some (previous) Comecon-countries about Russian oil and gas pricing and deliveries and routes also played an important role and this was not always understood in the western and southern European member states.[26] The noughties gas conflict between Ukraine and Russia was a new chapter in this conflict over these energy relations.[27] In general, West-

25 Various World Energy Outlooks, 2015, 2016, 2017 and Gas Market reports, IEA.

26 Thane Gustafson, Crisis amid Plenty, The Politics or Soviet Energy under Brezhnev and Gorbachev, Princeton University Press, 1989, Chapter five.

27 Tom Smeenk, Russian Gas for Europe: Creating Access and Choice, CIEP 2010;
Timothy Boon von Ochsee, The Dynamics of Natural Gas Supply Coordination in a New World, CIEP, 2010;
Coby van der Linde and Jacques de Jong, Upping the Stakes, some lessons for the EU from the recent Russia-Ukraine gas crisis, February 2009; Coby van der Linde and Geert Greving, Turbulentie in de pijpleiding, Gasconflict Rusland-Oekraine en Russisch-Europese energierelaties, in: Spectator, jaargang 60, nr. 4, April 2006.

and South-European countries were until recently more comfortable with supplies from Russia than East-European countries. At the same time, security of demand and transit for Russia also became an issue, when the relationship with the EU deteriorated. The 'schadenfreude' in some EU member states over Germany's current gas supply position is not helpful in the current crisis.

The unshared histories in energy relations were unfertile ground for the enlarged EU to agree on stable energy relations with Russia and narrowed the EU security of supply discussions and solution space, while the options to diversify pipeline supply to the EU remained limited.[28] The asymmetric distribution of underground storage space, due to the different geology of member states, proved to be a complicating factor in the discussion on security of gas supply policies. This could have been remedied by creating a package of instruments which included dual firing capacities in gas power generation as a security of supply measure for member states that were unable or only able at great costs to realise a strategic gas storage.[29] This is contrasted with the relative ease and lower cost of oil storages, both above and underground, and the optionality to use several modes of transportation for oil and oil products, which helped the IEA develop its strategic oil stock policy. Also, there was a radical difference between the wish to coordinate oil policies after the first oil crisis in 1974 and the subsequent battle in the 1970s among the member states over competency over energy policies between the EU and IEA, and within the EU. Some EU member states favoured the intergovernmental approach of the IEA, others the intragovernmental approach of the EU, and some insisted on maintaining a national say over energy policymaking. Preferences depended in part on the general policy tradition, the domestic resources of the member state and ideas about the level and type of integration.

Regarding future imported low carbon hydrogen flows, the asymmetric abilities of the member states to produce and import low carbon hydrogen must be considered in future EU security of supply policymaking and market regulation. These asymmetries may reflect the landlocked nature of central and eastern Europe when potential imported supplies from Russia remain blocked from entering the EU market. The domestic production potential of these EU member states is important to determine their need for imported low carbon flows and coast-inland infrastructure needs.

28 Outlook for gas series, 5 papers on gas supply and demand and options for Security of Supply, CIEP 2016.
29 CIEP, Study on Security of Supply and Geopolitics, January 2004.

FOCUS OF EU POLICYMAKING

With the emergence of new energy technologies and the EU *Green Deal* and the *Fit for 55* packages, the competence over energy policymaking of the EU is growing, compared to the (fossil fuel) competence of the IEA. Nevertheless, the focus of EU energy policymaking has been on climate change and expanding the renewable energy and resource system, and until recently, less on (traditional) security of supply. This could be explained because initially introducing alternative (domestic) low carbon supplies improves security of supply in a still fossil fuel dominated system. Nevertheless, with self-sufficiency impossible to achieve, as is sometimes suggested, new import dependencies will emerge which require policy attention.[30] The growing dependency on rare earths and minerals production and processing is already clear and closely monitored by both the EU and IEA. [31,32] Particularly, the development of geographically long hydrogen value chains warrants a closer look at these new dependencies and the ability to develop security of supply policies.

The *Fit for 55* programme and REPowerEU progamme will only magnify these new dependencies and will require accompanying security of supply policies to manage these new dependencies. This management can be at the level of the member states, or, in line with recent moves by the EU Commission (for instance in their proposal for joint purchasing of natural gas), become an EU-competency because of the current energy crisis and the interdependencies in the EU internal energy market. It would also fit in the recent trend of increasing government intervention in energy markets which could be further accelerated by the current crisis. How that fits with initiatives of companies to develop long value chains in low carbon hydrogen is unclear, also because the EU treats hydrogen as a gas (see proposed gas and hydrogen market directive[33]) and does not consider the possibility of landing the low carbon hydrogen carriers as a liquid. Nevertheless, the EU Commission may have been stimulated by the joint purchasing of vaccines in the covid-19 crisis and the example of the German Global Hydrogen Fund. If they apply this model to low carbon hydrogen, the German Global Hydrogen Fund would become 'EU-inised' and turned into a joint purchasing platform for low carbon hydrogen. Such a development would conflict with the Lisbon Treaty (at least with the spirit of it), and the professed (but maybe outdated) aim of the EU to become the most competitive and open economy in the world. Such a development could make the EU a

30 CIEP, Security of Supply in the run-up to the post-2020 period, 2014.

31 https://ec.europa.eu/growth/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en

32 IEA, The Role of Critical Minerals in Clean Energy Transitions, World Energy Outlook Special Report, May 2021.

33 https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/hydrogen-and-decarbonised-gas-market-package_en and https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/729303/EPRS_BRI(2022)729303_EN.pdf

monopsony or at best an oligopsony in the budding low carbon hydrogen import market.

The OECD defines a monopsony and an oligopsony as: "A monopsony consists of a market with a single buyer. When there are only a few buyers, the market is defined as an oligopsony. In general, when buyers have some influence over the price of their inputs, they are said to have monopsony power."[34] It is important to understand the impact of such a proposal on the international market structure and the development of low carbon hydrogen from one phase of development into the next one. Such a strategy could help expediate the transition from the introduction to the expansion phase, by guaranteeing demand and helping investors to build production capacity more quickly. However, the government may fail to retreat in time as a market player once the expansion phase is underway, and thereby hinder the competitive drive of investors in the low carbon hydrogen value chain. The expected increase in efficiency and cost reduction translating in affordability may materialise later than when the market drives investments and competition in this phase. The development of a low carbon international value chain would have to be viewed through a different lens if that were to occur.

Though perhaps not intended as an outcome, the efforts of the EU to accelerate the energy transition and force all the member states in the same direction, coupled with the changing geopolitical context, seems to make the EU develop into a more corporatist state than maybe anticipated a few years ago. Moreover, such a development, where the (energy) economy is dominated by the state, is exactly what the EU is opposing in China, Russia, and other countries.

Government and regulatory authorities are assumed to adapt to the phase of development of the value chain and market, and the level of concentration and competitiveness.[35] Nevertheless, it is possible that government intervention will (temporarily) persist as a result of the current serious energy crisis, and impact on the logic of value chain and market developments as assumed here.

34 Glossary of Industrial Organisation Economics and Competition Law, compiled by R. S. Khemani and D. M. Shapiro, commissioned by the Directorate for Financial, Fiscal and Enterprise Affairs, OECD, 1993. "One common use of the notion of monopsony power arises in the context of defining market structure. For example, in cases where monopoly power is the issue, it may be useful to examine the extent to which such power is offset by powerful buyers. This is sometimes referred to as countervailing power. The ability of a firm to raise prices, even when it is a monopolist, can be reduced or eliminated by monopsony or oligopsony buyers. To the extent that input prices can be controlled in this way, consumers may be better off. A second important use of the concept of monopsony power arises in cases of vertical integration and merger. It is generally agreed that where monopsony power exists, there will be an incentive for vertical integration. Moreover, under some circumstances it can be shown that vertical integration, even when it occurs between a monopolist and a monopsonist (bilateral monopoly), can increase economic efficiency."

35 Coby van der Linde, Dynamic International Oil Markets, Kluwer, 1991.

Joint purchasing may not be the answer to accelerate the hydrogen economy. Particularly when the proposed regulatory framework is so strict, that companies applying the vertical integration model of development of imported low carbon hydrogen to mitigate investment risks, are forced in a straitjacket where they are turned into a 'delivery service at the EU door' and denied direct access to clients. Unlike the US, with its pragmatic regulation, the EU chose this model for LNG terminals, which resulted in very low utilisation rates for a long time and made the EU more vulnerable regarding imports from Russia. It would be wise to allow various business models to develop, value chains and markets to emerge, and to regulate more dynamically, fitting the stage of development of the value chains and markets. Here transparency may help, also in identifying potential low carbon hydrogen demand. The EU could still refrain from preferring one technology and/or carrier and/or one business model/market model over another, even if in the long-term a certain regulatory preference would become obvious. Only when the domestic and imported volumes grow to a more substantial size, more clarity will exist on how the new markets work and should be made to work, not beforehand. The current geopolitical climate may be one of the stress factors that changes the current underlying assumption of open international markets for resources and commodity flows for low carbon hydrogen. Although a certain mould is helpful at the introduction stage of developing new value chains and markets, history has shown that events and the international political and economic order are important in shaping these new energy carrier activities.

4 IMPORTANCE OF MARKET DEVELOPMENT PHASES AND SECURITY OF SUPPLY

Development of international hydrogen value chains and trade in hydrogen carriers may develop over time, similarly to that of oil and natural gas. The interesting part is that ultimately low carbon hydrogen must replace both current gas and crude oil/oil product consumption, to achieve net-zero emission energy systems. Although the value chain developments in oil and gas have a lot of similarities (also because of joint production and Natural Gas Liquids-NGL's and Liquid Petroleum Gas-LPG), they also have a lot of (defining) differences. These differences are technical-economic and caused by EU regulation (internal gas market, no market regulation on oil and oil products, apart from fuel quality specifications), but can also involve different business development models.

The development of hydrogen value chains will thus share similarities to the natural gas and oil business, but also display differences. An important factor is that different hydrogen carriers exist and are under development (LH_2, LOHC, methanol, and ammonia are the most mentioned, although other carriers may also be developed). The technical differences in both producing, conversion and transportation of the hydrogen carriers require different models of absorption in the market (conversion), but also have different infrastructural needs. Although hydrogen will be consumed as a near homogenous energy carrier (depending on the purity of the hydrogen needed), the production, conversion and transportation may become less homogenous than initially thought and may be much more like the current energy system where solids, gases, and liquids all play their role.

In addition, these different preferences may also depend on the core capacities and capabilities of the companies developing an value chain for the import of certain hydrogen carriers. These companies may have roots in or outside the energy sector (power companies, oil and gas companies, industrial gases companies, wind developers, chemical companies, transportation companies, traders, utilities, etc.) and develop imported low carbon hydrogen value chains within the logic of their existing business. Some companies will engage in forward or backward integration, and initially vertical integration may increase, while others may increase their participation in joint ventures. These developments are typical for a new life cycle, where many uncertainties still exist and need to be managed. Collaboration can be a way to organise deficiencies in expertise, the ability to raise capital and mitigate risks.

The initial trade in low carbon hydrogen (carriers) will be relatively modest in volume, in comparison to other energy trade flows, and most likely involve point to point trade, underpinned by long-term contracts from production to end-user. Such a development is typical for new capital intense value chains. Also, government support is not uncommon. The first LNG-cargoes were stimulated by government support to facilitate the development of the value chain and guarantee demand for imported gas. This support helped to mitigate the investment risk in these capital intense projects. The government of Japan was instrumental in developing LNG-imports from Malaysia and Brunei, while the governments of the United Kingdom and the US were instrumental in developing LNG-exports from Algeria in the 1970s.

Just like the first international flows of exported oil and natural gas, at first the flow of low carbon hydrogen (carriers) will be very concentrated, with one or few suppliers and few buyers. This is typical for this phase of development. In the expansion phase the market will begin to deconcentrate, due to the entry of more producers and consumers entering the market. Depending on the barriers to entry (and exit), the number of market players may be limited and result in an oligopolistic market with a competitive fringe (like in oil and natural gas) in that stage of development (of the European market). The entry of state oil and gas companies in the production and conversion of oil in the 1970s, of gas in the late 1990s and early 2000s, and the internationalisation of Asian state companies from the 2000s onward, has changed the ownership landscape of the oil sector. The prominence of China in renewable production, minerals and mineral processing indicate an early strategic position in the new low carbon hydrogen value chain development and market. The current geopolitical developments of decoupling from Russia and to some extent from China, may stimulate production and processing of minerals elsewhere, as well as other resources needed for energy transition, and influence the market development of low carbon hydrogen. These developments should be monitored closely, because they may impact on future security of supply.

