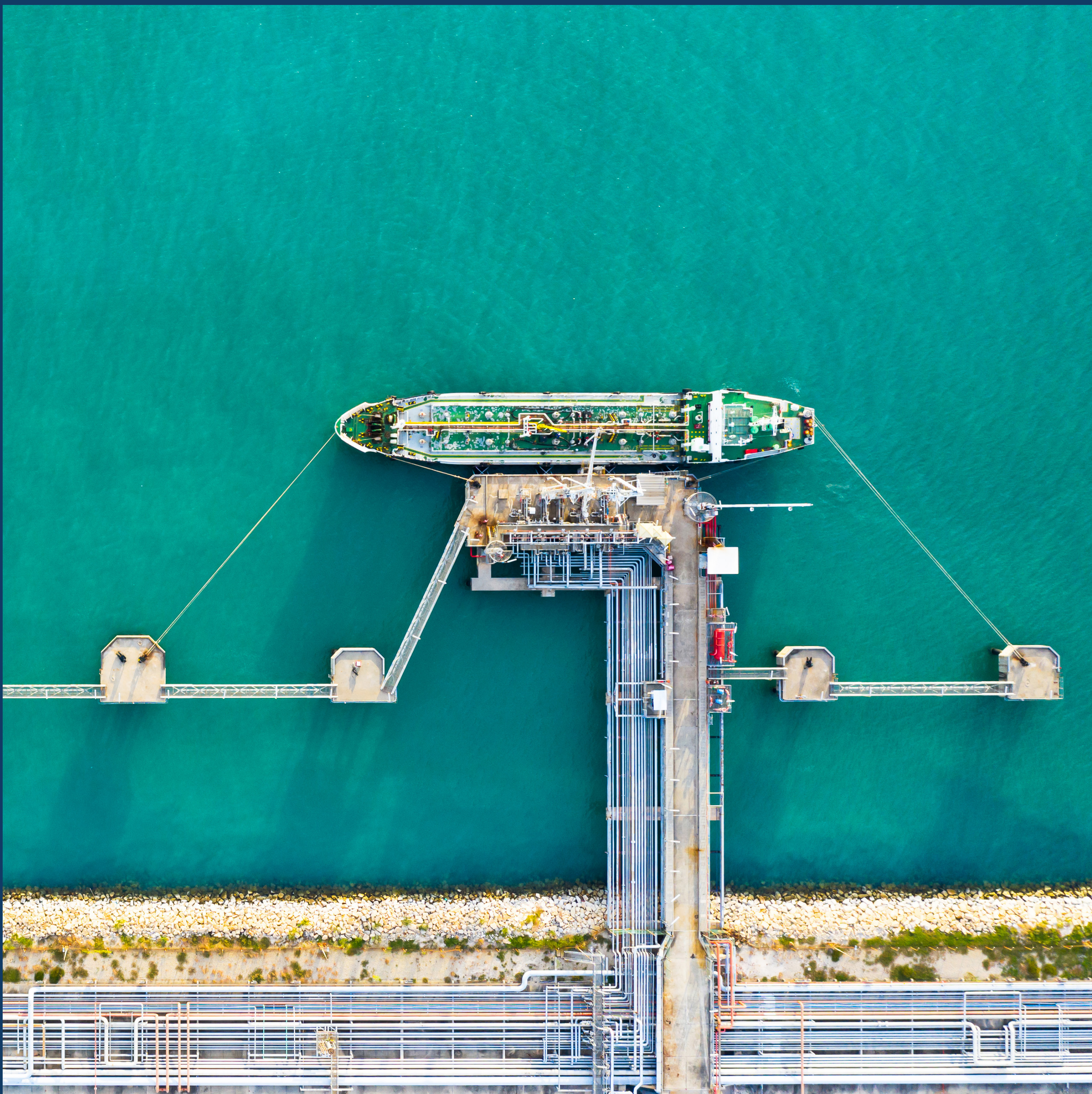
The Hague Centre for Strategic Studies

The European tank storage sector
2050 and beyond

Irina Patrahau, Michel Rademaker, Lucia van Geuns, Philip Geurts and Sarah Ojukwu

May 2022



The Hague Centre
for Strategic Studies

The European tank storage sector
2050 and beyond

Authors:
Irina Patrahau, Michel Rademaker, Lucia van Geuns,
Philip Geurts and Sarah Ojukwu

May 2022

The conclusions and recommendations presented in this paper are the result of independent research. Responsibility for the content rests with the authors and the authors alone. The research was made possible by a financial contribution from VOTOB (The Dutch Association of Tank Storage Companies) and FETSA (Federation of European Tank Storage Associations) to the The Hague Centre for Strategic Studies.

Table of Contents

Executive summary		IV
Executive summary (NL)		V
Implications of the Russian invasion of Ukraine for Europe's energy policy		VI
1.	Introduction	1
2.	Background and rationale	2
3.	Europe in 2050	4
4.	The international playing field	9
5.	Pathways to 2050	13
6.	Energy technologies for decarbonization	18
7.	Observations and conclusions	35
References		38

Executive summary

As the world is aiming to reach carbon neutrality by 2050 and beyond, policy support, international relations and the development of new technologies are key determinants of what the next decades will look like. Despite significant uncertainty, reliable energy infrastructure, including storage, handling and transport, is essential in the fight against climate change. This paper seeks to distinguish long-term trends for energy infrastructures by analysing technological developments against the background of global climate ambitions.

As the future cannot be anticipated, scenario analysis is the only way of identifying potential pathways to 2050. New energy markets and emerging dependencies between suppliers and consumers of different low-carbon energy sources are reshaping geopolitical realities. So far, Europe is leading the energy transition. The war in Ukraine in 2022 provided momentum to further accelerate climate action and reduce dependency on Russia. The world's largest oil consumers and producers, like China and the OPEC+ countries, respectively, are heading toward climate neutrality as well, although at a different pace. Middle Eastern and North African countries may become important producers of green hydrogen, helping countries all around the world reach their climate goals.

The extent to which countries follow through with their announced pledges and commitments will determine the future role of energy infrastructure. Three broad pathways to 2050 can be distinguished.[1] The first is a pessimistic outlook, describing a world guided by energy security, isolationism, and declining international cooperation. For the storage sector, this scenario implies the least significant change in infrastructure, but as far as Europe is concerned, a continued struggle to maintain the social license to operate.

The second pathway describes a world that is mainly driven by economic growth. Even though climate policies become stricter across the world, the huge discrepancy between the emissions reducing efforts and expectations hampers the achievement of pledged targets. This translates into a world dominated by volatility for decades to come, as the transition period will be chaotic and last longer than planned. In this case, infrastructure will have to balance the old and new system for a long time, with little certainty of when a complete decarbonization could take place.

In the third and most sustainable pathway, the growth of renewables can smoothly substitute fossil fuels and net zero targets can be achieved as planned. This would imply an increase of the carbon price, significantly more renewable electricity generation, hydrogen and carbon capture, utilisation and storage (CCUS), as well as a shift in behaviour towards more conscious, sustainable and ecological consumption. While this requires the most investments and change in infrastructure in the mid-term, it would ensure that a more stable period could emerge by 2050.

Hydrogen will likely be a substantial energy carrier in industrial and chemical production, aviation and heavy transport – i.e., sectors that are difficult to electrify. Liquid hydrogen, methanol, ammonia and Liquid Organic Hydrogen Carrier (LOHC), are expected to take on an important role in the future energy storage system. Whether a product is suitable as energy carrier is determined by the energy density, costs of transport, production and conversion. Hydrogen hubs could emerge outside Europe in regions like North Africa, South America and Australia.

Electricity storage serves as backup for variable renewable energy sources and will become a main part of the transport and electricity sector. Nevertheless, an extensive increase in stationary battery development is uncertain because it is costly. Carbon capture, utilization and storage (CCUS) technologies capture CO_2 in order to store and/or use it. Like biofuels, CCUS yields a halfway solution. Both contribute to decarbonization leading to emissions reductions but do not fully avoid them. In the industrial sector, considering the growing global demand of industrial products, the focus is increasingly shifting toward waste management and recycling, especially pyrolysis, that offer more sustainable solutions.

1 This paper does not develop new scenarios. Rather, it makes use of existing ones developed by the International Energy Agency, Equinor and TNO.

Executive summary (NL)

In het mondiale streven naar koolstofneutraliteit in 2050 en daarna, zijn ondersteunend beleid, de ontwikkelingen in de internationale betrekkingen en innovatie van nieuwe technologieën bepalende factoren. Ondanks de aanzienlijke onzekerheden is een betrouwbare energie-infrastructuur, inclusief opslag, overslag en transport, essentieel in de strijd tegen klimaatverandering. Dit rapport beschrijft mogelijke toekomstbeelden voor energie-infrastructuren door technologische ontwikkelingen te analyseren tegen de achtergrond van mondiale klimaatambities.

Omdat de toekomst richting 2050 niet kan worden voorspeld is gebruik gemaakt van scenarioanalyses. Door nieuwe energiemarkten en veranderende afhankelijkheden tussen leveranciers en consumenten van verschillende koolstofarme energiebronnen verandert ook de geopolitieke realiteit. Tot op heden loopt Europa voorop in de energietransitie. De oorlog in Oekraïne in 2022 zorgt voor een impuls om de energietransitie verder te versnellen en de afhankelijkheid van Rusland te verminderen. Belangrijke energieverbruikers als China en India hebben toegezegd tegen 2060 en 2070 CO_2 neutraal te zijn. De VS en de meeste OPEC+-landen hebben ook koolstofneutraliteitsdoelstellingen aangekondigd voor de lange termijn (2050-2060), maar zullen nog olie en gas blijven produceren op de middellange termijn.

De mate waarin landen hun aangekondigde doelstellingen en beloftes nakomen, zal bepalend zijn voor de toekomstige rol van de energie-infrastructuur. Er zijn drie mogelijke scenario's richting 2050 te onderscheiden.[2] De eerste is een pessimistische vooruitblik op een wereld die wordt beheerst door energieveiligheid, isolationisme en afnemende internationale samenwerking. Voor de opslagsector betekent dit scenario de minste verandering in infrastructuur, maar voor Europa een voortdurende strijd om de sociale *'license to operate'* te behouden.

Het tweede scenario betreft een wereld die vooral gecontroleerd wordt door economische groei. Hoewel het klimaatbeleid over de hele wereld strenger wordt, belemmert de enorme discrepantie tussen de inspanningen en verwachtingen om de uitstoot te verminderen het behalen van de toegezegde doelen. Dit vertaalt zich in een samenleving die de komende decennia wordt gedomineerd door volatiliteit, aangezien de overgangsperiode chaotisch zal zijn en langer zal duren dan gepland. In dit geval zal de infrastructuur lange tijd het oude en het nieuwe systeem in balans moeten houden, met weinig zekerheid over wanneer een volledige decarbonisatie zou kunnen plaatsvinden.

In het derde en meest duurzame scenario kan de groei van hernieuwbare energiebronnen soepel de fossiele brandstoffen vervangen en kunnen doelstellingen voor koolstofneutraliteit worden bereikt als gepland. Dit zou een stijging betekenen van de koolstofprijs, meer hernieuwbare elektriciteitsopwekking, waterstof en koolstofafvang, -gebruik en -opslag (*Carbon capture, utilization and storage*, CCUS), evenals een gedragsverandering naar bewuster, duurzamer en ecologisch energieverbruik. Hoewel dit op middellange termijn de meeste investeringen en verandering in infrastructuur vereist, zou het ervoor zorgen dat er tegen 2050 een stabielere periode kan aanbreken.

Waterstof zal waarschijnlijk een belangrijke energiedrager worden voor de zware industriële en chemische productie, luchtvaart en zwaar transport, sectoren die moeilijk te elektrificeren zijn. Vloeibare waterstof zal naar verwachting, naast methanol, ammoniak en Liquid Organic Hydrogen Carriers (LOHC), een belangrijke rol gaan spelen in het toekomstige energieopslagsysteem. Of een product geschikt is als energiedrager wordt bepaald door de energiedichtheid, kosten van transport, productie en conversie. Waterstofhubs kunnen buiten Europa ontstaan in regio's als Noord-Afrika, Zuid-Amerika en Australië.