A complication for imported low carbon hydrogen carriers in the Netherlands can be that the Dutch government is currently also supporting the development of domestic low carbon value chain. The implication could be that domestic value chain development/the domestic hydrogen industry will be given a preferential treatment, as an 'Infant industry', which may make market entry for imported low carbon hydrogen more difficult. The fact that the EU still applies the trade tariff for industrial gas to hydrogen may be a first stumbling block, while some companies already made a plea for inclusion of hydrogen in the Carbon Border Adjustment Mechanism (CBAM).[36] The current world average tariff on hydrogen is 4.64%, slightly higher than that on ammonia (4.62%).[37] Much will depend on the development of the dimensions of these first flows, and the ability to bring these first flows to clients. Both flows will be initially modest, but may expand quickly if demand grows due to policy pressures towards 2030, and if the logistics can accommodate this growth.

The export capacities in countries with good solar, wind, or CCS resources and assets can either be solely developed for export purposes, or for both domestic consumption and exports. However, it is also possible that the optimal location to produce solar and/or wind is far removed from domestic demand or requires substantial local infrastructure investments, and that the initial investment by foreign investors is done for export purposes only. Discussions about the sustainability of these investments in terms of economic, social, and environmental (ESG) standards are already ongoing. Despite the understandable discussion about preventing export-oriented energy production enclaves for the sake of EU countries, the cost of the first of these projects might be so high for a producing and exporting country that it prohibits them from offering to domestic consumers. Particularly when cheaper, but not always low carbon, alternatives are available. The carbon footprint of some of these potential exporting countries is so low that benefitting from lower cost energy should be possible. At the same time, local benefits of these solar and wind parks should be clear, either in terms of clear payments for land, a minority shareholding, or the development of a solar or wind park closer and easier to integrate into the domestic market to compensate for the enclave. This would be a typical issue under developing long-term good relations between an exporting and importing country and could encompass other (economic) exchanges.

DYNAMIC MARKET THEORY

The dynamic market theory emphasises the changes that each market for a product undergoes through various stages in its lifecycle.[38] The market is seen as a series of

36 https://www.euractiv.com/section/energy/news/electricity-giants-call-for-carbon-tariff-on-eu-hydrogen-imports. Electricity companies, also the ones operating on an international scale, still deliver their product to local markets, while other companies may derive their competence from setting up a value chain and delivering their product to international markets. It shows that the core competences of companies can deliver different strategies and outcomes when engaged in building up new value chains.

37 https://oec.world/en/profile/hs/hydrogen-6280410 and https://oec.world/en/profile/hs/ammonia

38 H.W. de Jong, Dynamische Markttheorie, StenfertKroese, 1981.

‘structures’, changing over time, rather than a static structure. “Market developments” describe these changes, while “market situation” describes the current state of the market for the product(s). This dynamic perspective makes the dynamic market theory an excellent tool to analyse the various market phases and the security of supply issues that may arise or disappear when evolving into the next phase of a market structure.

As a market goes through different stages, it may encounter new security of supply issues which require measures and regulations that fit that phase of market development. This is especially important for markets that require complex infrastructures to produce, convert, transport, and distribute the product, as regulations need to provide the proper incentives for market players to invest in timely capacity expansions along the value chain. Moreover, with the expansion of the market, non-industrial users may not have a back-up energy carrier available and become structurally dependent on a specific supply and network to meet demand, while also the economic impact of a disruption in supply will be larger when more sectors and households rely on a certain energy carrier. The ‘vulnerable consumers’, often households and small and medium sized companies, hospitals, and other care institutions, but also crucial consumers which protect continuity and security of the state (government institutions, police, fire department, army etc.), require additional protection in case of a disruption. The current energy crisis makes clear that also vital industries should fall under this protective status to minimise economic disruption. Depending on the costs to mitigate the risks, several instruments can be used to manage security of supply. Their effectiveness depends on the development phase of the market. In general, the number of security of supply measures increase in the late expansion and maturity phase of the market.

MARKET STRUCTURE

In the introduction phase, the market structure is concentrated, while in the expansion phase the market grows fast, and new entrants quickly reduce market concentration and make the market more competitive.[39] Such a development is important and implies that policy measures to reduce concentration are often not necessary. Much depends on the availability of infrastructure that can absorb the growing flows and connect the growing number of producers and importers with a growing number of users. In the mature phase, the market structure becomes more concentrated again and the focus of suppliers shifts to maintaining or growing their market share through mergers and acquisitions. In this phase of the market development regulatory policies to maintain competition become more relevant. In

39 H.W. de Jong, Dynamische Markttheorie, StenfertKroese, 1981.

the stagnation/decline phase, with only a few surviving companies supplying the market, this becomes even more pertinent (see Figure 6). These companies can be challenged by newcomers bringing an innovation to the market, allowing new applications to emerge, or a different low carbon hydrogen carrier, starting an extension of the life cycle. The incumbents either adapt or disappear (as a separate company).

In the case of the hydrogen market development, much depends on hydrogen becoming an energy carrier outside industry in the expansion phase, to determine the market strategies of market players in the late expansion phase (when growth of the market begins to slow down) and the mature phase. If low carbon hydrogen becomes a systemic energy carrier together with electricity, there will likely be a few large suppliers and multiple users across demand sectors. This would require a different approach in regulation and security of supply policymaking than when low carbon hydrogen largely remains an energy and feedstock carrier for the industrial and power sector. Obviously, the important function low carbon hydrogen will probably play in the economy already warrants security of supply policies due to the importance to the economy. Only when more vulnerable consumers are directly involved in consumption will security of supply policymaking become more pertinent and targeted to protect those consumers also in the short-term, while industry and the power sector need more strategic and long-term guarantees. These measures will depend on how low carbon hydrogen is consumed, indirectly (as a back-up for other heating sources or as a main source for heating), or directly in the form of low temperature heating (like natural gas currently) and in transportation.

PHASES OF MARKET DEVELOPMENT

The dynamic market theory divides the market life cycle into four phases: introduction, expansion, maturity, and stagnation/decline (see Figure 6). In the introduction phase only a few suppliers and users will be in the market, but in the expansion phase more suppliers from more destinations will enter the market and serve growing demand. Often a new life cycle builds on an existing one. In the case of hydrogen, current unabated hydrogen for industrial use can be seen as the launching pad for abated hydrogen and electrolysis hydrogen in particular.

In the case of low carbon hydrogen both the introduction and expansion phase have been placed in a policy pressure cooker, first by the Fit for 55 programme, and since February 2022 because of the short- and medium-term impacts of sanctions on Russian energy exports. In May 2022, as part of the REPowerEU plan to reduce energy imports from Russia, accelerated plans for low carbon hydrogen production and imports were launched.[40] Although many projects (both for domestic production and imports) in NW Europe are in development, they are still on the drawing board and are under increasing pressure to come to Final Investment Decision (FID) sooner than anticipated. The REPowerEU plans anticipates 10 Mton of low carbon hydrogen of domestic production and also 10 Mton imports in 2030 to replace oil, coal and natural gas and intends to expedite investments in production and imports by increasing financial arrangements, projects of common interest and a joint purchasing programme.[41] Much will depend on delivering on all parts of the value chain, including infrastructure, to move quickly from the introduction to the expansion phase of development. In the Netherlands, existing bottlenecks in the capacity of the electricity network, industrial areas, nitrogen emissions and the housing shortage, may make this acceleration difficult to achieve before 2027, the date the European Commission mentions. This comes on top of rising commodity prices and interest rate increases to mitigate the substantial rate of inflation in the EU, likely to make investments more expensive soon.

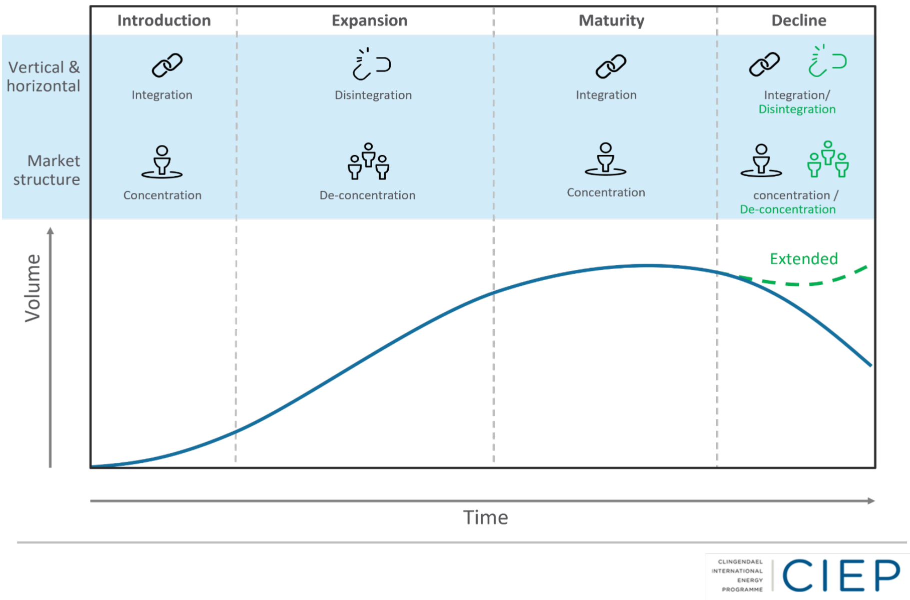

FIGURE 6 LIFE CYCLE, MARKET STRUCTURE AND MARKET DEVELOPMENT

40 FT, EU warns of Euro 195bn cost to free bloc from Russian energy, 12 May 2022
41 https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131

INTRODUCTION AND EXPANSION PHASE

The introduction phase is the innovative stage in the low carbon hydrogen industry life cycle. In this phase an 'innovation' is introduced, which creates a new market. This innovation can be technical, policy driven or both, and create new demand. The production of electrolysis hydrogen and fossil fuel with a high CCUS rate (Carbon Capture Use and Storage) can both be considered to be in the introduction phase (see Figure 7). The latter is built on the long-time experience with Steam Methane Reforming (SMR) and Autothermal Reforming (ATR) to produce hydrogen for industry and is as such an extension of the unabated life cycle. In most cases, natural gas is processed into hydrogen, but increasingly also industrial waste gases are used to optimise energy and feedstock use. The low carbon hydrogen developments can be part of an extended hydrogen life cycle, building on the experience with hydrogen in industry and now developed as low carbon hydrogen to include other demand functions. In addition, electrolysis hydrogen has a long production history, but at a much smaller scale and under different circumstances. The industrial scale and the flexibility with which electrolysis hydrogen must be produced in the future, requires substantial adjustments in the technology to handle the planned volumes.

The demand for low carbon hydrogen has become even more pertinent with the sanctions and countersanctions on Russian oil and natural gas, and the plans of the EU Commission to replace some of the EU gas demand (from Russia) with low carbon hydrogen under the REPowerEU programme. The hydrogen ambitions in REPowerEU are a substantial step up compared to the revised Renewable Energy Directive of July 2021.[42]

The development of electrolysis hydrogen is currently the least far developed for industrial scale application. The first 200 MW electrolyser in the Netherlands has reached FID. Government support into this development helps scaling up in the short-term. The 'resource' for electrolyser hydrogen is electricity from the North Sea wind parks. It is expected that electrolysers will be scaled up in the coming decade to gigawatt scale. The advantage of electrolyser hydrogen is that it produces pure hydrogen, important for applications that require 100% purity, like in transportation. Other applications, like in power generation or low and high temperature heating, may not need that level of purity, depending on the specifications of the equipment, nor conversion when it can be consumed directly.

42 https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en

The Netherlands is the second largest unabated fossil fuel-based hydrogen producer of Europe[43], and it is safe to say that this is a mature/stagnating market, serving industry.[44] However, the emergence of low carbon hydrogen and new policymaking on CO_2-emissions, opens the door to different hydrogen applications and production methods, changing both the value chain and the potential players. The emergence of low carbon hydrogen creates new hydrogen markets such as mobility, heating in buildings, power generation and industrial heating. Low carbon hydrogen has the potential to become an energy carrier with systemic functions. Due to new production processes, import possibilities and new applications, the value chain and market players may differ from conventional hydrogen producers and users. Therefore, electrolysis and abated hydrogen is viewed as an innovation and is currently in the introduction phase.

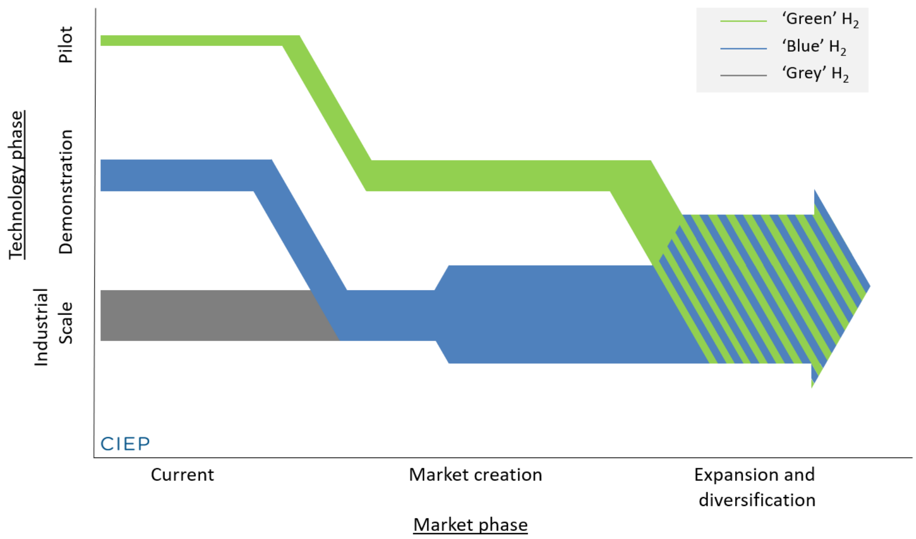

FIGURE 7 POSSIBLE DEVELOPMENT OF LOW CARBON HYDROGEN MARKET

SOURCE: HTTPS://WWW.CLINGENDAELENERGY.COM/PUBLICATIONS/PUBLICATION/VAN-ONZICHTBARE-HAND-NAAR-MEER-ZICHTBARE-HAND-WATERSTOF-EN-ELEKTRICITEIT

The market in the introduction phase is characterised by its relatively small scale, low or no profits and a few (concentrated) suppliers and consumers. In this phase there is still limited experience in production, transportation, and potential applications of the product. The focus in this phase is therefore on research, development and experimentation with pilot and demonstration projects. Security of supply plays no or a very small role in this phase, although early nurturing of new energy relations and help with investments are important for future supply security.

43 R.J. Detz, F.O Lenzman, J.P.M Sijm, M. Weeda, Future Role of Hydrogen in the Netherlands, TNO (TNO2019 P11210), 2 October 2019, p. 6.

44 https://www.clingendaelenergy.com/inc/upload/files/NW-Europe-Hydrogen-Final.pdf

Initially, low carbon hydrogen is expected to be used in sectors that currently use unabated or grey hydrogen (such as the fertiliser industry and refineries), or for processes that cannot easily be decarbonised by RES-based electrification (such as high temperature processes in the industry). The heavy industry is therefore well positioned to be an early adopter of low carbon hydrogen. Policy pressure is an important reason for these industries to become an early adopter. When the industry imports hydrogen in this phase, this will be organised via bilateral agreements and long-term contracts between the industry and exporting business (business to business), and can be seen as first steps to adapt their energy and resource systems.

During the introduction phase there is a high degree of chain dependency between the various parties investing in the new value chain. Sufficient investor confidence needs to be established, while at the same time end-users seek protection against potential market power abuse. Therefore, in order to deal with these investment insecurities and to successfully set up new value chains from production to consumption, it is of paramount importance there is effective cooperation and coordination regarding the necessary investments between the various stakeholders in production, transport, trading, and marketing of low carbon hydrogen. Vertical integration in the form of consortia, joint ventures, or long-term contracts, or combinations of cooperation forms, are commonly used to decrease supply and demand insecurities. Security of supply issues will be dealt with through commercial stocks and back-up installations.

INSTRUMENTATION OF SECURITY OF SUPPLY POLICY

In the introduction and early expansion phase, it is expected that only the industry, as early adopters, will be consumers of domestic and imported supply. Therefore, the operational and strategic risks in the introduction and early expansion phase are mainly company specific hazards. Government policies will be mainly directed at expanding production and imports, and making sure that low carbon hydrogen (both domestically produced and imported) can be transported and stored (see Figure 8). Here the type of low carbon hydrogen carrier may become important. For gaseous transportation and storage the choice will probably fall on building on gas sector assets and structure. Liquid low carbon hydrogen carriers may build on the oil sector assets and structure. This is important, because also refurbishing liquid assets for transportation and storage may offer substantial societal benefits in terms of lower (security of supply) costs and versatility of the new energy system. The latter is important, because also refurbishing liquid assets for transportation and storage may offer substantial societal benefits in terms of lower (security of supply) costs and versatility of the new energy system.

In the Netherlands, the development of infrastructure to connect the industrial clusters is the responsibility of a state-owned company (Gasunie). Gasunie is retrofitting gas pipelines to realise early opportunities to move low carbon hydrogen between the industrial clusters. At the same time, private companies are preparing a pipeline bundle, among which a hydrogen pipeline, to bring (imported) low carbon hydrogen to inland clients in the Netherlands and Germany. The development of infrastructure is important for suppliers and importers to realise demand.

	Compressed H2	LH2 (cryogen)	NH3	LOHC (MCH)
Volumetric energy density	Compressed at 70 Mpa: 5.6 MJ/L	9.1 MJ/L	15.6 MJ/L	5.66 MJ/L
Gravimetric energy density (LHV)	120 MJ/kg	120 MJ/kg	18.8 MJ/kg	7.35 MJ/kg
Existing infrastructure	No specific infrastructure available (parts of the current gas network can be repurposed)	Almost no infrastructure available	Some infrastructure available	Conventional chemical and oil infrastructure can be used
Safety risks	Limited	Explosion risk	Highly toxic	Limited
Technological maturity / experience	Experience with production, transportation and storage	Limited experience	A lot of experience with production, transportation and storage	Limited experience however, not overly complicated to scale up
Direct application of carrier	Power generation, steel industry, chemical process industry, refineries, transport fuel, heating	Chemical process industry, transport fuel, steel mills etc.	Maritime fuels, fertilizer, chemical process industry. Potentially in power generation and industrial furnaces	Unknown, conversion necessary

Characteristics of different hydrogen carriers

CIEP

FIGURE 8 CHARACTERISTICS OF DIFFERENT HYDROGEN CARRIERS[45]

From a security of supply perspective, it is important that various hydrogen carriers can come into development, because it is hard to predict the winners (see Figure 9), or the best combinations of carriers further along the life cycle of low carbon hydrogen. Some may in the end fail to reach full market scale and/or remain niche, while others may offer a certain functionality that another hydrogen carrier does not. Together, they may create a more robust foundation for the low carbon hydrogen economy. For instance, LOHC might be easier (and cheaper) to store and easier to ship, but requires the carrier molecule to be shipped back to the exporting country to 'collect' a new batch of H_2 molecules. Ammonia may be used directly in ocean-going vessels or power generation, avoiding conversion costs, but may be more difficult to store dispersed, close to inhabited environs due to the toxicity. A variety of low carbon hydrogen carriers may thus come to the market to serve different market segments or consumers in different applications, depending on the transportation, storage and distribution costs, and the value it generates.

45 Volumetric energy density: https://www.ammoniaenergy.org/articles/ammonia-for-power-a-literature-review/; Gravimetric energy density: https://www.sciencedirect.com/science/article/pii/S1002007116303240#:~:text=Importantly%2C%20hydrogen%20has%20the%20highest,of%20~120%20kJ%2Fg. https://www.sciencedirect.com/science/article/pii/S0360128517302320 https://pubs.acs.org/doi/10.1021/acsenergylett.1c02189; Existing infrastructure: https://www.energy.gov/sites/prod/files/2018/10/f56/fcto-infrastructure-workshop-2018-32-kurosakipdf / https://www.portofrotterdam.com/sites/default/files/2022-02/hydrogen-different-packages.pdf; Safety risks, experience, application and costs: https://www.portofrotterdam.com/sites/default/files/2022-02/hydrogen-different-packages.pdf;

Introduction phase

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Market characteristics	Considerations
Pioneering stage of a new market (small scale)	High degree of **chain dependency** between parties investing in new value chain. Sufficient investor confidence needs to be established.
Vertical and horizontal integration	Heavy industry expected to be early adopter. As only the industry depends on its supply, supply risks are in this stage **company specific hazards.**
Concentration of market structure	

Security of supply measures | **What to pay attention to**

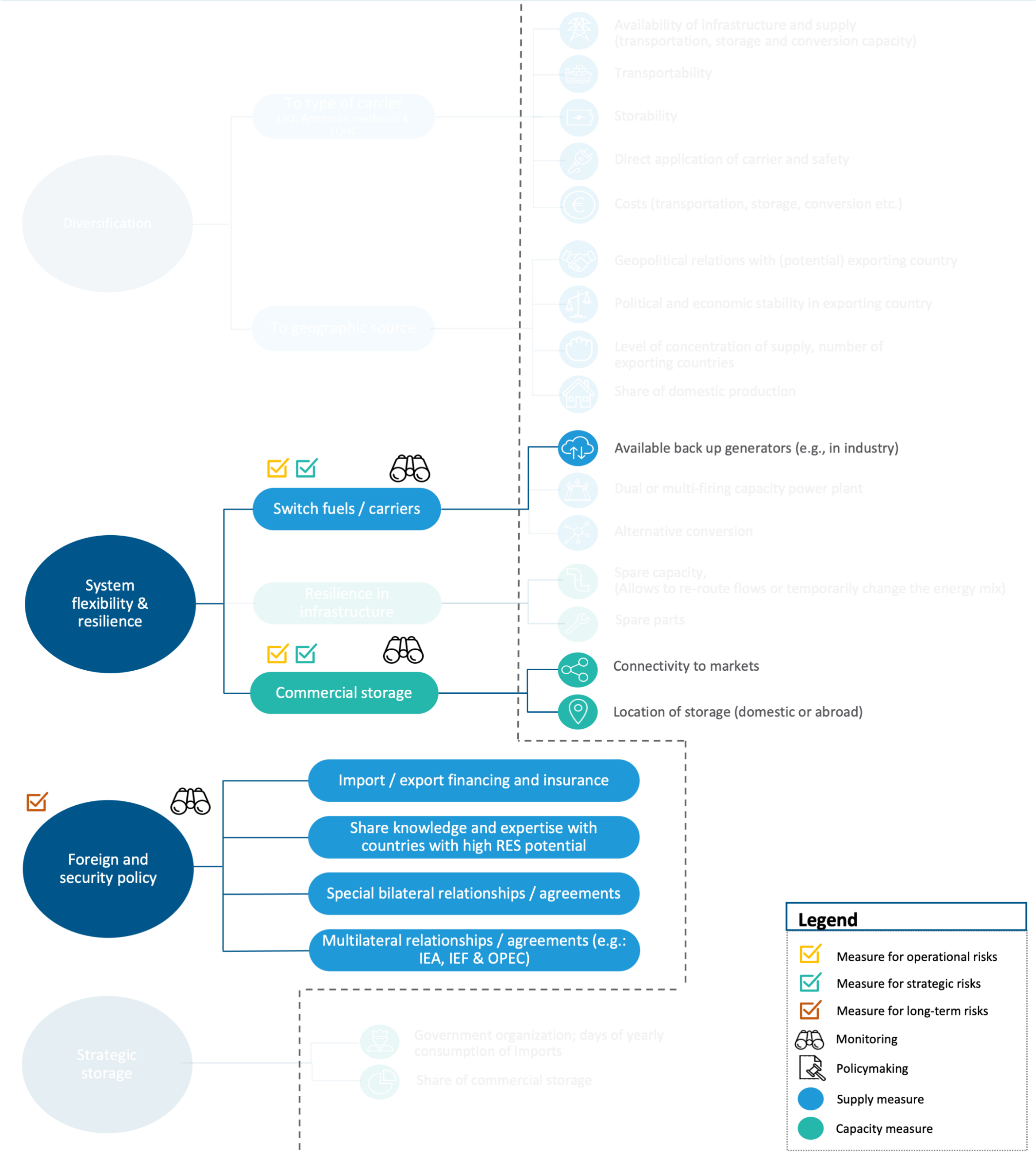


FIGURE 9 SECURITY OF SUPPLY MEASURES IN THE INTRODUCTION PHASE

Currently, most of the discussions assume low carbon hydrogen carriers to be landed at the coast and converted into hydrogen gas and transported to end consumers. In the introduction and early expansion phase this is a logical assumption, also because the gas sector has initiated investments to transport the low carbon hydrogen beyond industrial clusters in the NW European region. Particularly imports may introduce a second market development model, carrying unconverted low carbon hydrogen carriers further inland. Developing a value chain of imported low carbon hydrogen involves longer supply lines and more risk. The companies involved in building such a supply line, will mitigate these risks by concluding long-term contracts along that new value chain, and/or obtain (co)ownership of transportation (ships and pipelines) to make sure they can reach their clients. This is important because they can only realise a return on investment if they can deliver the low carbon hydrogen to the market. In an 'oil market model', the company in the early development phase organises production, transportation and conversion in a vertical value chain, and delivers the product in a hub or directly at the gate of the client. Later (in the expansion and maturity phase), certain parts of the value chain may be (in part) handled by specialised companies (traders, distributors). This development model can be recognised in the initiatives of the liquid cluster in Rotterdam to develop the Delta corridor to Germany and Limburg. Partners in this initiative are companies in the oil and oil product pipelines to Germany.