Elektriciteitsopslag dient als back-up voor variabele hernieuwbare energiebronnen en zou een hoofdonderdeel kunnen worden in de transport- en elektriciteitssector. Toch is een grote toename van de ontwikkeling van stationaire batterijen onzeker vanwege de hoge kosten. CCUS technologieën vangen CO_2 af om het op te slaan of te gebruiken, en bieden net als biobrandstoffen een tussenoplossing. Beide technologieën dragen bij aan decarbonisatie, wat leidt tot emissiereducties, maar voorkomen emissies niet volledig. In het licht van de wereldwijd groeiende vraag naar industriële producten, verschuift de focus in de industriële sector waarschijnlijk steeds meer naar afvalbeheer en recyclingtoepassingen waaronder pyrolyse, dat duurzamere oplossingen biedt.

2 Dit document heeft niet tot doel om nieuwe scenario's te ontwikkelen. Het maakt eerder gebruik van bestaande scenario's die zijn ontwikkeld door het Internationaal Energieagentschap, Equinor en TNO.

Implications of the Russian invasion of Ukraine for Europe's energy policy

This report was finalized approximately two months after the Russian invasion of Ukraine (01.05.2022). It has become clear that the expected mid-term developments under various scenario studies, such as Russia supplying the European oil and gas markets for at least another decade, will be strongly affected by this conflict. The previous paper in this series, analyzing the outlook to 2030 for tank storage companies, touches upon mid-term consequences of the war in Ukraine.

The conflict will likely have long-term consequences for Europe's climate goals as well. European energy policy has for a long-time balanced security of supply and strategic autonomy with climate goals and energy affordability. Currently, European energy policy is led by geopolitical concerns and security of supply, but affordability and climate goals remain key considerations. In the long term, climate goals have utmost priority in European policymaking. The Russian invasion of Ukraine brought about two key developments that are relevant for Europe's energy sector up to 2050. First, it is a strong catalyst accelerating the energy transition. Second, it forced European countries to rapidly develop a concerted response to Russia, leading to further European integration.

The dependency on Russian oil and gas has become a highly salient issue since the war erupted. Whereas energy security issues had been part of public discourse in the European Union since at least 2014, the current war showed the potential of Europe's maneuver space in its energy policy. Introduced as REPowerEU[3], the EU announced ambitious plans to reduce dependency on Russian gas and to accelerate the energy transition. This includes supporting the sustainable production of biomethane and hydrogen, installing more solar panels, heat pumps and wind turbines, as well as speeding up permitting procedures for renewables. The geopolitical challenges of being reliant on Russian fuels will likely lead European governments and the private sector to take increasingly larger steps toward climate goals.

Another determinant of Europe's energy transition is the degree of cooperation between governments within and outside of Europe. The war in Ukraine led to unprecedented coordination levels within the EU. Member states rapidly mobilized under the leadership of the European Commission in imposing concerted and substantial sanctions on Russia. For the first time, an embargo of Russian fossil fuels is discussed at the European level, despite

3 "Press Conference on the REPowerEU Communication," Text, European Commission, March 8, 2022, https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_22_1632.

energy policy having been under the authority of sovereign states until now.[4] The United States, Canada, Japan and South Korea imposed some degree of sanctions related to the SWIFT banking system, oil imports and individual Russians associated with Putin's regime. At the same time, the support offered to Ukraine, both in terms of humanitarian aid and military assistance, has come from governments all around the world.

As argued in this report, the behavior of governments in global politics is a key determinant of whether the energy transition will be cooperative or competitive. In a world based on mutual assistance and burden sharing, countries will follow the net zero pathway to 2050 and smoothly phase out fossil fuels. However, in a world characterized by isolationism and nationalism, climate goals will not be achieved and governments will struggle to mitigate the consequences of climate change. The war in Ukraine has shown that cooperation is not only possible but also desirable, meaning that the world may be heading toward an optimistic rather than pessimistic pathway up to 2050.

The energy transition is an inherently unstable and uncertain period, given that it relies on a variety of factors, such as policy support, international relations, technological development and security of supply. Energy infrastructure, including storage, transport and handling, will be transformed according to new energy needs. This paper discusses pathways to 2050 by looking at global climate plans and the latest technological developments in the energy sector.

4 European Parliament, "MEPs Demand Full Embargo on Russian Imports of Oil, Coal, Nuclear Fuel and Gas," July 4, 2022, https://www.europarl.europa.eu/news/en/press-room/20220401IPR26524/meps-demand-full-embargo-on-russian-imports-of-oil-coal-nuclear-fuel-and-gas.

The Hague Centre for Strategic Studies

The European tank storage sector

2050 and beyond

The international playing field in 2050-2070

The US aims to achieve carbon neutrality by 2050.

European policy is concentrated on net zero, aiming to secure supplies of new materials and technologies.

Russia aims to achieve carbon neutrality by 2060, but it relies on domestic reserves of oil and gas in the mid term.

China is the world's largest carbon emitter as well as a leader in manufacturing low-carbon energy technologies.

India targets net-zero by 2070, although its oil and gas consumption will increase in the mid-tem.

Saudi Arabia and UAE pledged to reach carbon neutrality by 2060 and 2050. Both are ramping up oil production and have good prospects to become green hydrogen exporters.

Chile, Morocco, Egypt and Australia, together with other countries with relatively cheap solar power, are prospected to become the main global producers of green hydrogen.

Energy technologies for decarbonisation

HYDROGEN:

COMPRESSED HYDROGEN: Most mature hydrogen storage technology for transport on small distances. Lowest energy density, with large spatial requirements for storage.

LIQUID HYDROGEN: Most mature hydrogen storage technology for transport on large distances.

METHANOL: E-methanol, made from hydrogen with CO2, not yet mature. Advantageous due to relatively high energy density compared to other carriers.

AMMONIA: Green ammonia, made from green hydrogen, not yet mature. Highest energy density out of energy carriers, but highly toxic.

LIQUEFIED ORGANIC HYDROGEN CARRIERS (LOHCs): Expected to become the cheapest form for transporting hydrogen >15000 km. Dehydrogenation process, needed to release hydrogen from carrier, not mature.

ELECTRIFICATION & BATTERY STORAGE: Continuous decrease in costs for batteries and expansion of grid battery storage expected. Types of batteries are lithium-ion batteries, flow batteries or saltwater batteries.

CARBON STORAGE: Carbon capture, utilization and storage (CCUS) can enable the production of low-carbon hydrogen and can help decarbonize the industrial sector.

BIOFUELS: Advanced technology for the liquid biofuel production like the usage of woody feedstock will grow substantially up to 2050. Synthetic fuels will most likely play a role in the fuel supply for the transport sector.

RECYLING: The global consumption of plastics makes it likely that in the long term recycling will become indispensable. This gives opportunities to decrease emissions and the consumption of fossil fuels as feedstock.

List of abbreviations

APS	Announced Pledges Scenario
BEVs	Battery Electric Vehicles
BIO	TNO and Smartport Biomass Scenario
Bio-FT	Fischer-Tropsch biomass gasification
CCUS	Carbon capture, utilisation, and storage
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
COP26	Conference of the Parties 26
CYC	TNO and Smartport Waste Scenario
DAC	Direct Air Capture
EU	European Union
EVs	Electric Vehicles
FETSA	Federation of European Tank Storage Associations
GDP	Gross Domestic Product
GHG	Greenhouse Gas
Gt	Gigatonne
GW	Gigawatt
HEFA	Hydrogenated Esters and Fatty Acids
HFO	Heavy Fuel Oil
HVC	High Value Chemicals
HVO	Hydrotreated Vegetable Oil
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt-hour
LNG	Liquefied Natural Gas
LOHC	Liquid organic hydrogen carrier
Mt	Million tonnes
MW	Megawatt
NZE	Net Zero Emissions
OPEC	The Organization of the Petroleum Exporting Countries
PtX	Power-to-X
SAFs	Sustainable Aviation Fuels
SDS	IEA's Sustainable Development Scenario
Solar PV	Solar Photovoltaic
STEPS	IEA's States Policies Scenario
SYN	TNO and Smartport Synthetic Fuels and Green Hydrogen Scenario
TNO	*Nederlandse Organisatie voor Toegepast Natuurwetenschappen* [Netherlands Organisation for Applied Scientific Research]
TWh	Terawatt-hour
UAE	United Arab Emirates
US	United States
VOTOB	*Vereniging van Nederlandse Tankopslagbedrijven* [Association of Dutch Tank Storage Companies]
VRE	Variable Renewable Energy

Acknowledgements

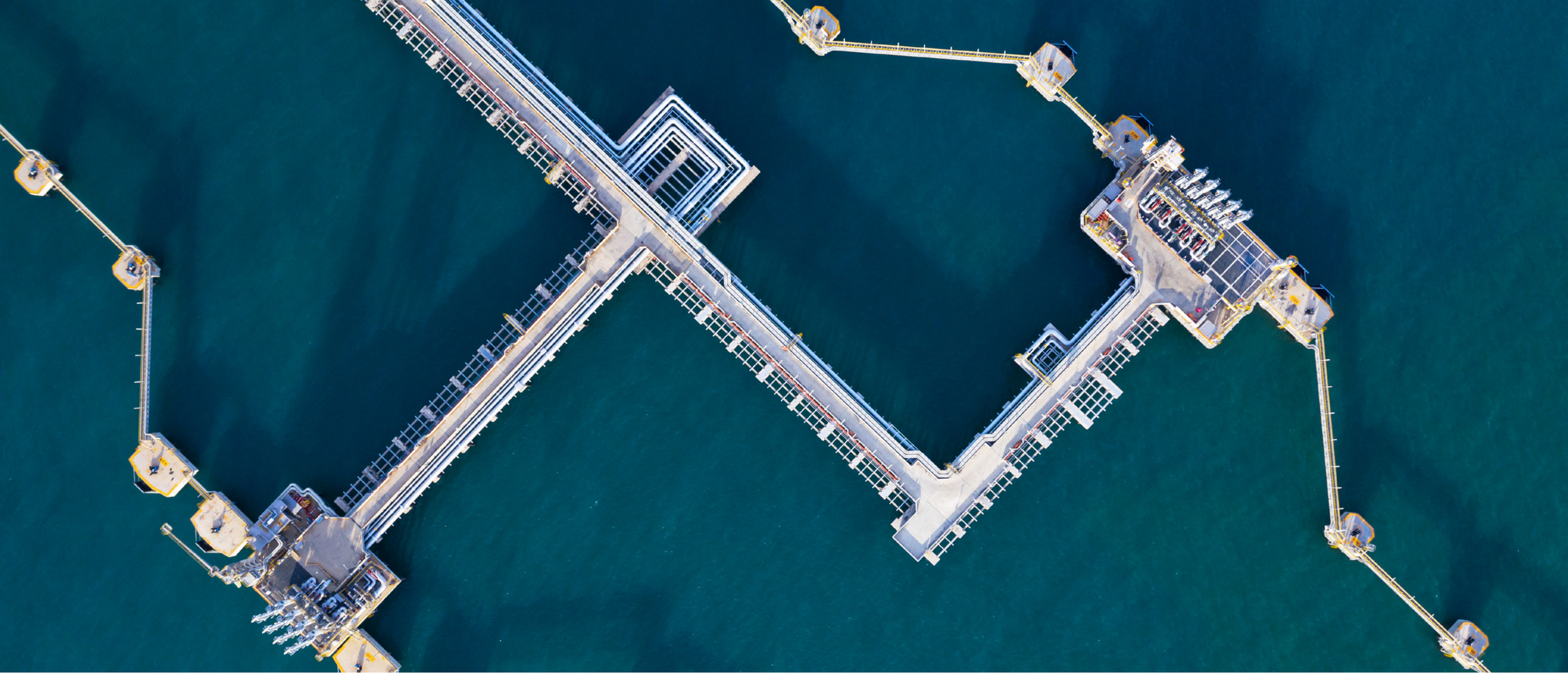
For this series of HCSS/VOTOB/FETSA papers, interviews were conducted with representatives from tank storage companies (amongst others: VOPAK, Koole, Oiltanking, ETT, LBC), from the Port of Amsterdam and Port of Rotterdam, Shell, COVA, DPO, MVO. The seven national tank storage associations within FETSA (Belgium, France, Spain, the Netherlands, Germany, Italy, the UK) provided valuable inputs for these papers. We would like to thank the representatives of these companies and associations for sharing their insights. The information was used to gain a better understanding of the context in which tank storage companies operate and to collect a wide range of perspectives regarding the energy transition, from some of the main stakeholders in the industry. We would further like to thank Insights Global for supporting the series of papers with data regarding the tank storage sector.