In a 'gas market model', the imported low carbon hydrogen is delivered at a conversion plant (which can either be owned or capacity booked, like in LNG terminals) and fed into the transportation system and into the market. Much depends on the regulatory model. Consumers can purchase the low carbon hydrogen at the gate of the conversion plant and book their own transportation capacity to the point of consumption. The EU seems to steer towards a 'gas market model'[46], perhaps also because it has competence in natural gas, while there is no EU internal oil market (model/regulation). The initiative of Gasunie to connect the industrial clusters with refurbished and new hydrogen transportation pipelines, fits this model of development. The fear is that both models will increase the transportation investment risk in the introduction phase when volumes are still small, while at the same time it is understandable from a market development perspective, because the value of the imported low carbon hydrogen can only be realised when the large clients in the hinterland can be served. Given the fact that these clients will enter into long-term contracts, the capacity to transport also needs to be available for the same duration. Here, the oil market model and gas market model of value

46 https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/hydrogen-and-decarbonised-gas-market-package_en

chain development clash. This is only an issue in the introduction and early expansion phase, but may create a hindrance to developing imported flows when this certainty of delivery at the client's gate cannot be guaranteed in a long-term agreement. This issue becomes less relevant when the flows increase in volume and more newcomers enter the market, like traders and other types of companies. When the market for low carbon hydrogen expands further and reaches maturity, all sorts of other companies, some beyond the industrial sector, come into the market. Moreover, some inland consumers (and governments because of their own security of supply preferences) may want to develop commercial storages closer to their activities and prefer conversion closer to demand. It is likely that from the perspective of the industrial sector, the power sector and other energy demand sectors, different qualities may be valued differently and may create the foundation for these different carriers to emerge. Provided the carriers can easily move between conversion centres, transportation modes and storages. This will depend on the dedicated assets these low carbon hydrogen carriers command in production, transportation, storage, and applications.

Some future fuel and feedstock choices will depend on the ability to ramp up production and flows. The ability to build a low carbon hydrogen eco-system by some industries and the subsequent ability of other sectors and industries to benefit in their wake is also important. Security of supply in the introduction phase is not really an issue, because unabated hydrogen can serve as a back-up in case of supply disruptions. This option is less likely when old unabated installations are retired and replaced by either abated or electrolysis hydrogen. Since the replacement of unabated hydrogen will take some time, traditional production capacity will easily outlast the introduction phase of low carbon hydrogen, and only when the expansion phase is well underway, this may become an issue.

For the sake of security of supply and compliance with abatement policies, the development of abated hydrogen based on waste gases can be a welcome complement to electrolysis hydrogen, which relies more on variable production. Combining the two technologies makes more low carbon hydrogen available to the market and mitigates security of supply risks, or prevents a fallback on unabated supplies. This is particularly important when the unabated production begins to shrink, while demand for low carbon hydrogen is growing, also beyond industry. Furthermore, allowing abated hydrogen to enter the system will help mitigate the risks of setting up the domestic and imported low carbon hydrogen value chains based on variable sources. Moreover, the development of domestic value chains could reduce the supply risks that come with low carbon hydrogen import flows.

Nevertheless, like import flows, the first domestic developments also require complex coordination and cooperation, which will be organised around long-term contracts and may offer limited flexibility to divert flows.

Due to the limited number of producing countries (and producers) in the market during the introduction and early expansion phase, the risk of losing the ability to meet firm demand in the event of a severe disruption of the principal supply source can be a risk. If the supplier fails to deliver the necessary volumes, due to geopolitical tensions or supply chain issues, it will be difficult to replace the missed low carbon hydrogen volumes in a market with few or no substitute suppliers, except with unabated or abated hydrogen. In this phase, contractual uncertainty and opportunistic behaviour of the buyer are a risk. The limited amount of competition provides the supplying party with asymmetric market power, as users of hydrogen cannot easily switch to other suppliers, due to switching barriers or a general lack of alternative low carbon sources. This constitutes a business risk in case additional CO_2 emission permits or capacity in the CCS system must be purchased to substitute supplies with abated or unabated hydrogen.

At the end of the introduction phase and the beginning of the expansion phase, when supplies (both domestic and imported) are taking off, and unabated hydrogen production is reduced (and installations retired), the security of supply risks increase as the industry increasingly depends on steady supplies from the new low carbon hydrogen flows.

Aiming to deal with the abovementioned supply risks and mitigate market power of the producing market players, companies will be inclined to set up joint ventures, enter long-term contracts with solid penalties on non-delivery, or arrange multiple contracts to diversify their supply and spread their risk. Long-term contracts usually provide for a distribution of the price and volume risks between producers and importing consumers. In the transition from the introduction to the expansion phase, supply problems might also occur due to insufficient redundancy of capacity in the infrastructure system. The same goes for the inability to reach multiple customers, because of dedicated point-to-point connections, which do not allow for the redirection of flows and storage in case of a missing component or operational failure, or the limited trading possibilities.

The long-term risk to first mover investors in domestic and imported low carbon hydrogen value chains, is the pace of demand development and the pace of cost reductions. Uncertainty of demand development can be mitigated by vertical integration and/or long-term contracts along the value chain, to make sure all parts are in place for supply to meet demand. Long-term contracts can assure timely investments to avert future shortages and guarantee delivery. In the introduction phase of the market, competition authorities should therefore allow for a certain level of cooperation between companies, and between companies and governments, to enable the market to develop. Nevertheless, they should ensure that market power is not abused.

The reduction of production costs is another uncertainty. Electrolyser hydrogen still needs to be scaled up substantially and depends on the ample supply of wind or solar energy. The expectation is that countries with favourable solar and wind conditions may be more competitive than NW European countries. For investors, the willingness to invest large amounts of dedicated capital in a producing country, will depend on the political and economic stability of a potential exporting country. The current international uncertainties may stimulate investments in 'friendly' countries, rather than in the 'cheapest' countries. Governments may steer investments in this direction for strategic reasons. International uncertainties also stimulate the development of domestic low carbon hydrogen value chains, and they will provide the foundation for and confidence in low carbon hydrogen as a system energy carrier. This is not only the case in a geopolitically unstable world. Also, in a more harmonious world domestic supplies will increase the comfort with import dependency.

EXPANSION AND MATURITY

In the expansion phase, the market for low carbon hydrogen is rapidly growing domestically and elsewhere, and the market is expanding beyond industry. More consumers and producers enter the market and the incumbents from the earlier period are challenged by newcomers in the market often able to compete more on price, rather than on quality (see Figure 10). The current proposal of the EU to engage in joint purchasing may be a complication in this phase of development. Much will depend on whether the government will give up its monopsony or oligopsony position in this phase of international market development, to allow newcomers into the market. At the same time the government, as the single buyer, may own a portfolio of relatively expensive (long-term contracted) import flows, while newcomers undercut them in the market. If the government does not give up this practise in time, it may be difficult for newcomers to enter the market with new imported flows. Newcomers rely on the accessibility of infrastructure and services (conversion, transport, storage) to break into the market, or can match their supplies with a company short in low carbon hydrogen.

If the government defends its market position, it may be reluctant to open the market for newcomers and maintain high barriers to enter. This could seriously hamper diversification to source and geographic origin, important when the dependency on imported low carbon hydrogen flows needs to grow. The position of the EU as a (prolonged) monopsony for European member state market players, could be mitigated by setting an indicative and realistic date on liberalising trade and access to infrastructure. This should be reflected in the duration of the contracts engaged in, or it should allow competition for clients to occur, regardless its own exposure. Already the current proposal for a new gas and hydrogen market proposal can be read by announcing a certain date for the market regulation to kick in.[47] This proposed directive was published before the plans to create a joint purchasing platform for gas (and low carbon hydrogen) surfaced (again), but may have been in the back of the EU-policymakers' minds longer. However, setting an upfront date may create a mismatch with market developments, or become subject to stakeholder and/or political interest seeking.

In the absence of joint purchasing, setting an early date for the EU regulation based on the gas market regulation to kick in, as proposed by the gas market directive[48], may not match with the stage of development of the low carbon hydrogen market. In particular, the uneven development of the domestic low carbon value chains and imports in various parts of the EU, may become an issue in introducing these regulatory arrangements. The focus on electrolysis hydrogen and transporting it as hydrogen gas is obvious from the proposal and little thought has gone into the contribution of other carriers. Particularly for imported low carbon hydrogen the focus on gaseous transportation (from the entry point) may be less logical when inland storage and conversion is preferred.

Underinvestment in hydrogen supply and capacity can be mitigated by companies through vertical integration of upstream, midstream and downstream activities, or by entering long-term bilateral contracts, to ensure a return on investments. Especially internalising upstream and midstream activities is important, due to the asset specificity of these segments of the value chain. Upstream infrastructure (e.g., hydrogen production facilities) and midstream infrastructure (e.g., pipelines and storage facilities) are often 'site specific'. The assets are bound to a specific location and cannot be moved and used in other geographic areas. As it is impossible to use the assets in a different way than was originally intended, these are risky investments without assurance of long-term usage. The integration of the various parts of the value chain also implies that loss-making activities in one part (e.g., the construction of large pipelines with a risk of underutilisation for a longer period) can be sustained, when this can be compensated elsewhere in the chain.

47 https://ec.europa.eu/commission/presscorner/detail/en/IP_21_6682

48 https://eur-lex.europa.eu/resource.html?uri=cellar:2f4f56d6-5d9d-11ec-9c6c-01aa75ed71a1.0001.02/DOC_1&format=PDF

Expansion phase

Market characteristics

- Rapidly growing market with a large share of new entrants
- Declining vertical and horizontal integration
- De-concentration of market structure

Considerations

- As H2 starts to perform a more fundamental role in the economy, supply risks transform from company specific hazards to **societal security of supply risks.**
- Usually from this phase onwards, **more government involvement** is necessary to ensure security of supply.

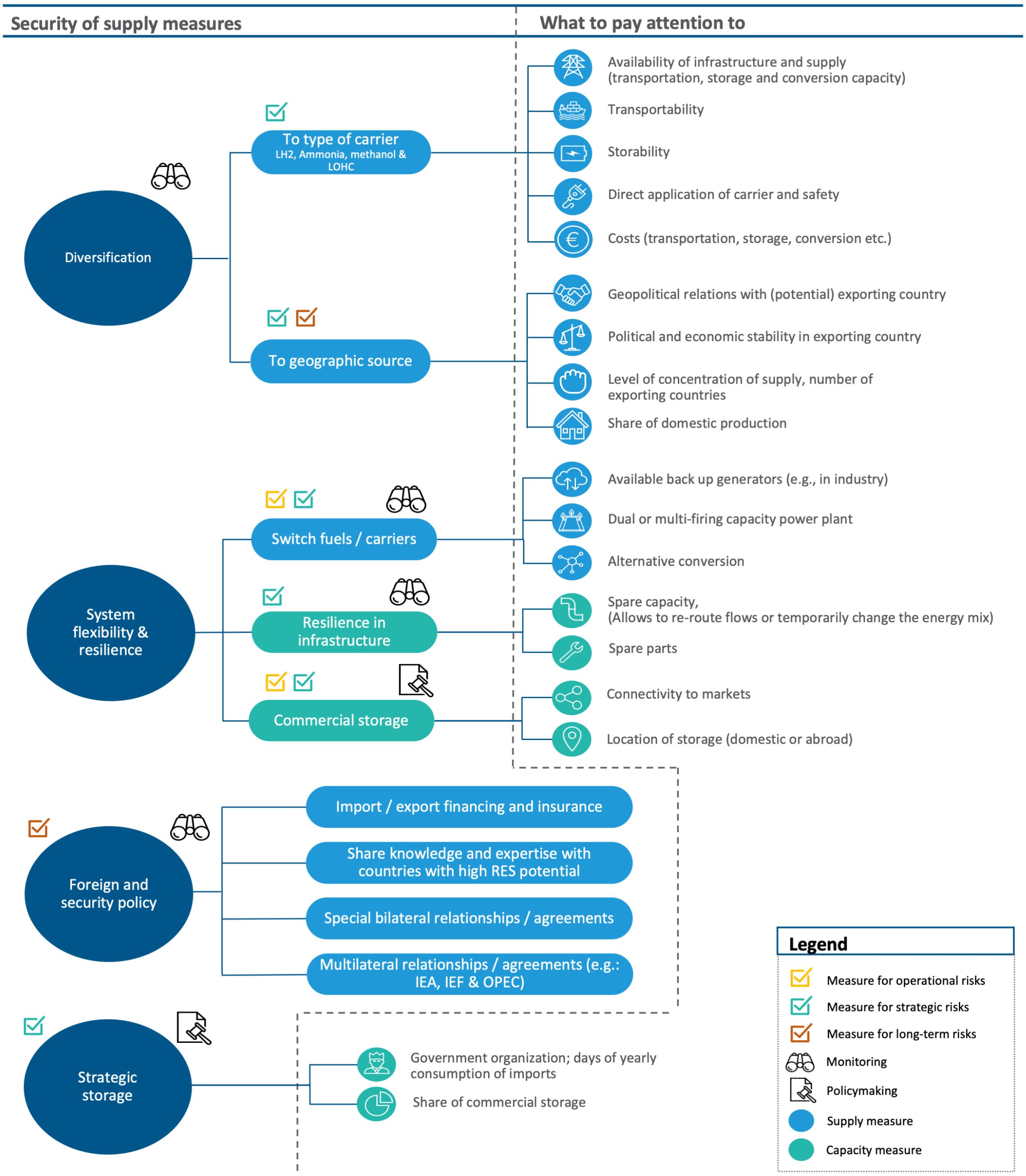


FIGURE 10 SECURITY OF SUPPLY MEASURES IN THE EXPANSION PHASE

The Dutch government, or government companies like Gasunie can contribute to securing enough capacity for the long-term, by investing in or providing financial stimulation for the necessary infrastructure, conversion technologies and import terminals. A good example of government stimulation to secure sufficient transport capacity is the Gasunie hydrogen backbone initiative HYway27 that will connect industrial clusters, develop hydrogen storage facilities, and facilitate domestic production sites to bring low carbon hydrogen to the market. Much like during the 1960s 'gas campaign', the various plans need to be brought together.

Another important long-term consideration is the potential threat of the emergence of market power of a single or several (organised) supplying countries. Although solar and wind are more distributed across the world than oil and gas reserves, the number of sweet spots where solar and wind together can substantially increase the utilisation of the electrolyser facilities and optimise production are limited. Market dominance could put a producing nation in a position to influence prices, availability, or quality of the hydrogen resource, and at the same time be a reason for a joint purchasing platform to stay in place. Competition for economic rents between consuming and producing countries is not new, and buyer's and seller's markets will, once maturity is approached, become a fact of life. Although, a collaborative world seems further away than in previous decades, given the duration of life cycles in general, and the one of low carbon hydrogen in particular, security of supply will benefit if the costs and benefits of developing low carbon value chains are reasonably divided and not made a tool in international power politics.

The security of supply risks come from the capital intense assets that must be developed in countries that are rich in renewable energy potential, which are found in the Middle East, Africa, and South America. The stability of these countries and their position in a geopolitically divided world matter. The solidity of diversification and the degree of willingness to become dependent on these flows may require the development of strategic reserves, in addition to diversification policies. Here, energy diplomacy and maintaining mutually benefitting relations becomes an important part of security of supply policymaking. Sharing knowledge and expertise of renewable energy production and low carbon hydrogen conversion technologies with other countries, can contribute to security of supply of low carbon hydrogen in the Netherlands. In general, also investing in domestic applications in exporting countries, through for example the provision of import-export investment credits, development banks or training domestic workers, can improve energy security, while preventing the global decarbonisation gap from widening.[49]

49 IRENA, Geopolitics of the Energy Transformation, The Hydrogen Factor, January 2022.

MATURITY AND FUNCTIONING OF THE MARKET

Low carbon hydrogen is destined to become a systemic energy carrier, balancing (day-to-day and seasonal) supply and demand and enabling further electrification of demand. Together with electricity, low carbon hydrogen will form a backbone. Both domestic production and imports of low carbon hydrogen work together with electricity markets. The fact that low carbon hydrogen is easier to store and cheaper to transport, helps the integration of variable solar and wind production into the energy system. In this phase of development, the CCS system changes in a predominantly CCU system, carrying increasingly carbon through a pipeline system connecting industrial clusters. These pipelines were initially used to transport captured CO_2 to places for permanent storage, but the increasing circularity of the energy and resource system has changed its functionality in bringing carbon, together with low carbon hydrogen, to industry for conversion into low carbon fuels and feedstocks. In this phase, the imported low carbon hydrogen is an important mechanism to satisfy demand with solar and wind from elsewhere, when domestic production falls short. Depending on the development of technology (for instance wind and solar energy which is generated in deeper waters off the EU coast), the ability to efficiently to bring it to markets, and the geopolitical make-up of the world, trade will grow to optimise demand and supply in a larger part of the world, through commoditisation of low carbon hydrogen, electricity and (near) circular carbon.

The new ecosystems around offshore wind and low carbon hydrogen plants have spawned new industrial clusters involved in processing molecules into products and energy. The vertically integrated value chains were challenged in the expansion phase by specialised companies, focusing on parts of the value chain and servicing other companies in the value chain with storages and transportation and distribution. Depending on the regulation of the market, the level of vertical and/or horizontal integration will begin to increase again in the maturity phase when growth of demand slows, economies of scale matter and mergers and acquisitions help secure market shares. Some companies will have ventured into other markets to realise growth.

In a mature market, security of supply will play a more important role because of the large size of the flows, a market organisation with diverse players in various segments of the value chain, more inelastic demand, and vulnerable consumers (see Figure 11). Some market participants will be too small to organise their own security of supply, or are functioning as a small cog in the bigger wheel. With more market participants, the responsibility for the functioning of the market and security of supply relies more on the market design or regulatory make-up.

In the envisaged mature low carbon hydrogen market, free flows of low carbon hydrogen carriers must go together with measures on security of supply, because the market will not organise security of supply by itself. When low carbon hydrogen becomes an international tradeable commodity, like LNG markets did, the strategic and geopolitical behaviour of countries and certain market players (for instance state companies) warrant security of supply policies. The most important ones are strategic reserves, diversification, and energy system flexibility measures, while investing in good relations with trading partners is also crucial.

Maturity phase

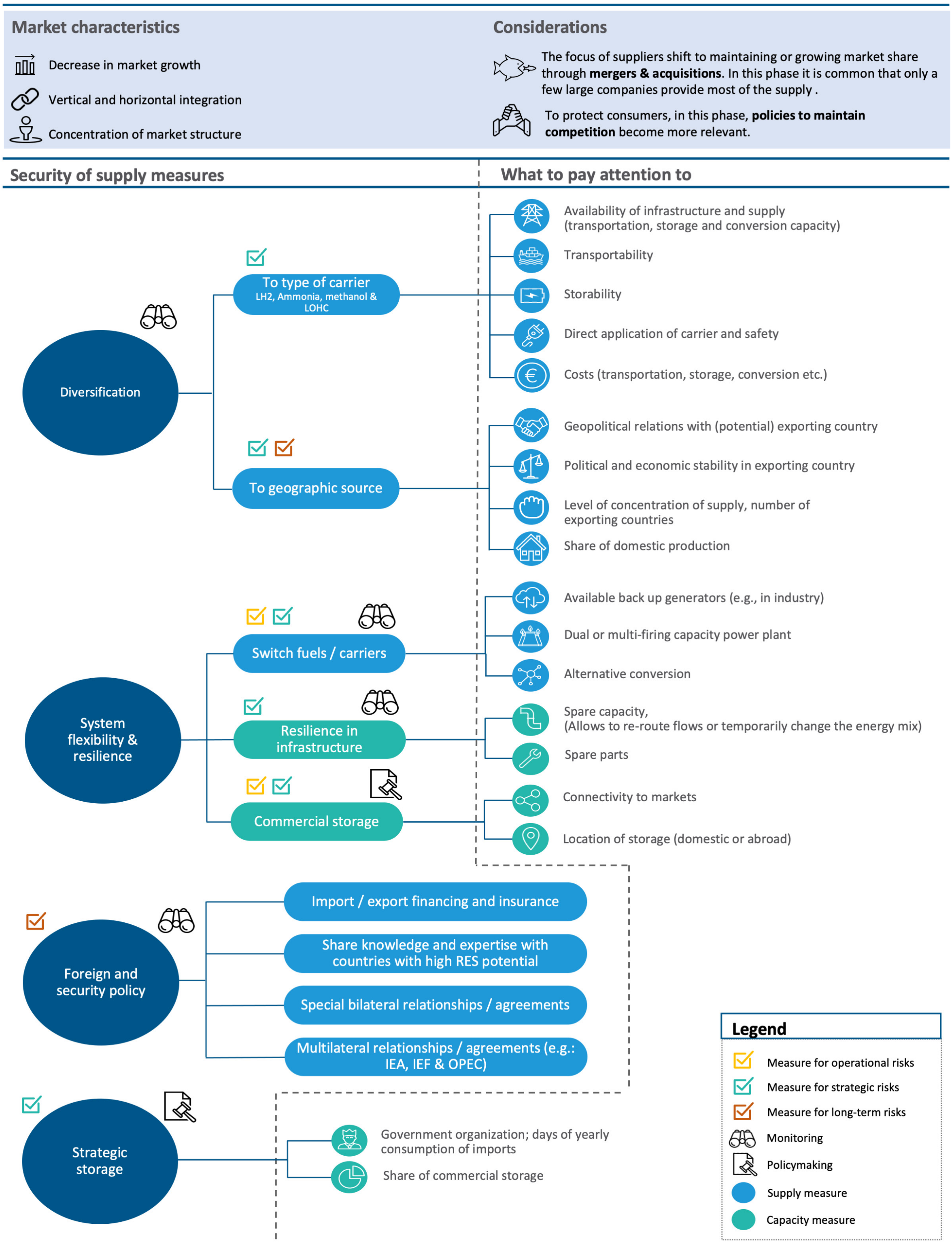


FIGURE 11 SECURITY OF SUPPLY IN THE MATURITY PHASE

THE NEW BACKBONE

Today's and tomorrow's liberalised electricity markets can benefit greatly from a regional hydrogen market, thanks to a range of possible technologies linked to a future hydrogen backbone and the electricity grids.[50] Electrolysers can act as the gateway between the grids, transforming electricity into hydrogen, bridging the markets (see Figure 12). And power plants fuelled by hydrogen act in a similar but reversed way, converting hydrogen fuel into electricity.

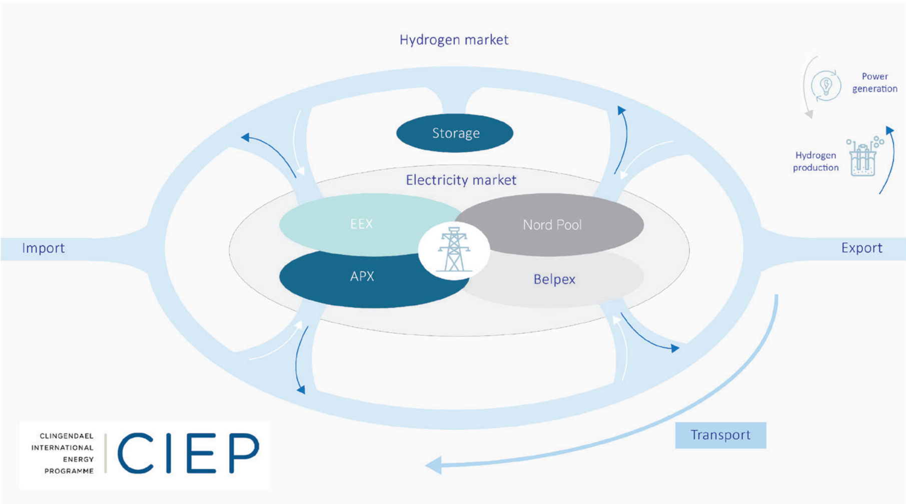


FIGURE 12 HOW ELECTRICITY AND LOW CARBON HYDROGEN MARKETS COULD WORK

SOURCE: PIER STAPERSMA, MARKET COORDINATION OF DYNAMIC ENERGY FLOWS, CIEP, DECEMBER 2020.