1. Introduction

Promising technologies that are expected to facilitate the energy transition are emerging. Green hydrogen and energy carriers, large-scale battery storage, biofuels and carbon capture, utilization, and storage (CCUS) are expected to become the foundation of a new low-carbon energy system, although their current application remains rather limited. It is therefore only in the long-term – up to 2050 – that these technologies will come to play a major role in the ecosystem in which tank storage companies operate.

Tank storage companies are essential components of our energy, manufacturing, and food industries. Many actors involved in current supply chains are undertaking significant efforts to design their long-term visions and adapt to new realities. Today's technological developments in the energy sector together with governance and policy support will be primary determinants of the energy landscape in 2050. This report analyzes how such technological developments fit into European net zero climate ambitions and how they could impact the tank storage sector.

This is the last part of a series of four reports analyzing the role of tank storage in the energy transition. The objective of this report is twofold: (1) to assess the developments that can be expected in the clean hydrogen, battery storage, industrial, biofuel and CCUS sectors up to 2050 and (2) to determine what these developments mean for European tank storage. The first report set the scene by discussing the European tank storage sector in the global energy landscape. The second report, *European tank storage in today's global value chains: What role does it play in our economy*, provided a snapshot of the role of European tank storage in today's global supply chains. The third report, *European tank storage in global supply chains: Outlook to 2030*, analyzed the mid-term outlook by looking at threats and opportunities that the European tank storage sector will face up to 2030-2035.



2. Background and rationale

Tank storage is one of the sectors that strengthen Europe's prosperous international position. Storage companies are part of a large ecosystem of producers, traders, shipping companies, as well as consumers. Tank storage is an important component of energy infrastructure, storing energy supplies for the European economy.

FETSA, the Federation of European Tank Storage Associations, represents the European bulk liquid storage sector. National tank storage associations from seven European countries are part of FETSA, as well as four associated members from three other countries. These national associations represent 140 companies across Europe. Together, these companies operate 120 million m^3 of storage capacity with a yearly throughput of 1 billion tons of liquid bulk.[5] VOTOB, the association of Dutch Tank Storage companies is the second largest member within FETSA in terms of storage capacity, accounting for 27 million m^3 of liquid bulk. VOTOB members primarily store oil products, as well as biofuels, chemicals and edible oils.

Tank storage companies store liquid energy products, chemicals and edible oils (Table 1). The energy sector is expected to significantly change, with new products, supply chains and infrastructures being established. While the chemical industry will undoubtedly be impacted by decarbonization efforts, the types of chemicals used by our societies will remain the same in the mid-term. Lastly, the storage requirements for edible oils are unlikely to suffer any disruptive changes in the mid or long-term. The edible oils market is therefore not discussed in relation with pathways to 2050. The focus of this paper is the energy sector, although industrial developments are also briefly considered in section 6.

5 "FETSA," accessed September 28, 2021, https://fetsa.eu/.

Table 1. Examples of liquids stored by tank storage companies

Energy products	Chemicals	Edible oils
• Crude oil	• Specialty Chemicals	• Soybean oil
• Fuel oil	• Intermediate Chemicals	• Palm oil
• Gasoil/ Diesel	• Base Chemicals	• Rapeseed oil
• Gasoline	• Specialty Greases	• Sunflower oil
• Jet kerosene	• Lube oils	• Specialty Blended oil
• Naphtha		• Molasses
• Liquid petroleum gas (LPG)		
• Liquid natural gas (LNG)		
• Bioethanol		
• Biodiesel		

The coming decades will bring important challenges for tank storage. The European Green Deal[6] and Fit for 55 package[7] set clear goals for what Europe should look like in 2030 and up to 2050. As a result of the 2022 Russian invasion of Ukraine, the EU announced plans to accelerate the energy transition under REPowerEU.[8] This involves an increase in the production of biomethane and renewable hydrogen, as well as wind and solar power, among others. Countries all over the world have also announced ambitions of net zero in the coming decades, leading to a significant increase in the demand for low carbon energy technologies. Like many other participants in energy supply chains, storage companies must shift their focus from conventional fuels to renewable and low-carbon energy carriers in order to facilitate the energy transition. Policy support and governmental choices across the world are defining the pathway to 2050, guided by technological developments. Innovations in hydrogen storage, e-fuels or flow batteries in the next years could create significant opportunities for the tank storage sector to take on an important role in the energy transition. This report provides a long-term outlook for storage companies by analyzing the future energy system and the associated geopolitical and technological challenges.

6 "A European Green Deal",European Commission, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

7 European Commission, "'Fit for 55': Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality," COM(2021) 550, https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0550&from=EN.

8 "Press Conference on the REPowerEU Communication."

3. Europe in 2050

3.1. Climate ambitions

Climate goals set the tone for Europe's strategic approach in the next 30 to 50 years. The EU aims to reach net zero greenhouse gas (GHG) emissions by 2050, maintaining a competitive energy sector. Net-zero will be reached through a combination of increased energy efficiency, electrification, renewable energy and low-carbon hydrogen.[9] Table 2 outlines the main European ambitions for 2030 and 2050. As industrial and heavy transport processes cannot solely rely on electrification, green hydrogen poses a carbon-free alternative to substitute conventional fuels. The REPowerEU strategy introduced in 2022 aims to stimulate the use of sustainable biomethane by doubling current production levels, increase the production and import of hydrogen and install more renewable power capacity.[10] The following section analyzes European energy ambitions up to 2050 in the main oil consuming sectors, also taking into account electrification.

9 European Commission, "A Clean Planet for All A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy," November 28, 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0773.

10 "Press Conference on the REPowerEU Communication."

Table 2. European climate ambitions in the medium and long term[11]

Sector	Europe today	Europe in 2030 (ambitions)	Europe in 2050 (ambitions)
Road transport	Road transport (gasoline and gasoil/diesel) accounts for roughly half of oil consumption in the EU.	Cars will be powered by (1) blending biofuels into conventional fuels and (2) electricity, decreasing the consumption of gasoline and diesel.	All transportation vehicles will be carbon neutral, powered by electricity and low carbon fuels.
Aviation	Air transport (kerosene/jet fuel) consumes about 9% of oil in the EU, when domestic and international voyages are included.	The EU aims to enhance fuel blending and introduce zero-emissions large aircrafts.	The ambition is to power 63% of the aviation sector with low-carbon fuels. Synthetic fuels will account for 28% of the used fuels.
Shipping	Around 9% of the total EU oil consumption goes into maritime transport, when domestic and international voyages are included.	The EU aims to increase low-carbon fuel levels by 6-9% of the international maritime transport and to introduce zero-emission marine vessels.	86-88% of EU used fuels should be renewable and low-carbon. Around 18.9% will be cell-powered vessels and 5.4% will be produced through electric propulsion technologies.
Households	As of 2019, 34% of consumed electricity in the EU was powered by renewables. About 5.5% of EU oil goes into households for electricity and heating. Natural gas provides almost 38% of heat across Europe.	65% of electricity for households and 40% of heating and cooling for buildings and industry should be generated by renewables. Natural gas is expected to continue being an important fuel.	Household energy consumption should decrease and the heating and cooling of buildings will be powered through waste heat of the electrification process.
Industry	The industrial sector uses up to 21% of oil products in the EU, with the majority being used for non-energy purposes in the chemical industry and construction sector.	The EU Emissions Trading System is the primary driver of industrial decarbonization, as well as energy efficiency and circularity.	There are no specific decarbonization targets communicated. The chemical industry aspires to reach carbon neutrality in the long term.

Road transport accounts for almost half of Europe's oil demand.[12] This sector is therefore at the heart of Europe's decarbonization efforts, and its future development is highly important to the European tank storage sector. For road transport, the EU has outlined four broad goals in its 2020 Sustainable and Smart Mobility Strategy.[13] In practice this implies that by 2050, almost all transportation vehicles will need to be carbon-free. The European car fleet will be composed primarily of electric and (low-carbon) hydrogen fuel cell vehicles.[14] While the EU has set the goal of no more sales of fossil fuel-fired cars beyond 2035[15], there are no concrete targets in terms of the prioritization of electric vehicles (EV) and hydrogen fuel cell vehicles. However, EVs – particularly battery electric vehicles (BEVs) – are considered to be the most cost-effective and feasible low-carbon solution. Moreover, infrastructure for fuel cell cars is lagging behind.[16] As such, it is likely that the majority of low-carbon vehicles by 2050 will be EVs and that the increase in low-carbon hydrogen demand coming from the road sector will be limited.

11 Table based on Eurostat, "Oil and Petroleum Products - a Statistical Overview," August 2021, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Oil_and_petroleum_products_-_a_statistical_overview; IEA, "European Union 2020 - Energy Policy Review," 2020, https://iea.blob.core.windows.net/assets/ec7cc7e5-f638-431b-ab6e-86f62aa5752b/European_Union_2020_Energy_Policy_Review.pdf; European Commission, "Proposal for a Regulation on Ensuring a Level Playing Field for Sustainable Air Transport," July 14, 2021, https://ec.europa.eu/info/sites/default/files/refueleu_aviation_-_sustainable_aviation_fuels.pdf; European Commission, "Reducing Emissions from the Shipping Sector," accessed November 10, 2021, https://ec.europa.eu/clima/eu-action/transport-emissions/reducing-emissions-shipping-sector_en; European Commission, "A Clean Planet for All A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy."

12 Eurostat, "Oil and Petroleum Products - a Statistical Overview."

13 European Commission, "Sustainable & Smart Mobility Strategy," September 12, 2020, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789.

14 Carlos Calvo Ambel, "How to Decarbonise European Transport by 2050," November 27, 2018, 9, https://www.transportenvironment.org/discover/how-decarbonise-european-transport-2050/.

15 Ewa Krukowska and Alberto Nardelli, "Europe to Propose End of Combustion Engine Era in Green Overhaul," September 7, 2021, https://www.bloomberg.com/news/articles/2021-07-09/europe-to-propose-end-of-combustion-engine-era-in-green-overhaul.

16 Calvo Ambel, "How to Decarbonise European Transport by 2050," 10.

Aviation and shipping are more difficult to decarbonize than road transport, as they require a high energy density that is difficult to achieve through electrification, even with prospected progress in battery technology. To become a viable alternative for those sectors, battery weight would have to decrease at least tenfold, which is unlikely to happen up to 2050.[17] Decarbonization of the aviation and shipping sectors will therefore hinge on low-carbon fuels such as synthetic fuels and advanced biofuels.[18]

By 2050, the EU intends to cover 63% of the **aviation** fuel supply with low-carbon fuels.[19] Synthetic aviation fuels are the most beneficial to lowering CO_2 emissions due to their resource efficient production process.[20] However, since the price levels of synthetic aviation fuels amount to between 3 to 6 times the current market costs of fossil aviation fuels, stricter policy regulations have to be implemented, promoting their breakthrough in the market.[21] It is projected that synthetic aviation fuels (produced by combining hydrogen with carbon coming from CO_2[22]) will account for at least 28% of the used fuels in aviation by 2050.[23]

The current fuel mix in the **maritime** sector is based on liquid fossil fuels and liquified natural gas (LNG).[24] To reach Europe's climate targets, renewable and low-carbon fuels need to account for 6-9% of Europe's maritime fuel mix by 2030 and for 86-88% by 2050.[25] Yet, similar to renewable and low-carbon fuel in aviation, their usage is affected by price levels, which in the mid-term are projected to remain high.[26]

Energy efficiency can be increased by innovations such as slow steaming, weather routing, contra-rotating propellers, and propulsion efficiency devices.[27] A regulatory framework has been proposed by the FuelEU Maritime Initiative to reach those objectives.[28] It is expected that this initiative will lead to a 18.9% share of fuel cell-powered vessels and 5.4% share of electric propulsion in Europe's maritime sector by 2050, compared to no share as of 2021.[29]

The industrial sector accounts for approximately 21% of Europe's total oil consumption, most of it being focused on non-energy uses.[30] While the EU aims to decarbonize this sector, it has introduced no specific decarbonization, energy efficiency or renewables targets.[31] The Emissions Trading System is the main instrument used to decarbonize industry, as Europe's chemical industry aspires to be climate neutral by 2050.[32] The industrial sector is considered

17 Fuels Europe, "Vision 2050: A Pathway for the Evolution of the Refining Industry and Liquid Fuels," 2018, 12, https://www.fuelseurope.eu/wp-content/uploads/DEF_2018_V2050_Narratives_EN_digital.pdf.