Storages in the form of batteries in the electricity grid can smoothen variable electricity flows by 'buffering' electricity in the grid for shorter (seconds, minutes), or longer (hours, days) periods of times. Often at local levels in distribution grids, but sometimes also in transmission grids. Intraday and balancing markets largely coordinate the utilisation of these technologies. Batteries in electric vehicles connected to the grids can perform similar roles, just as home batteries adopted by some consumers, often without knowing how the batteries are exactly used, since this is managed by specialised electricity businesses that offer appealing value propositions to consumers to get access to their hardware. Coordination of electricity flows is happening real-time and has a short-term focus, greatly facilitated by continuing improvements in information and communication technology.

50 This section is largely derived from Pier Stapersma, Market Coordination of Dynamic Energy Flows: The Future Interplay of Solar &Wind Electricity and Hydrogen Infrastructures, CIEP, December 2020.

Moreover, storages in the hydrogen backbone, in the form of salt-caverns, depleted gas fields and line-packing, but also (after conversions) tanks for liquids and gases, or even bulk solids, can smoothen things out over substantially longer periods of time. Withdrawal from such storages, characterised by massive working volumes that cannot be offered by the batteries, can supply consumers with additional energy for days and weeks, and perhaps even months.[51] Some energy from these storages can be directly consumed by end users, while a portion of it is converted into electricity and supplied to the electricity market.

If more stored energy is needed than the regional hydrogen backbone has readily available, hydrogen imports from further away, through pipelines or ships provide the required commodity, just like the thousands of kilometres of gas pipelines and ships carrying liquified natural gas (LNG) facilitate today.

The installed wind and solar capacities are not evenly distributed across Europe. Moreover, wind and solar energy availability varies from hour to hour, from day to day, from week to week, and even from season to season, so the installed capacities are utilised in a highly dynamic manner. Crucially, while variability can be managed, since weather forecasts tell actors in electricity markets many days in advance when and where solar and wind electricity is available, the production cannot be realised when the resource is not there. In other words, the variable electricity flows from solar and wind capacities can be predicted but not planned. Therefore, the other technologies mentioned here are so essential for the markets to function and to match demand and supply throughout the year.

One relevant consideration relates to differences in relative energy transport costs. If transport costs per unit of energy are relatively low, then it is easier to organise a market that spans a larger distance.[52] It is often assumed that the transport cost per unit of energy is lower for gasses than for electricity, especially with a view of the capacities of already existing legacy gas infrastructure that can be converted for hydrogen use. In that case a hydrogen market in North-West Europe (and beyond) can more easily have a uniform pricing (or strongly correlated prices) across the

51 Natural gas infrastructure has historically played an important role in dealing with the seasonality in energy demand in the region, and in the Netherlands in particular. In future, periods of low availability of both wind energy and solar energy can coincide with a cold spell, which leads to high demand for heating for prolonged periods of time. Consider Figure 2 in Chapter 2 of the CIEP publication 'The Transition of the Residential Heating System', showing the seasonal pattern in historical gas demand, which must be overcome.

52 In fact, historically, this is one major reason why markets for crude oil became more easily integrated globally, than markets for natural gas. Transport costs for crude oil per unit of energy are relatively low. Only when the liquified natural gas supply case became more competitive, gas markets started to become more global.

region. If electricity bidding zones were to be expanded in a similar fashion, this could prove to be more problematic. Transmission System Operators (TSOs) can facilitate it, but will carry the costs of making expanded market areas work. Such costs are ultimately passed through to energy consumers, especially when substantial grid reinforcements and expansions are required.[53]

Once realised, a future hydrogen backbone supplements, if not underpins, the electricity infrastructure. In Europe's liberalised energy markets, price signals largely coordinate the behaviour of rational economic actors, elegantly shaping an interplay between the hydrogen backbone and electricity grids, which would be difficult to realise by central planners. Once again, this is how the European liberalised energy market functions, and how the coordination of (short-term) daily operations takes place. For (long-term) investments in the infrastructures such signals may be more muted, due to the large role of government policies in the sector. This distinction is crucial to stress and should not be forgotten when discussing Europe's liberalised energy market model and the applicability to low carbon hydrogen.

SECURITY OF SUPPLY IN A MATURE MARKET PHASE

In a mature market, security of supply policymaking is becoming a more prominent government or regulatory authority task. The optimisation process may result in optimisation and physical concentration of certain imported flows. In a liberalised mature market, if such a market comes about, competition for market share can become fierce and companies may use all sorts of strategies to defend their market position. Some concentration is normal at this stage of market development. Production, including imports, may become organised in larger companies, often in a more horizontal type of organisation.

In a globalised market for low carbon hydrogen, the market organisation may be different in a world with a hybrid model, with a mixture of private, public and state companies, serving different interests of stakeholders, than in a world in which state interests dominate the organisation of the market. The oil and natural gas industry has lived through a variety of different organisation models in the course of time. The emergence of state oil companies from Asian countries in international oil and natural gas production is relatively new, while state oil and natural gas companies in producing countries preceded this development in Asia. The international oil (and

53 In the short run, electricity TSOs may intervene in the market through 'redispatching' electricity production, basically overturning the earlier production plans established through the market. In the long run, they will be forced to make expansions to electricity grids, even if other solutions are a better deal for society but do not fall within their mandate, ranging from batteries, demand-side responses, or transporting energies through other infrastructures such as pipelines.

gas) companies that dominated international oil and natural gas production before that (prior to the 1973), have seen their dominance of the oil and natural gas value chain decline substantially. Their share of production, processing, transportation, and distribution was very large indeed, and many importing countries relied on these companies to provide them with security of supply. It is possible that something similar will happen with the development of low carbon hydrogen, because the development of these long low carbon hydrogen value chains looks dominated by companies from the OECD. Given the important position of China in key resources for the solar, wind and perhaps also electrolyser industry, Chinese companies may quickly develop into serious competitors and compete for (the same) solar and wind sweet spots, while for instance Saudi Aramco also is positioning in this field. The current geopolitical uncertainties and potential for the world breaking up in opposing camps will emphasise the strategic importance of certain low carbon hydrogen producers over others, depending on the ability of states or groups of states to secure the supply lines over longer distances. Most of the naval bottlenecks for today's oil, oil products and LNG trade, will also be bottlenecks for low carbon hydrogen trade.[54] Much depends on which countries or groups of countries guarantee free and safe passage in future.

It is possible that the EU market (or the OECD) reaches maturity before other markets do, and that competing markets complicate diverse sourcing of low carbon hydrogen. This is more so when market liberalisation forces market players to compete on price and less on quality (security of delivery). The lesson from EU internal gas market regulation is that in a liberalised mature market, security of supply regulation (diversification, system resilience and strategic reserves) is very important to prevent substantial dependencies on one or a few low-cost suppliers of imported low carbon hydrogen. The current energy crisis is in part of the EU's own making, and is also caused by the inability to move beyond a legacy transportation system in a quest to maintain competitiveness of EU economies. The future measures can be seized to fit the regional production of domestic low carbon hydrogen, the distribution of storages, the deepness of the transportation and distribution network, and the ability to manage demand. The conclusion is that in a mature market phase the full toolbox of security of supply measures (see Figure 12) should be used and monitored for efficacy. Complacency may be a short-term gain, but will end up in a longer-term pain.

54 https://www.eia.gov/international/analysis/special-topics/World_Oil_Transit_Chokepoints

THE IMPACT OF CERTAIN MARKET PLAYERS

In the introduction and early expansion phase, investment risks are managed through vertical and horizontal integration, joint-ventures, consortia, and other forms of collaboration (long-term contracts). However, the potential participants in the low carbon hydrogen market are more diverse than those in the earlier oil and natural gas value chains, where the upstream, midstream, and downstream were initially dominated by the large international oil companies. The low carbon hydrogen value chain may become a much more diverse playing field, with industrial gases companies, international oil/liquid fuel companies, gas companies, chemical companies, electricity producers competing for parts of the value chain, depending on their ability to finance the investments and manage the complex investments and contractual relations over a long distance.

In the development of the domestic value chain, we already see various parties collaborate in the development of a low carbon hydrogen value chain. Some companies have developed strong competencies in developing solar and wind production in various markets, others are used to organise complex (international) projects and transport products over long distances (pipeline or ship), bring the low carbon hydrogen to specifications (level of purity), trade and arbitrate between products and markets, etc. Some market players will bring competence in carbon capture and storage into the collaboration, others have already developed biofuel value chains, and others a portfolio of clients. The changing role and function of various players from the current fossil fuel value chains into new relations is evident in the newly emerging ecosystems around offshore wind and solar, conversion industries and transportation modes and providers. The likelihood of various parts of the energy and feedstock sector merging into a new energy and feedstock sector is very large indeed.

In the early expansion phase, the market is large enough to accommodate the different players in ramping up production and imports of low carbon hydrogen. In the expansion phase some mergers and acquisitions will occur to propel latecomers into the market and gain market share, but when the market reaches the late expansion and maturity phase, these mergers and acquisitions will reflect a more defensive strategy, because market growth more and more becomes a strategy to maintain market share. It is in this phase of market development that competition law is important to maintain competition and prevent oligopolistic market structures to settle. Although the market can be oligopolistic in the introduction and early expansion phase, market expansion draws newcomers in the market which challenges the market position of the incumbents. In the maturity phase, when unit costs and optimisation of the value chain matters for a company's competitiveness, an increase in advertising, backward and forward integration in certain markets and taking over a competitor, become strategies for companies to survive. Another strategy may be to internationalise the activities to other markets.

The different types of energy companies may prefer either the so-called 'gas market model' or 'oil market model' of development, depending on their abilities and capacities. The domestic gas and power sectors will likely prefer the 'gas market model' of development, also because they are familiar with the regulatory organisation of the current markets, while energy- and resource intense industrial users, as they are dependent on a continuous flow of resource and energy, may prefer the 'oil market model' of development and may also be more interested in long-term contracts and/or vertical integration to secure these flows. They need that sort of certainty to make the very large investments in their production processes.

In the introduction phase, we see that all sorts of companies from various industrial sub-sectors, oil, gas, and power companies develop investment plans. Some of these plans are focused on domestic markets, while others also look at international developments to supply low carbon hydrogen into the NW European market. Most of the plans are related to their current activities and to reducing CO_2-emissions from processing or manufacturing low carbon (bio)fuels.

International oil companies are also preparing investments to absorb more low carbon hydrogen into their refining processes and to use the expanded supply of offshore wind for conversion into electrolyser hydrogen, while also looking at opportunities to convert refinery gases into low carbon hydrogen (with CCS). Such plants offer security of delivery of low carbon hydrogen when the production of electrolyser hydrogen is still modest. In later years, the low carbon hydrogen factory is a useful back-up for domestic variable electrolyser production, also when strategic or seasonal storages need filling.

In the Netherlands, an international oil company is developing plans for domestic offshore wind parks integrated into electrolyser hydrogen production for the domestic and German market. This project, H2North, can be seen as a project that helps them move on the learning curve and can later be developed elsewhere for other markets. Also, other projects in countries around the North Sea have the potential to serve as examples of first mover projects. The collaboration of the countries around the North Sea, creating a special environment for electrolyser hydrogen based on offshore wind, will come off the ground first, connecting these markets with both electricity and hydrogen networks.

Other companies interested in developing imported flows of low carbon hydrogen are currently mainly the international industrial gases companies and international oil companies, working in various jurisdictions around the world and on the verge of internationalising their activities through trade flows.

5 MARKET DEVELOPMENT AND THE CURRENT ENERGY CRISIS

Under the current geopolitical and economic pressures, fast forwarding value chain developments, forces success to battle with failure. Value chain developments rely on industry to do the first heavy lifting of creating these domestic and imported low carbon hydrogen flows. They are capable to organise these flows, because they have the expertise, the capital and the ability to bring all the parts together. Government can help to secure demand and organise transportation. However, the current move away from one of the largest oil and gas producers in the world, is challenging certain companies to step up their transition. Some chemical companies are confronted with increasing production costs, as both energy and feedstock costs have risen. Although the gap with still more expensive low carbon solutions has become smaller, the ability to sustain business may decline and impact the ability to invest. This is especially the case for companies competing on international markets.

GRADUAL TRANSITION: OFF THE TABLE?

However, the energy crisis has clarified the direction in which the energy system of the EU must change. First mover industries that are, or are close to, setting up low carbon hydrogen value chains will be stimulated by recent developments in oil and natural gas markets, and some of these companies may be able to invest, regardless of the conjunctural swings. Still, with less doubt about the direction, the doubt about industrial competitiveness and the ability to make the expedited switch has grown substantially. The current energy crisis may have removed the option of a more gradual transition path for EU industry, where earnings from traditional business were destined to be invested into the energy transition. For companies benefitting from higher oil and gas prices the ability to invest may have grown.

Although policymakers may see the current crisis as an opportunity to press ahead even faster, by bringing targets forward, industries may be unable to switch so radically from a relatively low-cost energy and resource base to a higher cost one, without restructuring their business to survive their abrupt change in competitiveness. This is particularly the case for industries competing on international markets.

STRATEGIC DILEMMAS FOR COMPANIES UNDER PRESSURE

In terms of the dynamic market theory, the jump from the current unabated hydrogen market, which is stagnating or already in decline[55], towards the low carbon

55 https://www.clingendaelenergy.com/inc/upload/files/NW-Europe-Hydrogen-Final.pdf

value chain (extended), may have become more difficult for various market participants. With margins under pressure, their investment agenda may have to change radically and focus on restructuring their business instead. Nearly finalised partnerships or long-term contracts for low carbon hydrogen may fall through, unless governments or other institutions can prevent industries relocating away from the EU. The sudden deterioration of competitiveness may force companies to make different strategic choices, and could, in some cases, arrest low carbon hydrogen projects nearing FID in their tracks. Moreover, if the current energy crisis produces substantial demand destruction in industry, the demand outlook for low carbon hydrogen must also be adjusted.

The REPowerEU programme, presented as a medium to longer-term 'security-of-supply-cum-energy-transition' programme, may be too much in too little time for industry to sustain. As the energy policy trilemma has taught us time and again, policy instruments should not be seen as a jack of all trades, but should focus on the specific policy priority. In this case, affordability is already under pressure, while the ability of industry to invest has also become more uncertain. This may impact the outlook and speed with which electrolyser hydrogen can replace the unabated hydrogen in a large cluster like ARRAR. This was already a tall order under normal circumstances, because the speed with which electrolyser capacities can be ramped up, is hard to combine with the current large market for hydrogen in the cluster. Fortunately, first investment decisions have been taken by companies leading the charge, but maintaining the momentum may become more difficult after a few years of constraint energy markets. Without an impact analysis of the current energy crisis (oil, gas, and electricity), and an assessment of potential second and third order effects, it is very uncertain what the impact of the current energy crisis on the various sectors of the economy will be (and on potential low carbon hydrogen demand), and how much investment-firing-power is lost.

THE MACRO-ENVIRONMENT AND FINANCIAL MARKETS

The pressure on governments to spend on the energy system transition will be large, while the ability to raise capital in the current inflationary environment may be strained when interest rates go up. The current crisis may also reduce the pressure on all sorts of ideological arguments for or against certain investments in imported hydrogen, such as the carbon footprint of the exporting country's energy system, or the risks of low carbon enclaves. The driver for the development of low carbon hydrogen has shifted from a climate change policy perspective, to including a security of supply perspective, changing the urgency towards the survival of the state and the economy in the short-term instead of the longer-term.

At the same time, history has shown us that a big energy event can produce a completely different energy market structure in a relatively short space of time. The profound economic crisis resulting from the oil crises in the 1970s, deeply restructured both the European energy and industry sectors, and stimulated North Sea oil and gas production. Old industries disappeared and were replaced by new ones.

WORLD MAPS ARE BEING REDRAWN

A similar development as in the 1970s and 1980s may occur again, depending on how deep the pockets of governments and companies are, and on their willingness to collaborate in the development of the new low carbon value chains. Maybe the changing geopolitical make-up of the world will be a stimulus to move ahead, as there is no longer another option. The concentration of minerals and processing industry for renewable energy technologies in China is a big problem and a pressing security of supply problem. The resistance of society to produce and process these minerals in the EU or elsewhere, to reduce dependency on China, may be a stumbling block. If the number of places where to source low carbon hydrogen is becoming smaller than anticipated, because of changing geopolitical relations, investment in foreign relations and energy diplomacy may become an immediate task.

In the part on phases of development of low carbon value chains and market development, we looked at the developments without taking these geopolitical complications into account and assumed that sourcing from the world market would be unhindered. The IEA Report 'Securing Clean Energy Technologies' of July 2022, discusses some of the security of supply risks of developing clean energy technologies, among which low carbon hydrogen. They point out that these technologies depend mainly on minerals and mineral processing, which are also subject to long and concentrated supply lines, mainly in China. Figure 7 on page 18 assesses the likelihood and impact of potential supply disruptions, while figure 8 in the report presents the geographic concentration. If we connect that to the current development of geopolitical fault lines, sourcing may become an issue. On page 37 of the IRENA report "the Geopolitics of the Energy Transformation, the Hydrogen Factor" (January 2022), a map of the expanding hydrogen trade routes, plans and agreements showed the intense activity from Europe to build imported low carbon hydrogen value chains (see figure 13). If the world becomes more fractured some of these plans may not be realised because of geopolitical stumbling blocks and opposing alliances, making the world less harmonious (a precondition in the IEA's scenario for Net-Zero in 2050), and world markets smaller and more strategic.

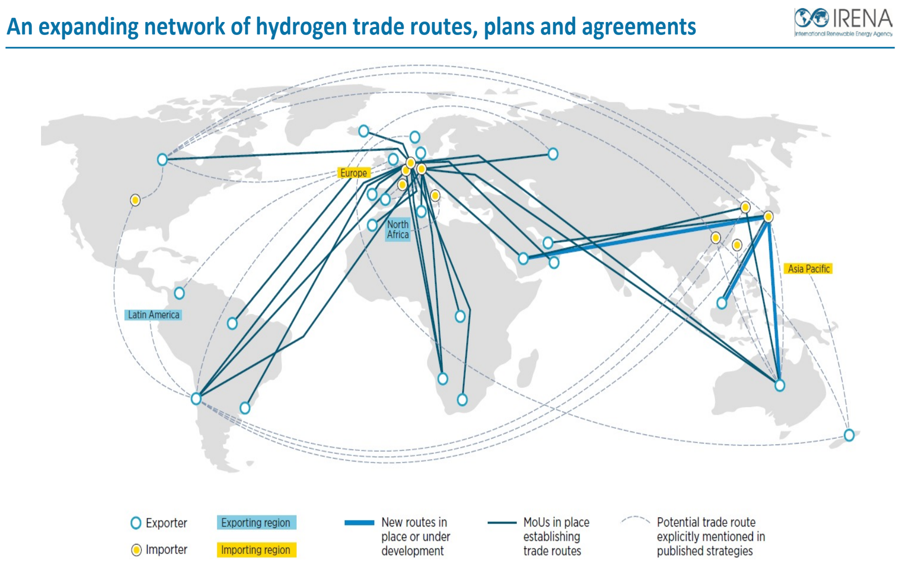


FIGURE 13 AN EXPANDING H_2 NETWORK OF MOU'S AND TRADE ROUTES

SOURCE: HTTPS://WWW.IRENA.ORG/PUBLICATIONS/2022/JAN/GEOPOLITICS-OF-THE-ENERGY-TRANSFORMATION-HYDROG

Furthermore, governments may be forced to make strategic choices between companies that can, under the circumstances, help bring forward the new domestic and imported low carbon hydrogen supplies in sufficient quantities. This is also important from a security of supply point of view because the new supplies help reduce the dependence on imported oil and natural gas. Such a course of action may encounter some resistance in parts of society, and it will take some leadership to both engage these oppositional forces and move forward. The urgency to organise substantial domestic and imported flows of low carbon hydrogen has increased dramatically and gained importance in diversification of source and geographic origin with regards to the oil and gas security of supply.

Ownership of companies may matter in a geopolitically divided world. Just like in IT and telecommunication systems, certain companies may be banned from investing in the domestic low carbon sector due to connections with or shareholdings by unfriendly states. Again, the current sanctions may have an unforeseen wider future impact. The behaviour of the EU in norms and value discussions is not always appreciated and often thought of as condescending. The current energy crisis may invoke a rethinking of our relationship with western multinational companies that are able to accelerate building the new low carbon hydrogen value chains to size and other companies interested in investing.

6 LESSONS LEARNED

Security of supply must be seen in the context of import dependency, geopolitics and diversification options, system flexibility and the phases of market developments. The largest incidents of security of supply in oil and gas are related to geopolitical events, but the most occurrent ones are home grown (due to natural disasters, technical problems). A new security of supply problem is vulnerability to cyber-attacks on critical energy infrastructure.

THE 1970S OIL CRISES AND INDUSTRIAL RESTRUCTURING IN THE OIL SECTOR

The oil crises of 1973 and 1979 are still the most prominent examples in oil. But also the first Gulf War in 1991 led to a substantial shift in the oil market structure. As a matter of fact, it was the start of the growing importance of Russian oil flows into the EU, and the shift of Middle Eastern supplies to oil hungry Asia. These incidents seem to appear suddenly, but were preceded by enough signals that something was about to change. In the early 1970s, the NW European oil market ended the expansion phase and entered the maturity phase, and a long period of consolidation in refining and storage followed. In the 1980s, this consolidation had to be managed under the EU 'manifest crisis' heading to restructure the downstream industry. The resulting concentration of oil processing industries in NW Europe and the later phases of consolidation of refining and petrochemical industries in clusters, at the detriment of stand-alone operations is continuing until today. At the same time, new centres in the Middle East and Asia became competitors of the EU (mainly coastal) refining and energy-intense industries. Conversion of refineries into storage facilities has been ongoing for nearly 20 years[56], while conversion into biorefineries is a newer phenomenon.

The sanctions on Russia following the invasion of Ukraine on 24 February 2022 is resulting in another oil crisis. The acceptance of the sixth sanction package of the EU, which included an import boycott of Russian oil and oil products[57] will create large dislocation and scarcity of oil products. This decision was taken without making

56 https://www.clingendaelenergy.com/publications/publication/long-term-prospects-for-northwest-european-refining; https://www.clingendaelenergy.com/publications/publication/the-european-refining-sector-a-diversity-of-markets.

57 https://www.consilium.europa.eu/en/press/press-releases/2022/05/31/european-council-conclusions-on-ukraine-30-may-2022/

an impact assessment, apparently assuming crude oil and oil products could easily be replaced with crude oil from elsewhere, and without taking counter measures from Russia into account.[58] The economic impact of this decision may be large, particularly in combination with gas market shortages.

The experience of supply chain disruptions during the covid-19 crisis showed that the dependency on the chemical industry producing all sorts of crucial daily user goods, medical goods etc., may also be affected by oil market dislocations, because oil is an important feedstock. Strategic reserves might help some of the dislocations and shortfall of supply, but not all. Most strategic reserves contain a large share of crude and motor fuels and not feedstock for industry. Moreover, some of the strategic stock releases could leak away to other markets when not accompanied by strict instructions for the market players. This may change when countries are forced to go into crisis mode and manage demand and supply more strictly. The lesson from the 1970s oil crises is that it does lead to large changes in the structure of economies. The REPowerEU plan tries to steer this restructuring in a net-zero direction.

REGULATION AND RUSSIA-UKRAINE CRISES: MARKET DEVELOPMENTS IN THE GAS SECTOR

In natural gas, the Russia-Ukraine gas crisis of 2005 and 2009 feature prominently in security of supply issues. These crises boosted the prominence of LNG supplies, offering more diversity of supply compared to less flexible pipeline supplies. The transit country risk is often mentioned in this context, where the nuisance power of transit countries plays an important role. Depending on the gas supply contracts, the transit risks fall on the producing country, while security of supply of the consuming country is at stake. Managing the transit risk was left to Russia and only around 2009 did the EU become more involved in managing the disputes between the two countries.[59] In the meantime, Russia began to build new direct routes to its main markets in the EU to mitigate this transport risk to its main export market, but encountered stiff opposition.[60] The invasion of Russia in the Ukraine has completely

58 https://www.clingendaelenergy.com/files.cfm?event=files.download&ui=CVDL-Rondetafel-25-3-2022-Importen-Russische-olie-en-olieproducten-onrust-int-markt.pdf

59 The last agreement where the EU was involved in negotiating between Russia and Ukraine was in December 2019 on the use of the Ukrainian system under the assumption that Nord Stream 2 would come into operation. The agreement was set at 40 bcm. The agreement has not reduced the number of legal actions of the Ukrainian gas company against Gazprom.