18 Calvo Ambel, "How to Decarbonise European Transport by 2050," 3.

19 European Commission, "Proposal for a Regulation on Ensuring a Level Playing Field for Sustainable Air Transport."

20 European Commission, 2.

21 European Commission, 2.

22 Fuels Europe, "Vision 2050: A Pathway for the Evolution of the Refining Industry and Liquid Fuels," 15.

23 European Commission, "Proposal for a Regulation on Ensuring a Level Playing Field for Sustainable Air Transport."

24 European Commission.

25 European Commission, 1.

26 European Commission, 9.

27 European Commission, "Reducing Emissions from the Shipping Sector."

28 European Commission, "Proposal for a Regulation on the Use of Renewable and Low-Carbon Fuels in Maritime Transport and Amending Directive 2009/16/EC," 2.

29 European Commission, 8.

30 Eurostat, "Oil and Petroleum Products - a Statistical Overview."

31 IEA, "European Union 2020 - Energy Policy Review," 111.

32 European Chemical Industry Council, "How Can Europe's Chemical Industry Help Deliver on the Green Deal?," cefic.org, April 28, 2021, https://cefic.org/policy-matters/chemical-industry-green-deal/how-can-europes-chemical-industry-help-deliver-on-the-green-deal/.

to be the most difficult to decarbonize, as fossil fuels often serve as feedstock and are necessary to generate very high temperatures. Low-carbon hydrogen, electrification, circularity and carbon capture and storage (CCS) offer decarbonization potential.[33]

Households are required to make behavioral changes towards energy consumption, shaped by taxes and subsidies. The objective is to minimize energy consumption through energy efficiency, well insulated buildings, and by running heating and cooling systems with the waste heat of electricity generation coupled with heat and power (CHP) plants.[34] This entails the renovation of homes promoting electricity, district heating or renewable gas. Sustainable renewable heating, LNG mixed with hydrogen, or e-methane generated through electricity and biogas blends could potentially be utilized for buildings in the industrial sector.[35]

Finally, **electrification** is key to decarbonization. Europe's total electricity demand is therefore prospected to rise by 35% in 2050.[36] According to the EU's decarbonization scenarios, 65% of energy demand for passenger cars and light duty transportation vehicles could be supplied through electricity in the long-term. The expectation is that by 2050, more than 80% of electricity will be generated through renewable energy sources, like wind and solar energy, adding to 15% of nuclear power.[37] Based on the high renewables scenario wind power in particular is expected to be the most electricity producing technology in 2050.[38] In Northwestern Europe, all energy used by 2050 must come from renewable energy sources, with offshore wind coming from the North Sea playing a key role in the transition process.[39] Solar power from the Mediterranean countries will likely contribute to the share of European electricity supply.[40]

A hurdle in Europe's electrification goals relates to the scarcity of raw materials needed for building renewable energy technologies.[41] While dependencies on Russia and the Middle East will weaken with the consumption of oil and gas, new ones are emerging on producers of critical minerals. The demand for rare earth elements, cobalt and lithium, among others, will make the EU dependent on countries like China or the Democratic Republic of Congo for securing supplies. The importance of industrial gases for semiconductors and chips is surging as well. Global shortages will likely lead to massive increases in the price of minerals and gases. Established suppliers will be placed in an advantageous geopolitical and economic position, creating new dependencies for consumers in Europe. Stockpiling these critical commodities will likely become an important strategic action of the EU.

33 Samantha Gross, "The Challenge of Decarbonizing Heavy Industry" (Brookings, June 24, 2021), https://www.brookings.edu/research/the-challenge-of-decarbonizing-heavy-industry/; McKinsey & Company, "Europe's Path to Decarbonization," accessed November 5, 2021, https://www.mckinsey.com/business-functions/sustainability/our-insights/how-the-european-union-could-achieve-net-zero-emissions-at-net-zero-cost.

34 European Commission. Directorate-General for Energy, "Energy: Roadmap 2050" (Publications Office, 2012), 10, https://data.europa.eu/doi/10.2833/10759.

35 European Commission, "A Clean Planet for All A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy."

36 European Commission.

37 European Commission, "A Clean Planet for All A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy."

38 European Commission. Directorate-General for Energy, "Energy," 11.

39 Ministerie van Algemene Zaken, "Offshore Wind Energy - Renewable Energy - Government.Nl," onderwerp (Ministerie van Algemene Zaken, July 26, 2017), https://www.government.nl/topics/renewable-energy/offshore-wind-energy.

40 European Commission. Directorate-General for Energy, "Energy," 11.

41 For an in-depth discussion, see Irina Patrahau et al., "Securing Critical Materials for Critical Sectors Policy Options for the Netherlands and the European Union" (The Hague Centre for Strategic Studies, December 2020), https://hcss.nl/wp-content/uploads/2021/01/Securing-Critical-Materials-for-Critical-Sectors.pdf.

3.2. **Future infrastructure needs**

Infrastructure that supports the production, transport and consumption of renewables is essential for reaching net zero goals. The decline of oil in the European energy mix by 2050 and the simultaneous increase in usage of alternative fuels require an adaptation of the existing (tank) storage infrastructure. Many alternative fuels including biodiesel, bioethanol, Hydrotreated Vegetable Oil (HVO) and Sustainable Aviation Fuels (SAFs) can make use of existing infrastructure without requiring any significant or only minimal changes in existing storage infrastructure (Table 3).[42] Nevertheless, most storage capacity would need to be retrofitted in some way, for example to prevent the degrading effect of the new fuel, to adjust to new freezing temperatures or to prevent contamination and microbial degradation.[43] Moreover, many alternative fuels have a lower energy density than the energy sources that are currently used. As such, more storage is likely to be needed to provide the same amount of energy as today, leading to additional costs as well as new spatial requirements.

Table 3. Selected storage infrastructure needs per alternative fuel

Alternative fuel	Current energy source	Storage	Potential adaptation measures	Adaptation costs storage per 5000 m^3
Biodiesel[44]	Diesel	Can largely use the same equipment as conventional diesel, with slight adaptations.	• Requires more space than conventional diesel, as volumetric energy density is about 9% lower. • Usage of certain metals such as brass, bronze, lead, tin, zinc and particularly copper should be avoided, as biodiesel can degrade them. • Extra insulation or heating might be required due to higher freezing temperature.	€ 1.230.689
Hydrotreated Vegetable Oil (HVO)[45]	Gas oil	Can use existing gas oil infrastructure, does not require any significant adaptations.	N/A	N/A
Bioethanol[46]	Gasoline	Can largely use the same equipment as gasoline, with slight adaptations.	Some materials that are used for storing gasoline such as metals and polymers should be avoided, as they can lead to material degradation.	€ 1.279.163
Liquid hydrogen[47]	LNG	Not possible to use existing LNG infrastructure for liquified hydrogen due to different temperature requirements.	N/A	€ 5.700.474
E-methanol[48]	Heavy Fuel Oil (HFO)	Methanol storage infrastructure already exists on a large scale. Can also convert HFO tanks into methanol storage.	• Requires more storage capacity for the same amount of energy, only has about half of the energy density of traditional liquid fuels. • Small changes are required, such as cleaning the HFO tank and removal of thermal insulation.	€ 2.789.499
Sustainable Aviation Fuels (SAF)[49]	Kerosene	Can use existing aviation fuel storage infrastructure, with adaptations.	Unspecified, some slight changes in material and maintenance might be required.	€ 1.309.508

42 Ondrej Cerny et al., "Implications of the Energy Transition for the European Storage, Fuel Supply and Distribution Infrastructure" (Trinomics, 2021), 92.

43 Cerny et al., 92.

44 Cerny et al., 38–40.

45 Cerny et al., 47–48.

46 Cerny et al., 51–54.

47 Cerny et al., 57–59.

48 Cerny et al., 64–74.

49 Cerny et al., 75–80.

4. The international playing field

The geographical shift of the oil production and consumption centers towards the Middle East and Asia makes carbon neutrality pledges in the long-term highly dependent on the actions of regions outside of Europe.[50] The outcome of European decarbonization targets for the energy sector is heavily dependent on global actions, in particular on major players like China, the US and the OPEC+ countries. At least up to 2050, countries around the world will remain dependent on the Middle East to provide energy security of supply. Competition between low-cost suppliers in the Middle East might lead to downward pressure on global oil prices, while volatility and uncertainty will dominate the global market.

At the same time, a new geopolitical landscape will emerge, characterized by new dependency relations between producers and consumers. Europe will continue being dependent on foreign supplies of energy. Power politics in countries with critical minerals and low-cost hydrogen production facilities will emerge. Most of the (green) hydrogen used in Europe will likely be produced in countries where renewable energy power can be cheaply and easily generated, such as in the Middle East and North Africa.[51] Renewable energy generation is dependent on critical minerals and technologies largely produced in China.[52]

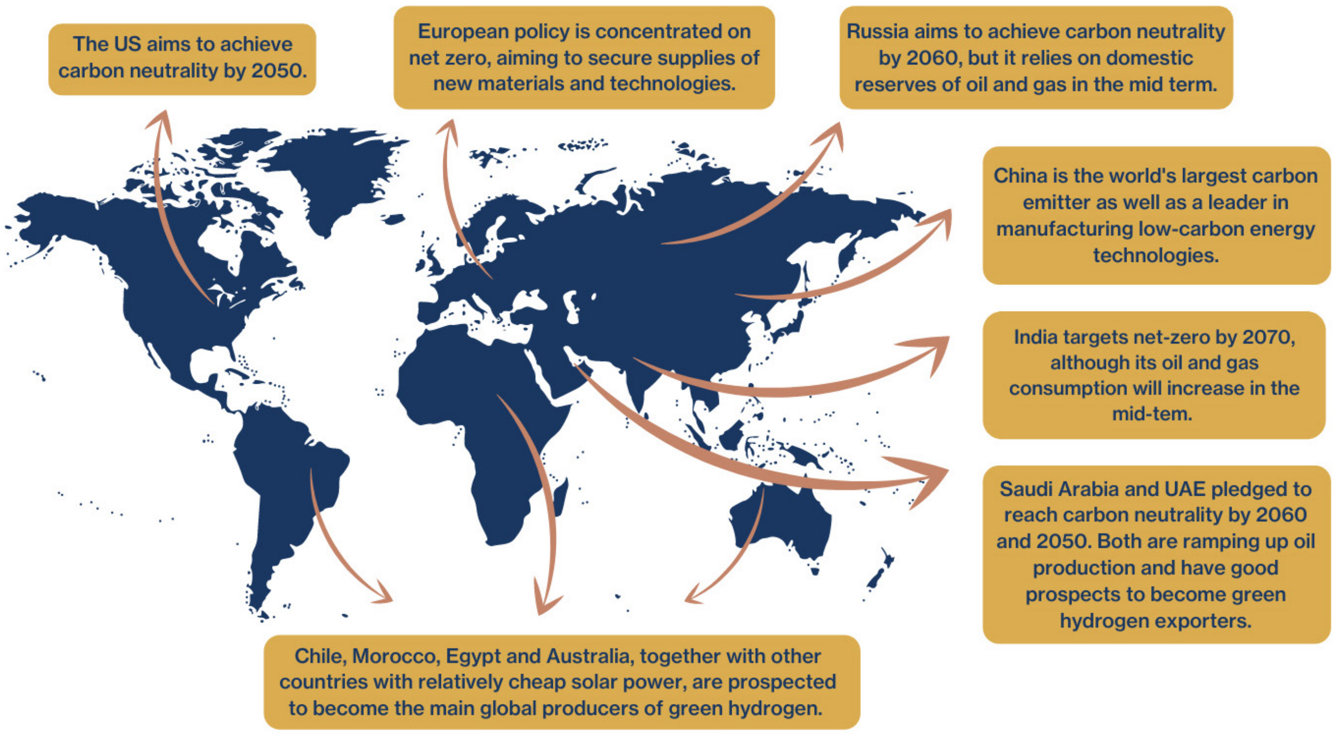
This section outlines the long-term climate ambitions of some of the key global oil consumers and producers, as well as emerging players in low-carbon energy production. It sets the scene for understanding what the world will look like in 2050 and how Europe fits in this emerging geopolitical scene. It is summarized in Figure 1.