60 https://www.congress.gov/bill/117th-congress/house-resolution/426/text?r=2&s=1;
https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/690705/EPRS_BRI(2021)690705_EN.pdf;
https://3.documentcloud.org/documents/21118732/germany-non-paper.pdf;
https://www.congress.gov/bill/116th-congress/senate-resolution/27/text?q=%7B%22search%22%3A%5B%22Nord+Stream+2%22%5D%7D&r=2&s=1;

changed the fate of the pipeline to be opened any time soon (or at all). The growing dependency on Russian gas supplies was due to declining domestic production and the liberalisation of the EU market, without regulation for security of supply. Also, the regulation of LNG terminals may have played a role in discouraging non-Russian suppliers from organising more long-term LNG flows to the EU. Instead, in the period 2012-2020, the EU became the market of last resort for LNG. Moreover, the buyer's market led to a substantial number of arbitrations to make the switch to hub pricing. The importance of hub pricing (TTF) was also confirmed in the May 2018 Gazprom East Europe competition case.[61] As long as the gas market was a buyer's market, consumers benefitted from lower natural gas prices, but in the current tight (seller's) market, the exposure to high prices resulted in more economic hardship for inelastic consumers and less security of supply. Also, hub pricing loosened the ties between producers and consumers in terms of sharing risks and benefits through contracts, while in times of crisis these relations with a diversity of suppliers may be important.

TRANSITION, RESTRUCTURING, MARKET DEVELOPMENT: LOW CARBON HYDROGEN

The lessons learned from oil and natural gas, are that the phase of market development matters, not just in the domestic (or regional) market, but also elsewhere. Moreover, the impact of security of supply events is most felt in mature markets, when large volumes are consumed beyond industry, and inelastic demand and the vulnerability of certain consumers plays a larger role, like in mobility and the built environment (trucking and river barges for goods and food transports, and backup generators in care institutions). For sure, changes in ownership of resources, or changes in the free movement of low carbon hydrogen flows for strategic and geopolitical reasons, can also play an important role in signalling changing reliability of low carbon hydrogen trade flows. The current strategic dependency on China for resources, minerals and processing for new energy technologies, is something to monitor closely, as the IEA is signalling in recent studies. In the absence of new suppliers of these goods and materials, it may become more important, in terms of security of supply measures, to focus on circularity of current goods to harvest resources and materials from decommissioned windmills and solar panels. Designing solar and wind assets with this in mind may be an important first step in overcoming this new dependency.

The interplay between (dispatchable) electricity and low carbon hydrogen markets, and the ability to balance these markets, will be very important in the future. The

61 https://ec.europa.eu/competition/elojade/isef/case_details.cfm?proc_code=1_39816

development of direct use of hydrogen carriers is still unclear and may become a determining factor in later years regarding transportation, storage (costs), and system flexibility choices. Depending on the technical and economic developments, governments should underpin the development of the low carbon hydrogen market with security of supply policies. In line with the stages of market developments, security of supply policies will have to intensify in terms of intervening in the market when the market becomes more mature. Depending on the regional (North Sea area) or EU (internal market) developments these policies should be advanced in concert with other countries. If other countries lag in policymaking, the Netherlands should investigate the merits of instrumenting domestic policies.

HYDROGEN: AN UNCERTAIN ENVIRONMENT REQUIRES CONSTANT MONITORING

Governments should monitor international market developments regularly, create market transparency rules (and make these publicly available) and assess the geopolitical signals for a larger event to take place that could disturb the trade flows of low carbon hydrogen. The method could follow the regular 'energie-rapport' method[62] in this case focussed on security of supply. The reporting should be guarded from becoming a political instrument for special interests (i.e., maintain the focus on security of supply in all its aspects).

In addition to monitoring, transparency is also important. Greater transparency of information on short-term and longer-term issues in security of delivery and supply should be promoted to facilitate investments and inform consumers. Development of knowledge about the hydrogen value chain should not be left to companies alone, but also developed in government institutions and society at large. This will also help bring about a timely implemented security of supply policy. This knowledge should also be organised in the government administration. Here the services of the Energy Information Agency of the US are a good example. Ideally, such a service should be organised at EU level, but also regional and local transparency can be a great help to monitor and develop knowledge about these markets.

Security of supply is cost increasing for consumers. In a buyer's market, pressure to take security of supply less seriously must be resisted.[63] A buyer's market usually signals an upcoming seller's market when investments in new production capacity

62 https://open.overheid.nl/repository/ronl-archief-c0b58a92-fdcc-4dda-9cfb-e6bf5f82704d/1/pdf/energierapport-transitie-naar-duurzaam.pdf

63 In the 1980s, the quality of the US strategic reserve deteriorated to reduce costs and the impact of a release no longer fitted the refining capacity to impact the market when needed.
https://www.gao.gov/assets/emd-80-19.pdf; https://www.everycrsreport.com/reports/RL33341.html

peters out, while demand continues to increase. In energy, the length of a buyer's market is usually longer compared to the duration of a seller's market. New investments in production and conversion come about when the market is tight and prices relatively robust. Governments must manage these cycles. Market players in a mature or even declining phase, where margins can be thin, may be more and more focused on short-term production and demand developments. In the power market, the renegotiations of pricing structures in long-term gas contracts took place when the incumbents in the power sector were confronted with soft demand and competition from (subsidised) wind production and coal.[64] The buyer's market created a period with more focus on short-term contracts and was heralded by the European Commission as proof that liberalisation delivered lower energy bills to consumers. Departure from active energy diplomacy with Russia, little or no sensitivity for investments risks of producers and optimism about the speed at which natural gas demand would be replaced by new energy technologies, created a situation of large dependence on the willingness of Russia to bring its unsold gas to the EU market. Fast forward to today and we can now conclude that the underpinning of a substantial part of the EU gas market was based on quicksand rather than solid regulations regarding storages and diversity of supply. In the future, with trade in low carbon hydrogen, these lessons should be taken seriously.

Security of supply should be insensitive to short-term market sentiments, but instead look at the longer-term value chain, the market and geopolitical developments. At the same time, the security of supply policies and instruments should be critically and regularly reviewed against the changing circumstances for efficacy. History shows that signals of an impending supply or value chain interruption are often missed. Sometimes because the 'what if' question is overlooked, or is deemed unfitting the short-term political energy discussions when the collection of information and analyses is not done on a structural basis. It would be wise to organise regular 'what-if' discussions to help the government to critically monitor developments.

64 http://clingendaelenergy.com/publication/european-power-utilities-under-pressure
http://www.clingendaelenergy.com/publications/publication/wind-and-gas

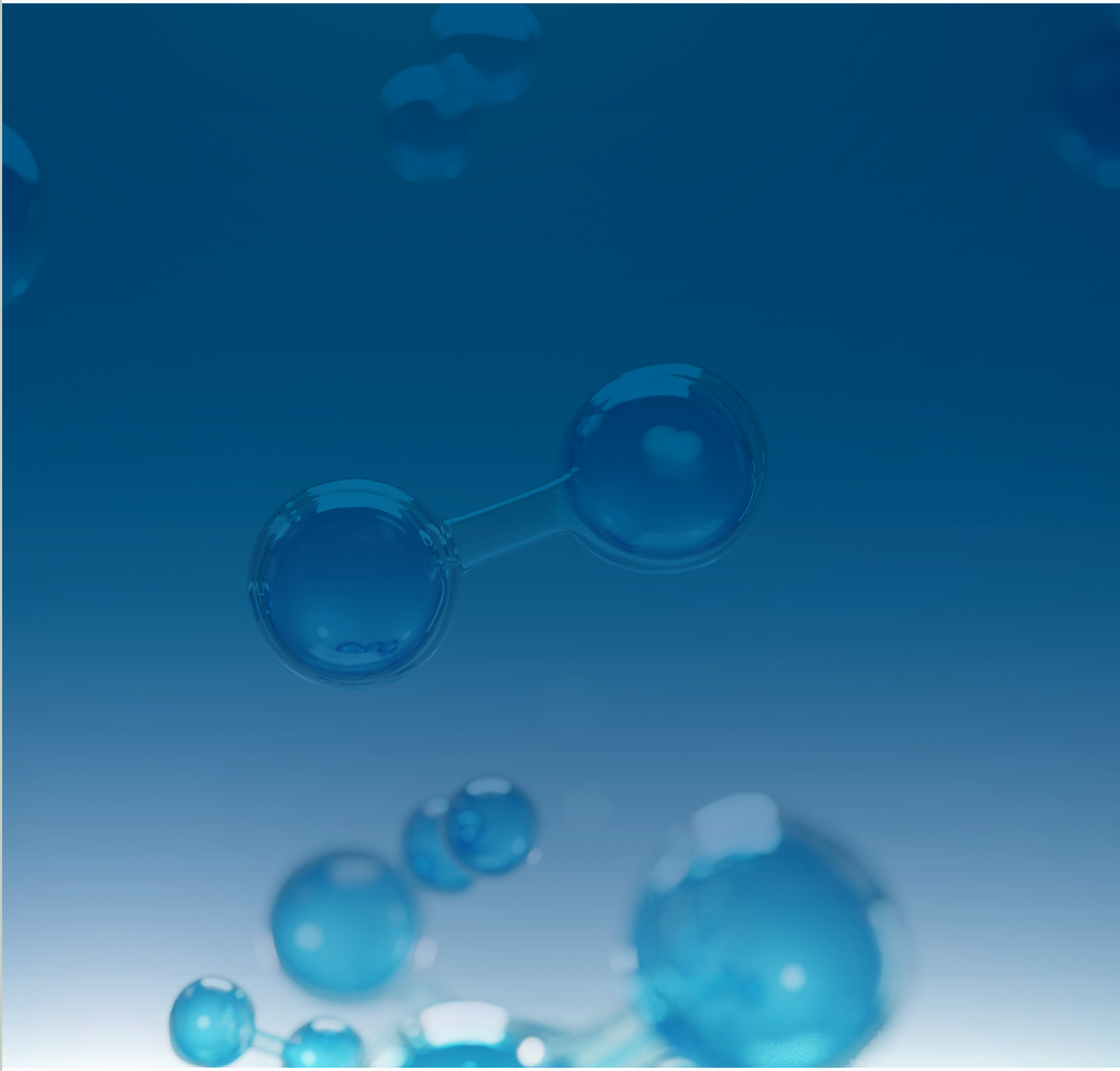
7 CONCLUSION

Market structure and market developments influence the type of security of supply tools that are needed. The toolbox for security of supply for low carbon hydrogen (carriers) is not much different from those for oil and natural gas. One difference is that low carbon hydrogen carriers in themselves may help diversify flows and serve different functions (like oil and gas served different demand purposes), while they also provide inherent switching qualities, as they can all be brought to the same hydrogen quality and ready for consumption. The potential to refurbish both natural gas and oil infrastructure to transport the different low carbon hydrogen carriers is a great benefit to society, both in terms of costs and in terms of diversity and versatility.

Governments should be aware that the different phases of development require an escalating use of the security of supply toolbox when moving towards maturity. Whatever the world or EU or Dutch economic model, regulation of the market should include security of supply from the expansion phase onwards.

The level of security of supply measures depends on the size of domestic production, the level of trade and structural dependencies. Governments should monitor the situation on a regular basis and implement policies to provide more security of supply when needed. Complacency in the past 20 years has taught us that markets can provide large and uninterrupted flows for a long time, but events always suddenly change this situation. The cost of providing security of supply may seem inefficient or costly in good times, but vital when an interruption occurs. The idea that the net-zero world will be less conflictual and security of supply not necessary, is a myth, starting with the growing dependency on China.

The world order is currently in flux. Security of supply in low carbon hydrogen should not only be seen against the background of a harmonious world, but also be tested for less collaborative or conflictual futures. This includes a less coherent Europe. Security of supply policy should aim for a robust energy system on a national, relevant regional, and inter-regional level/EU level, but is not always one size fits all. In the introduction and expansion phases, member states and market players need some room to develop these new value chains and markets.



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