50 For more information see Irina Patrahau et al., "European Tank Storage in Global Supply Chains: Outlook to 2030" (The Hague Centre for Strategic Studies, 2022), https://hcss.nl/report/european-tank-storage-in-global-supply-chains-outlook-to-2030/.

51 Jilles van den Beukel et al., "The European Tank Storage Sector and the Global Energy Landscape" (HCSS, 2021).

52 Patrahau et al., "Securing Critical Materials for Critical Sectors Policy Options for the Netherlands and the European Union."

Figure 1. The international playing field 2050-2070



China is the largest energy consumer and carbon emitter in the world.[53] Together with India, it will account for most of the increase in oil consumption up to 2030. Chinese president Xi Jinping declared the ambition to move toward a CO_2 emissions peak by 2030 and strives to achieve carbon neutrality before 2060.[54] The country's role in the global energy transition is two-fold. On the one hand, its emission reduction policies will largely determine the success of the global efforts to mitigate climate change. On the other hand, value chains of renewable energy technologies such as solar photovoltaics, and electric vehicles are concentrated in China.[55] Not only are the raw materials required for these technologies critical, but the gap between global supply and demand is rapidly growing. Every country depends on China for achieving its renewable energy goals.

India's prime minister Modi announced the country's carbon neutrality target at COP26: achieving net-zero by 2070. For India's clean energy transition to succeed, heavy investments are needed given technological shortages and infrastructural conditions.[56] Towards a

53 International Energy Agency, "An Energy Sector Roadmap to Carbon Neutrality in China," September 2021, 13, https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/Anenergysectorroadmaptocarbonneutralityin China.pdf.

54 International Energy Agency, 13.

55 See Irina Patrahau et al., "Securing Critical Materials for Critical Sectors: Policy Options for the Netherlands and the European Union," (The Hague Center for Strategic Studies, 2020).

56 International Energy Agency, "India Energy Outlook 2021" (IEA, March 16, 2021), 105, https://doi.org/10.1787/ec2fd78d-en; Rebecca Bundhun, "How India's 2070 Net-Zero Ambitions Will Boost Green Energy Sector in the Country," *The National News*, November 7, 2021, sec. Road to Net Zero, https://www.thenationalnews.com/business/energy/2021/11/07/how-indias-2070-net-zero-ambitions-will-boost-green-energy-sector-in-the-country/.

more sustainable Indian industry, the IEA's STEPS scenario projects a 80% rise of bioenergy demand in India from 2019 to 2040. Biofuels can replace coal in many industrial processes and low-carbon gases can substitute high-carbon gases.[57]

The **United States** supports the ambition of net zero emissions until 2050. The Biden administration aims to achieve a fully decarbonized power sector by 2035 and an economy based on net zero GHG emissions by 2050.[58] Between 2020 and 2050, natural gas could account for one-third of the total electricity generation.[59] Unless a shift in policy direction occurs, the US will remain a natural gas and oil exporter up to 2050, albeit of increasingly lower quantities.[60]

Apart from the US, most of the largest oil and natural gas producers, including **Russia, Saudi Arabia, Qatar and UAE**, have proven to be reluctant to implement strong long-term climate goals. Russia's stance on the energy transition has been to maximize the use of its domestic energy sources in order to generate economic growth and promote development in the country.[61] However, in its October 2021 low-carbon strategy, Russia includes climate targets, such as reducing GHG emissions by 79% until 2050, and aims to substitute coal facilities with gas turbines, nuclear, hydroelectric and renewable power plants.[62] Since fossil fuels constitute a large part of the Russian government's revenue and exports, it is likely that domestic and international decarbonization ambitions will negatively affect its economy.[63] Depending on developments in the Russia-Ukraine war and a potential global boycott of Russian oil and gas, Russia's energy system may be significantly impacted by Europe's ambition to decrease dependency on Russian oil and gas in the mid-term.

Like many other international players, countries in the Middle East want to continue maximizing profits from exporting their oil and gas. Although many did announce climate goals, they are often contradictory to fossil fuel policies. As an example, Saudi Arabia has pledged to reach net zero emissions by 2060, while state-owned Saudi Aramco aims to decarbonize operations by 2050.[64] However, the oil giant is also planning to increase its oil production capacity to 13 million barrels a day (mb/d).[65] Qatar's approach in the energy transition primarily focuses on supplying the global market with natural gas as a transition fuel.[66] Like Saudi Arabia, the major LNG exporter is trying to decarbonize its operations and has set the goal to increase its carbon capture and storage (CCS) capacity to 9 million tons a day

57 International Energy Agency, "India Energy Outlook 2021," 105.

58 The White House, "FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target The White House, April 22, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/.

59 EIA, "EIA Projects Renewables Share of U.S. Electricity Generation Mix Will Double by 2050 February 8, 2021, https://www.eia.gov/todayinenergy/detail.php?id=46676.

60 EIA, "Annual Energy Outlook," 2021, 28, https://www.eia.gov/outlooks/aeo/pdf/AEO_Narrative_2021.pdf.

61 International Energy Agency, "Russia - Countries & Regions," IEA, 2019, https://www.iea.org/countries/russia.

62 Reuters, "Russia Drafts New, More Ambitious Decarbonisation Strategy - Kommersant Newspaper," *Reuters*, October 7, 2021, sec. Environment, https://www.reuters.com/business/environment/russia-considering-more-ambitious-climate-targets-2021-10-06/.

63 See Jilles van den Beukel and Lucia van Geuns, "Russia's Unsustainable Business Model: Going All In on Oil and Gas," (The Hague Centre for Strategic Studies, January 2021), https://hcss.nl/sites/default/files/files/reports/Russias%20Unsustainable%20Business%20Model.pdf.

64 Isabelle Gerretsen, "Saudi Arabia Pledges Net Zero by 2060, but No Oil Exit Plan," *Climate Home News*, October 25, 2021, sec. Climate politics, https://www.climatechangenews.com/2021/10/25/saudi-pledges-net-zero-2060-no-oil-exit-plan/.

65 Yousef Saba and Saeed Azhar, "Aramco Aims for Net Zero Emissions from Operations by 2050, CEO Says," *Reuters*, October 23, 2021, sec. COP26, https://www.reuters.com/business/cop/aramco-aims-net-zero-emissions-operations-by-2050-ceo-says-2021-10-23/.

66 Rafiq Latta Nicosia, "Qatar Petroleum Rebrands as QatarEnergy," Energy Intelligence, October 11, 2021, https://www.energyintel.com/0000017c-6fef-d080-a5fe-7fff20f30000.

by 2030.[67] Lastly, while in the medium term the UAE is also increasing its oil production, the country targets zero carbon emissions by 2050 by investing over $160bn in clean and renewable energy sources.[68]

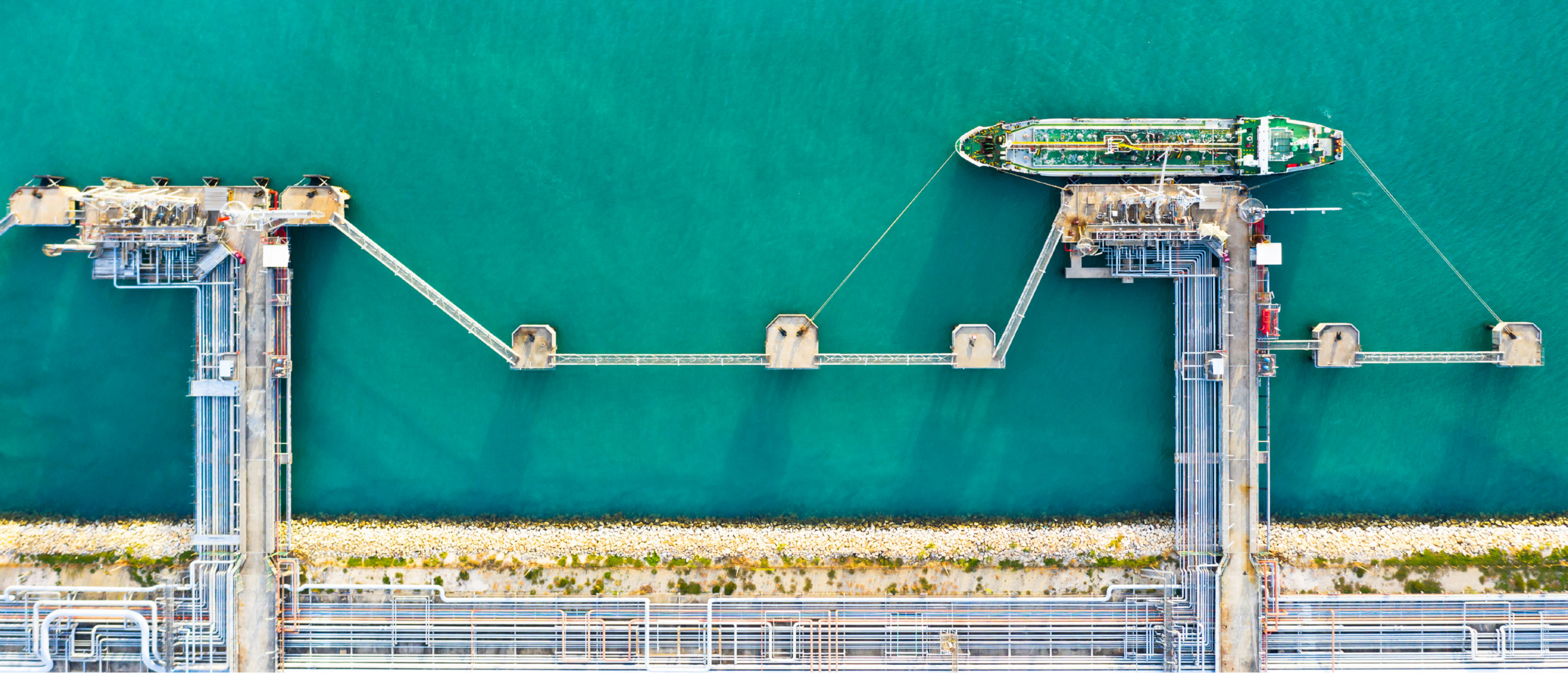
Like China, Middle Eastern countries could also have a dual role in the energy transition. On the one hand, they will likely reap benefits from the continued oil demand in Asia and Africa as Europe heads toward decarbonization. On the other hand, they are also heavily investing in renewable electricity and hydrogen production facilities, meaning that they could become key hubs for producing new energy carriers. In the long term, they are well positioned to produce low-cost green hydrogen due to large scale possibilities of cheap solar power. Moreover, Saudi Arabia and UAE's efforts to decarbonize their oil and gas production processes through CCUS could allow them to produce low-cost blue hydrogen, although this is considered less desirable than green hydrogen in Europe.[69]

North Africa and South America have similarly advantageous positions in producing low-cost green and blue hydrogen in the long term. Australia is another emerging player in hydrogen production, though its costs are expected to be slightly higher than in the previously mentioned regions. Given the worldwide increase in hydrogen demand, it is unclear whether hydrogen produced in the Middle East or South America will be delivered to Europe or will follow the highest market prices elsewhere, such as in South East Asia. Contrastingly, it may be more likely that North African hydrogen will make its way to Europe via pipelines due to relatively shorter distances and pre-existing gas pipelines. These dynamics are further explored in section 6.1 on hydrogen.

67 Nicosia.

68 Enerdata, "The United Arab Emirates Targets Carbon Neutrality by 2050," Energdata, October 8, 2021, https://www.enerdata.net/publications/daily-energy-news/united-arab-emirates-targets-carbon-neutrality-2050.html.

69 Malik Caline, "How Saudi Arabia, UAE can turn their decarbonization strengths to their advantage," *Arab News*, October 2, 2021, https://www.arabnews.jp/en/middle-east/article_56470/, https://www.arabnews.jp/en/middle-east/article_56470/.



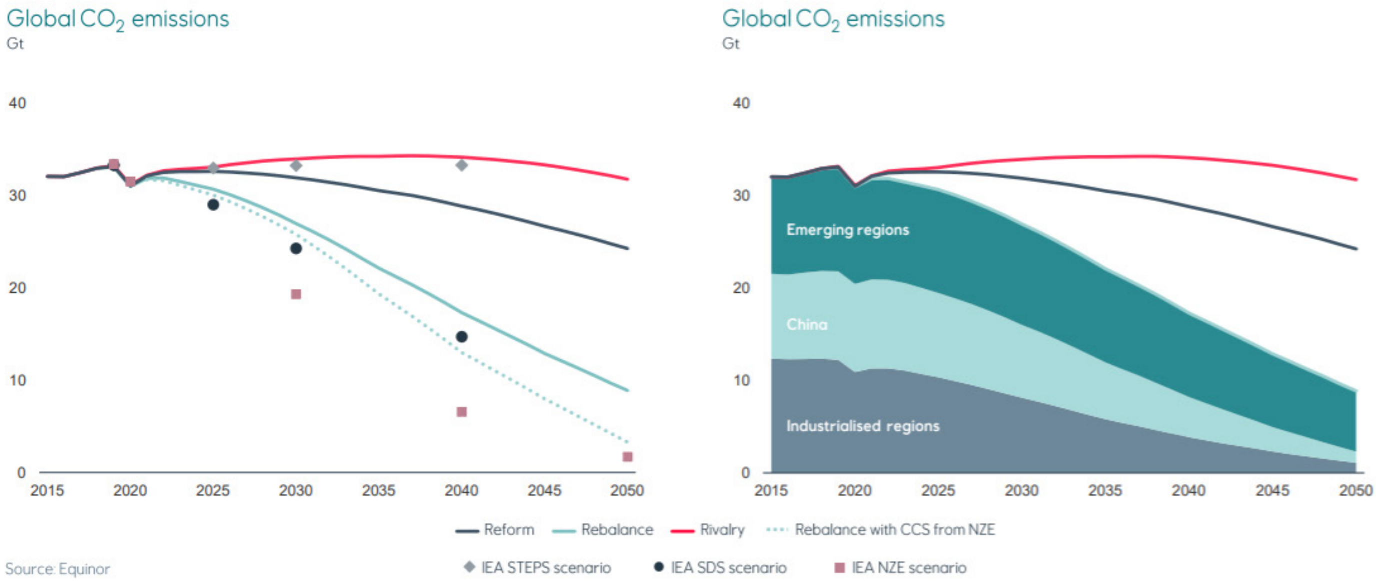
5. Pathways to 2050

Whereas for 2030 increasingly more specific targets, strategies and legislative frameworks are being established, the path toward 2050 remains blurry. The global ambition to reach net zero by 2050 and beyond could materialize in a myriad of ways, depending on factors such as technological developments, economic growth, domestic policy choices as well as state behavior in international relations. To a certain extent, the achievement of climate goals set out in the Paris Agreement depends on the degree of success of Europe's green revolution. Since oil consumption has already been decreasing in Europe, however, it is even more dependent on the actions of the most important players in the oil market, like China, the US, Russia and the OPEC countries. A new geopolitical world will be shaped by emerging players in renewable energy technologies and hydrogen production.

As the next decades are dominated by uncertainty, scenario analysis is the only way of identifying potential pathways to 2050. This section analyzes a variety of scenarios, taking into account the perspectives of the International Energy Agency (IEA), Equinor and TNO. In general, the scenarios developed by Equinor and the IEA are very similar, although they do differ in speed and scale. IEA's consideration of CCS as a major carbon reducing factor explains why the trajectories of the IEA scenarios in all three cases are always slightly below the Equinor scenarios (see Figure 2).

Three broad pathways to 2050 can be distinguished, which account for differing degrees of achieving global climate ambitions. The first one (Rivalry, STEPS) is the most pessimistic scenario from an environmental perspective, predicting a continued use of fossil fuels and the slowing down of renewables' deployment due to protectionist approaches. The second (Reform, APS) storyline refers to a case in which governments are making some progress toward net zero, but the gap between ambitions and policies is too large, leading to insufficient progress. Lastly, the third (Rebalance, NZE) storyline is the most desired pathway from a climate perspective, but is also relatively idealistic.

Figure 2. Comparison between IEA and Equinor scenarios to 2050[70]



Source: Equinor

The first pathway portrays a pessimistic long-term outlook, as projected in Equinor's Rivalry and IEA's STEPS scenarios (see Figure 2). It describes a future world that focuses on achieving energy security and independence, while neglecting economic growth and climate change.[71] Consequently, protectionism and authoritarianism grow as international cooperation slows down. Global warming remains largely unaddressed, interdependence between countries is discontinued, economic development significantly slows down, and technological development and transfer becomes more difficult than ever.[72] It becomes increasingly more challenging for emerging economies to catch up with developed states.

Countries with coal access continue to use coal as main part of their energy mix, causing more resource and energy intensity and consequently more pollution. Electrification and the deployment of renewables slow down. The consumption of crude oil and refined products is projected to remain the highest in this first pathway compared to the following two.[73] With continuous population growth and energy intensive technologies, the global demand for fossil fuels will grow. On the global scale, **tank storage** will continue storing fossil fuels with little change in terms of the large-scale usage of new products. In Europe, the demand for fossil fuels would decrease but not significantly. Deteriorating trade relations would disrupt global supply chains, making it more difficult for Europe to satisfy its domestic energy demand. This applies particularly to new energy carriers like hydrogen, the bulk of which will be imported rather than produced in Europe. For European companies active in fossil fuels supply, the social license to operate is likely to deteriorate regardless of the continued demand for such fuels. The public narrative of phasing out fossil fuels is already making it difficult for companies to operate without accounting for corporate social responsibility and environmental protection.

70 Eirik Woerness, "Energy Perspectives 2021," 11, https://www.equinor.com/en/sustainability/energy-perspectives.html.

71 Equinor, "Energy Perspectives 2021 Long-Term Macro and Market Outlook," 2021, 12, https://www.equinor.com/en/sustainability/energy-perspectives.html.

72 Equinor, 12.

73 Equinor, 12.

There is no doubt that the Covid-19 pandemic has had severe impacts on the global energy market. The pandemic unraveled traces of vaccine nationalism, lack of balance between rich and poor economies, and the weakness of multilateralism in fighting the global health crisis.[74] This kind of approach to international relations is a reminder of what the next decades could look like if governments become rivals rather than partners in front of climate disasters. Increased geopolitical tensions and volatility in the energy markets will ensue as a result of the concentration of oil and gas production in a few countries. The phase out of fossil fuels will likely be a turbulent process in which consumers suffer from high energy prices and little energy security. The energy crisis in 2021, characterized by surging oil and gas prices, was a first iteration of what a unstable energy transition might look like. At the same time, the Russian invasion of Ukraine in 2022 has caused unprecedented levels of international cooperation between EU countries, the US and other supporters of Ukraine. The existence of a threat tends to bring more unity than protectionist behavior between certain countries.

The second pathway to 2050 outlines a world in which governments are making some efforts toward climate neutrality, but to an insufficient extent. Up to 2021, the main energy consuming sectors are not transitioning fast enough to meet the goals of the Paris Agreement.[75] This pathway aligns with Equinor's Reform and the IEA's APS scenarios.[76] In a world that is mainly driven by economic growth, the energy transition becomes primarily dependent on national governments and their efforts to close the so-called ambitions gap.[77] Even though climate policies become stricter across the world, the huge discrepancy between the emissions reducing efforts and expectations hamper the achievement of pledged targets. Industrialized regions, particularly Europe, are the driving forces of the transition, but from a global perspective, national governments continue to focus on short-term economic development instead of long-term climate ambitions.[78] On the one hand, globalization promotes the spread of advanced technologies and integrated markets through cooperation and friendly competition among states.[79] On the other hand, nations pursue a low-cost energy approach first, before focusing on security of supply and the environment. This results in the continuous use of fossil fuels because alternatives are more costly. Consequently, this second storyline accounts for the highest GDP growth. This also accelerates development in poorer countries, but not to the extent that they can catch up with the wealthiest nations.[80]

In a market-driven world described in this second pathway, **the storage sector** should be prepared to keep storing fossil fuels while balancing out the increasing demand for low-carbon fuels. This is a task that tank storage companies and other players in energy supply chains have already encountered and are trying to tackle. The transition is likely to be characterised by volatility and uncertainty, followed by a more stable period where the world is functioning in a sustainable way. However, it is by no means a given that the transition period will last for a pre-determined amount of time. As such, if the ambitions gap is not closed, the transition period will continue well until 2050 and even beyond. Not only will the climate crisis not be adequately addressed, but actors in the energy supply chain will have to continue balancing out remaining fossil fuel demand with new energy sources.

74 Eirik Woerness, "Energy Perspectives 2021," 8.

75 Equinor, "Energy Perspectives 2021 Long-Term Macro and Market Outlook," 8.

76 Equinor, 8; IEA, "World Energy Outlook 2021" (Paris: IEA, 2021), 95, https://www.iea.org/reports/world-energy-outlook-2021.

77 IEA, "World Energy Outlook 2021," 95.

78 Equinor, "Energy Perspectives 2021 Long-Term Macro and Market Outlook," 8.

79 Equinor, 8.

80 Equinor, 8.

The most sustainable energy direction is laid out in the **third storyline**, which requires significant systemic changes[81] and immediate action to reach the goals of the Paris Agreement.[82] Equinor calls this scenario *Rebalance,* which is similar to the IEA's net zero scenario (NZE). This is the only scenario in which the growth in renewables so high that fossil fuels can be smoothly phased out.[83] Accordingly, electrification becomes a major part of road transport, the industrial sector and buildings.[84] The rail, shipping and aircraft sector will increasingly rely on biofuels.[85]

The third pathway to 2050 outlines a very challenging trajectory as it relies heavily on national governments and companies to act together, but historical trends show differently.[86] This is a rather idealistic future outlook, narrating the most desirable case of mitigating climate change.[87] A balanced world driven by sustainable economies and burden sharing would cause a rise of the global GDP and an increase in energy efficiency. The unsustainable ongoing economic growth must shift to a low but consistently positive economic growth in Europe, North America and industrialized Asia Pacific.[88] Fossil fuel use should be limited to poorer countries if necessary and the pressure of emissions reduction should be adjusted to their legitimate demands.[89] To reach net zero by 2050, new technologies require supportive policy measures and financing. This means an increase of the carbon price, more electricity generation through renewable sources and alternatives like carbon storage, as well as a shift in behaviour towards more conscious, sustainable and ecological consumption.[90]

If the world follows the sustainable pathway, **tank storage** has to adapt to changing circumstances in the global energy market by restructuring their business model and building new infrastructure. Since electrification will become one of the main energy sources, stationary battery storage capacity has to be extended. Entire supply chains have to be established to ensure stable supply of hydrogen in its different forms (ammonia, methanol, LOHC, etc.). The sector needs to respond to this changing development and provide new services in relation to the changing economic and geopolitical landscape.

Regardless of which pathway the international community will follow, Europe's ambition remains to reach net zero and increasingly strict policies are being passed to support the transition. It is therefore essential to anticipate what the new physical supply chains could look like from a practical perspective. These new supply chains depend on which sustainable source of energy becomes dominant in Europe.[91] TNO and Smartport present three scenarios, based on biomass (BIO), synthetic fuels and green hydrogen (SYN) and waste (CYC) (see Table 4).[92]

81 Equinor, 9.

82 Eirik Woerness, "Energy Perspectives 2021," 10.

83 Equinor, *Exploring an Uncertain Energy Future: Equinor Energy Perspectives 2021*, 2021, https://www.youtube.com/watch?v=YSd4kLpom38.

84 Equinor, "Energy Perspectives 2021 Speakers Notes Erik Woerness Senior Vice President and Chief Economist," October 6, 2021, 16, https://www.equinor.com/en/sustainability/energy-perspectives.html.

85 Equinor, 16.

86 Equinor, "Energy Perspectives 2021 Long-Term Macro and Market Outlook," 11.

87 Equinor, 11.

88 Equinor, 9.

89 Equinor, 11.

90 Equinor, 11.

91 "Decarbonization Pathways for the Indusrial Cluster of the Port of Rotterdam" (Wuppertal Institut, 2016); Remco Detz et al., "Ruimtelijke Effecten van de Energietransitie: Casus Haven Rotterdam" (TNO & Smartport, September 2021).

92 Although the scenarios were developed specifically for the Netherlands, the pathways toward different dominant energy products and the necessary supply chains from a technical perspective can be applied to the entirety of Europe.

Depending on which energy carrier will become dominant in the next decades, different supply chains need to be established. The scenarios outline what future supply chains for the production of sustainable fuels and chemicals could look like, given that these industrial processes cannot easily be electrified. The supply chains presented in Table 4 are simplified but touch upon the main steps required to produce sustainable fuels and chemicals.

In the BIO scenario, biomass would provide the vast majority of energy by 2050, meaning that the most prevalent products would be different forms of biomass and synthetic fuels. In the SYN scenario, green hydrogen is used to meet most of the energy demand. Green hydrogen, CO_2 for converting this hydrogen, and synthetic fuels are the most prevalent products in this scenario. Lastly, in the CYC scenario, waste is used to meet most of the energy demand, making waste itself and methanol the most prevalent products.

Table 4. Three scenarios for sustainable supply chains for fuels and chemicals[93]

Scenario	Assumptions per scenario	Technical supply chain for fuels	Technical supply chain for chemicals	Dominant products
BIO	• Energy demand for 88% satisfied by turning sustainable (particularly woody) biomass into fuels and chemicals • Woody biomass is largely imported • Remainder of demand is met by hydrogen, half produced domestically and half imported	Woody biomass → Syngas → Syncrude → **Fuels**	Woody biomass → Syngas → Syncrude → Naphtha → **Chemicals**	Different forms of biomass and synthetic fuels
SYN	• Energy demand largely met by hydrogen and CO_2 captured via Direct Air Capture (DAC) • 2/3 of required hydrogen is imported, 1/3 produced domestically by solar and wind power • CO_2 used mostly to convert hydrogen into synthetic fuels and chemicals • 20% of energy demand met by biomass	Green hydrogen → Combined with CO_2 → Syngas → Syncrude → **Fuels**	Green hydrogen → Combined with CO_2 → Syngas → Syncrude →Naphtha **Chemicals**	Green hydrogen, CO_2 and synthetic fuels
CYC	• Most energy demand met by waste, largely imported • 20% of energy demand met by biomass	Waste → Gasification → Syngas → Methanol → **Fuels**	Waste → Gasification → Syngas → Methanol → **Chemicals**	Waste and methanol

93 Table based on Detz et al., "Ruimtelijke Effecten van de Energietransitie: Casus Haven Rotterdam."

6. Energy technologies for decarbonization

Apart from policy choices and governmental behavior, the development of energy technologies, price levels, the establishment of secure supply chains as well as public acceptance will impact the path to 2050. Hydrogen, chemical carriers, battery storage, biofuels and circular approaches in industrial processes all play a role in Europe's energy transition. This section discusses the broad trends related to the adoption of these low-carbon energy sources by outlining their role in the energy transition, the factors that have been inhibiting their large-scale deployment and the prospect of surmounting those obstacles.

6.1. Hydrogen

Hydrogen is expected to be an essential component of the future energy landscape. As shown in Table 5, it can be used to decarbonize hard-to-abate sectors, such as heavy industry (iron, steel, etc.), chemicals, aviation and long-haul transport.[94] Different types of hydrogen exist. Grey hydrogen is produced by fossil fuels and is thus not a sustainable fuel. Green hydrogen is produced through the electrolysis of water with renewable energy, while blue hydrogen is produced from fossil fuels in combination with carbon capture and storage (CCS). There are no generally established colors for other forms of hydrogen production, though the one produced from nuclear energy is sometimes referred to as 'purple hydrogen'.[95] The low-carbon hydrogen versions – green, blue, and produced by nuclear power – are of particular interest for a net-zero world.

94 "Decarbonising End-Use Sectors: Practical Insights on Green Hydrogen" (IRENA Coalition for Action, May 2021), 9, https://www.irena.org/publications/2021/May/Decarbonising-end-use-sectors-green-hydrogen.

95 IEA, "The Future of Hydrogen," Technology report (Paris: IEA, 2019), 34, https://www.iea.org/reports/the-future-of-hydrogen.

Table 5. Decarbonizing sectors with low-carbon hydrogen

Sector	Energy source	Description
Industry	Hydrogen	Provides the high temperatures necessary for some manufacturing processes such as steel, chemicals, cement and glass; cannot be achieved with electricity.
	Hydrogen	Can replace fossil fuel-based feedstocks in the chemical and petrochemical industry, as well as used in the production of ammonia and methanol.
Road transport	Hydrogen or synthetic fuel oil	Can be used via fuel cell electric vehicles. Allows to travel longer distances, making hydrogen suitable for the decarbonization of trucks, trains and other heavy long-distance vehicles.
Aviation	Synthetic fuel oil	Can be produced from hydrogen. Needs to be used due to higher energy density. Also does not require redesigning aircrafts.[96]
Shipping	Ammonia	Can be produced from hydrogen. High energy density and lack of need for pressurized storage make ammonia suitable for decarbonization of long-haul shipping.
Power generation	Storage of hydrogen	Used as a means to store energy over a longer period of time when share of VRE increases.
Buildings	Hydrogen	Can be used for heat production.

Blue hydrogen

Almost all low-carbon hydrogen produced today is blue hydrogen. Globally, sixteen blue hydrogen projects are currently operational, yielding 0.7 million tons (Mt) of hydrogen per year. This meets less than 1% of total hydrogen demand.[97] Another 50 projects currently being developed could increase the total annual blue hydrogen production to more than 9 Mt by 2030.[98] The Netherlands is a strong proponent of blue hydrogen, developing projects such as H-Vision and the Porthos Project.[99] However, most other European countries that have large-scale hydrogen ambitions, such as France, Germany, Portugal and Spain, focus primarily on the production of green hydrogen.[100]

Green hydrogen

As green hydrogen is considered to be the only true zero-carbon option type of hydrogen, it is projected to play a central role in European and global decarbonization efforts.[101] The EU aspires to have 500 GW of electrolyzer capacity installed by 2050.[102] This compares to a

96 "Decarbonizing Aviation: Clear for Take-Off," Deloitte, accessed December 14, 2021, https://www2.deloitte.com/xe/en/pages/energy-and-resources/articles/decarbonizing-aviation.html.

97 "Hydrogen," IEA, November 2021, https://www.iea.org/reports/hydrogen.

98 "Global Hydrogen Review 2021 – Analysis," IEA, 5, accessed November 8, 2021, https://www.iea.org/reports/global-hydrogen-review-2021.

99 TNO, "Blue Hydrogen Paves the Way for Green Hydrogen," accessed November 22, 2021, https://www.tno.nl/en/focus-areas/energy-transition/roadmaps/towards-co2-neutral-industry/hydrogen-for-a-sustainable-energy-supply/blue-hydrogen-paves-the-way-for-green-hydrogen/.

100 "The European Strategy Is Undisputedly Green," January 15, 2021, https://www.enel.com/company/stories/articles/2021/01/europe-renewable-hydrogen.

101 International Renewable Energy Agency, "Green Hydrogen Cost Reduction," December 2020, 16, https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction.

102 European Commission, "A Hydrogen Strategy for a Climate-Neutral Europe," Pub. L. No. COM/2020/301, COM(2020) 301 (2020), 8, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301.

mere 0.1 GW of installed capacity in 2020.[103] Scaling up green hydrogen production has thus been difficult so far. This is primarily due to its high production costs, currently standing at about 3-6 $/kg compared to 1.3 $/kg for blue hydrogen.[104]

It is commonly agreed upon that these costs will fall significantly due to falling costs of renewable energy, a production learning curve and decreasing costs for electrolyzers. The costs for utility-scale solar PV and for wind already fell by 85% and 48-56%, respectively, between 2010 and 2020.[105] Annual cost reductions for both solar and wind power continue to be significant.[106] For electrolyzers, economies of scale, technological innovation and longer operating hours are expected to bring down costs.[107] Electrolyzer capital costs have already dropped ten-fold over the past decade.[108] By contrast, the production costs for gray and blue hydrogen are projected to remain stagnant as they are already well-established technologies.[109]

As mentioned earlier, Europe will nevertheless likely have to import about half of its green hydrogen demand by 2050.[110] This is because very large volumes of renewable energy are needed to produce green hydrogen, which also account for about 45-75% of green hydrogen's total production costs.[111] Therefore, countries in which renewable energy can be produced more cheaply and which are more spacious are better positioned to produce vast amounts of green hydrogen and export them to Europe (see Figure 3). This includes countries that are proximate to Europe such as Algeria, Egypt, Morocco, Russia, the UK and Ukraine.[112] However, it is by no means a given that the hydrogen produced in the Middle East or elsewhere would find its way toward Europe, given that hydrogen demand will increase in all countries trying to decarbonize their economies.

103 Alberto Gandolfi et al., "Green Hydrogen: The next Transformation Driver of the Utilities Industry," September 22, 2020, 4, https://www.goldmansachs.com/insights/pages/gs-research/green-hydrogen/report.pdf.

104 Nina Simon, Mike McCurdy, and Heidi Larson, "Examining the Current and Future Economics of Hydrogen Energy," ICF, August 13, 2021, https://www.icf.com/insights/energy/economics-hydrogen-energy.

105 IRENA, "Renewable Power Generation Costs in 2020," /publications/2021/Jun/Renewable-Power-Costs-in-2020, June 2021, https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020.

106 IRENA.

107 International Renewable Energy Agency, "Green Hydrogen Cost Reduction," 17.

108 IRENA, "Making the Breakthrough: Green Hydrogen Policies and Technology Costs," 2021, 21, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_Hydrogen_breakthrough_2021.pdf?la=en&hash=40FA5B8AD7AB1666EECBDE30EF458C45EE5A0AA6.

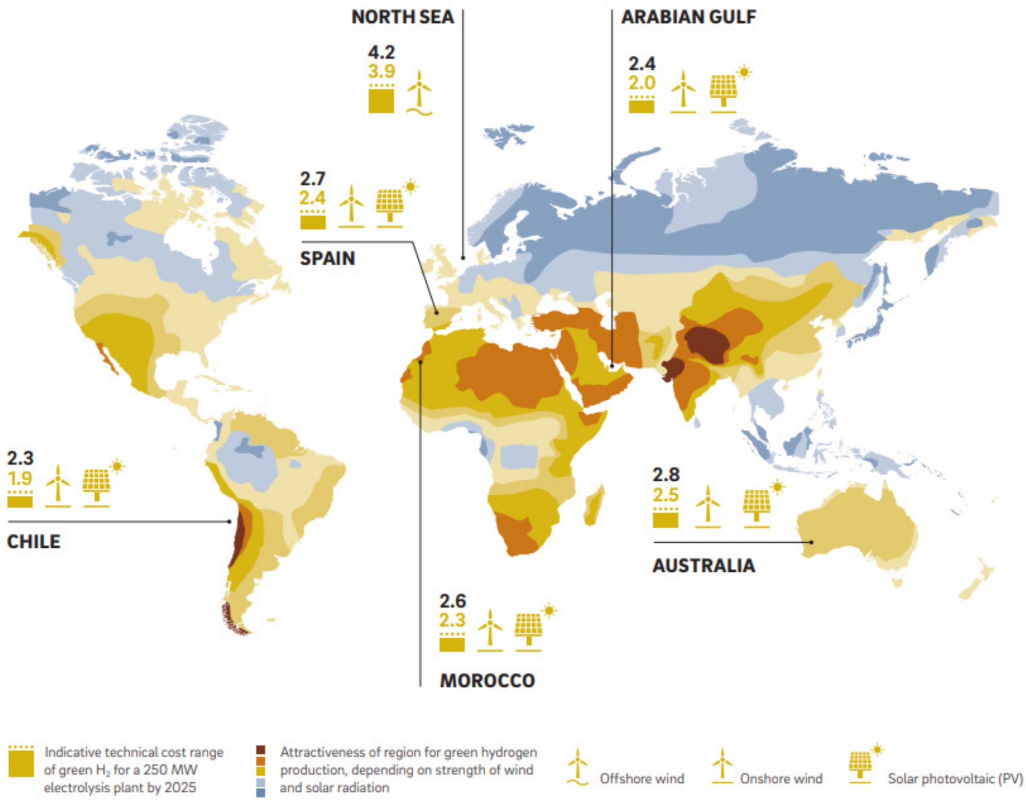
109 Simon, McCurdy, and Larson, "Examining the Current and Future Economics of Hydrogen Energy."

110 "Decarbonised hydrogen imports into the European Union: challenges and opportunities," October 2021, 5, https://www.weltenergierat.de/publikationen/studien/hydrogen-imports-into-the-eu/.

111 Michael Caspersen, "The Hydrogen Trajectory," KPMG, March 2, 2021, https://home.kpmg/xx/en/home/insights/2020/11/the-hydrogen-trajectory.html.

112 "Decarbonised hydrogen imports into the European Union," .

Figure 3. Production costs of green hydrogen around the world[113]



Nuclear-produced hydrogen

Hydrogen can also be produced using nuclear energy. Similar to renewable energy, nuclear energy can provide the electricity needed for water electrolysis.[114] However, hydrogen produced by nuclear energy is currently not deployed on a commercial scale. There are about a dozen demonstration projects that use nuclear energy for electrolysis in Canada, China, Russia, the UK and the US, amounting to a total of 250 MW of electrolyser capacity.[115] Depending on the success of these demonstration projects, nuclear energy as a source of hydrogen could be commercially viable within the next ten or even five years. Nevertheless, the large-scale deployment of such technologies can only be reached through incentivizing policies.[116]

113 Uwe Weichenhain, "Transporting the Fuel of the Future," Roland Berger, April 11, 2021, https://www.rolandberger.com/en/Insights/Publications/Transporting-the-fuel-of-the-future.html.

114 World Nuclear Association, Martin Kaltschmitt, and Matthias Finkbeiner, "Hydrogen Production and Uses," September 2020, https://www.world-nuclear.org/information-library/energy-and-the-environment/hydrogen-production-and-uses.aspx; Ellie Potters, "'Not Bonkers': Hydrogen Could Give US Nuclear Plants New Lease on Life," accessed December 1, 2021, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/not-bonkers-hydrogen-could-give-us-nuclear-plants-new-lease-on-life-63423340.

115 "Global Hydrogen Review 2021 – Analysis," 117.

116 Potters, "'Not Bonkers.'"

6.2. **Transport and storage of hydrogen**

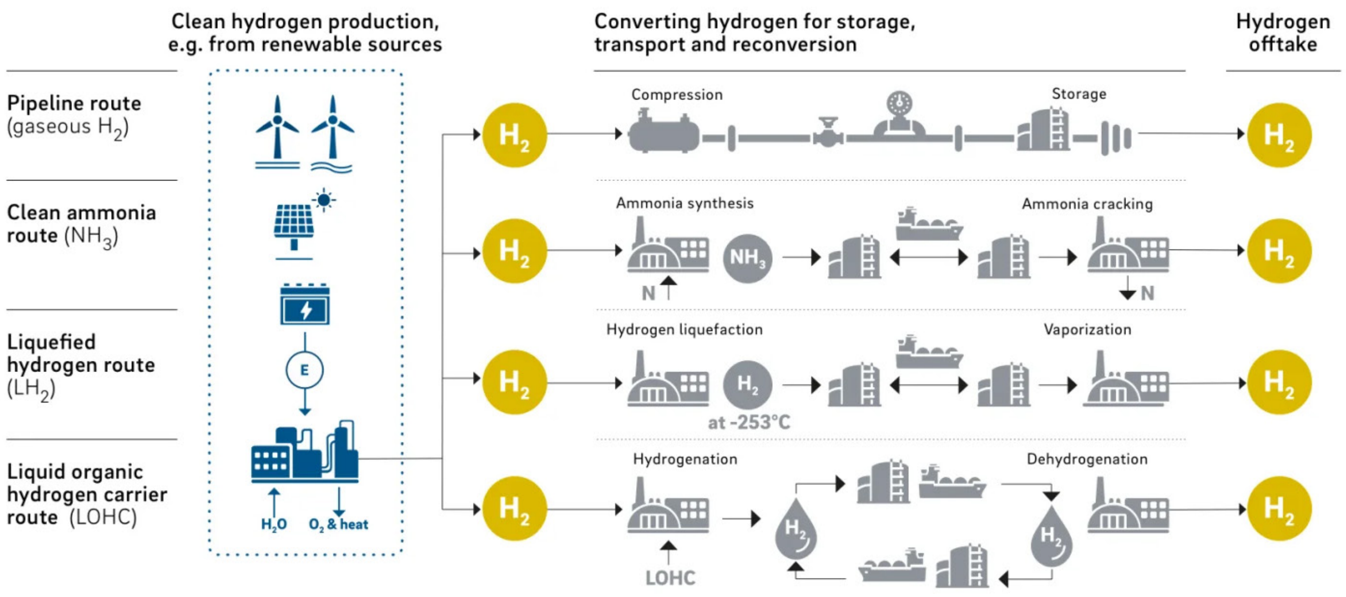
Hydrogen is expected to become the linchpin of the future low-carbon energy storage system. Yet it is unclear to what extent and in which form hydrogen will be stored and transported. An overview of various supply chains of hydrogen, depending on the way it is transported and stored, is provided by Figure 4.

There are different derivates into which hydrogen can be converted, each coming with its own strengths and weaknesses as seen in Table 6. Characteristics such as volumetric energy density, ease and costs of transport, production or conversion costs all determine how suitable a certain energy carrier is to be adopted on a large scale.[117]

If a hydrogen carrier has a low volumetric energy density compared to fossil fuels, it means that the same amount of energy as from oil can only be produced with physically larger volumes of that carrier. In other words, a low energy density translates to larger storage and transport requirements than for fossil fuels and therefore higher costs.

Moreover, existing oil, natural gas or LNG infrastructure can fully or partly be used for certain energy carriers like liquefied hydrogen or methanol, making these more cost effective as less investments are required. Finally, some carriers require more complex and energy intensive processes to be turned into a convenient and appropriate type of fuel. For instance, LOHCs or ammonia have complex reconversion processes, whereas compressed hydrogen can be used directly.

Figure 4. Large-scale hydrogen transportation in different forms[118]



117 Etienne Rivard, Michel Trudeau, and Karim Zaghib, “Hydrogen Storage for Mobility: A Review,” *Materials* 12, no. 12 (June 19, 2019), https://doi.org/10.3390/ma12121973.

118 Weichenhain, “Transporting the Fuel of the Future.”

Depending on the form in which hydrogen will be used, tank storage companies could take on different roles and expand their services into conversion and re-conversion, compression transport, handling, among others. This section outlines the strengths and weaknesses of the most commonly discussed forms of storing and transporting hydrogen, which are liquid and compressed hydrogen, methanol, ammonia and Liquid Organic Hydrogen Carrier (LOHC). Whereas other technologies, such as storage in solid forms or non-organic hydrogen carriers, are also under development, they are outside of the scope of this paper. An overview of the strengths and weaknesses is provided by Table 6.

Table 6. Gaseous and liquid hydrogen carriers and their characteristics[119]

Type of carrier	Pros	Cons	Maturity level
Compressed hydrogen	• **Cost**: least-cost transport option at small distances (<3,000 km) • **Infrastructure**: can make use of retrofitted natural gas infrastructure	• **Energy density**: lowest energy density out of hydrogen carriers, requiring more storage capacity and therefore more associated costs • **Energy intensity**: compressing hydrogen requires energy	• Most **mature** hydrogen storage technology for small distances
Liquified hydrogen	• **Cost:** least-cost option for distances between 3,000 and 16,000 km • **Infrastructure**: can be transported via vessels that are similar to LNG carriers	• **Energy density:** up to 75% higher volumetric density than compressed hydrogen; lower than ammonia or methanol • **Energy intensity:** about twice as much energy required to liquify hydrogen than to compress[120] • **Cost**: transport via truck/trailer is about 2-3 times more expensive than for compressed hydrogen[121]	• Most **mature** hydrogen storage technology for large distances
Methanol	• **Cost**: cheap transport • **Infrastructure:** can be transported via existing oil pipelines • Can be used as hydrogen carrier as well as fuel • **Energy density:** three times higher than compressed hydrogen and twice as high as liquefied hydrogen, but still about ½ of gasoline or diesel[122]	• No policy ambitions for methanol at the European level	• Conventional methanol, made from natural gas, **mature** • E-methanol (or green methanol), made from hydrogen with CO_2, **not mature**

Ammonia	• **Energy density**: high volumetric density compared to other carriers, slightly lower than fossil fuels
	• **Infrastructure:**
	  • can be stored at -33C instead of -253C like liquid hydrogen
	  • much transport infrastructure is already in place due to widespread usage of ammonia
	• **Cost**: cheapest option for long-distance transport
	• Can be used as hydrogen carrier as well as fuel
		• **Costs**: High conversion and reconversion costs
		• Toxicity can make permitting, storage and handling difficult and politically undesirable
			• Grey ammonia, made from natural gas, **mature**
			• Green ammonia, made from green hydrogen, **not mature**

Liquified Organic Hydrogen Carriers (LOHCs)	• **Infrastructure**: can use existing diesel and gasoline infrastructure • **Cost**: easy and low-cost storage and transport; is liquid at ambient temperature and pressure • **Energy density**: higher density than compressed and liquefied hydrogen	• Technology is not well-established • **Energy intensity:** reconversion requires much energy	• Dehydrogenation process, needed to release hydrogen from carrier, **not mature**

119 Table based on sources used in section 6.2.

120 Hydrogenious - LOHC Technologies, “Hydrogen Stored as an Oil!,” 4, https://www.hydrogen.energy.gov/pdfs/07-Schmidt-Liquid%20Organic%20Hydrogen%20Carriers.pdf.

121 Hydrogenious - LOHC Technologies, 4.

122 International Renewable Energy Agency and Methanol Institute, “Innovation Outlook: Renewable Methanol,” 2021, 57, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jan/IRENA_Innovation_Renewable_Methanol_2021.pdf.

Compressed and liquid hydrogen

Hydrogen can be transported and stored in gaseous (compressed) or in liquid form, without converting it into other molecules. Compressed hydrogen is the most mature hydrogen storage technology.[123] It can be stored in pressurized steel tanks and underground reservoirs and transported through ships that are similar to those transporting compressed natural gas (CNG) or pipelines.[124] The major problem with storing hydrogen in a gaseous state is that its volumetric energy density is very low, making it difficult and costly to transport and store.[125] Moreover, compressing hydrogen also requires energy.[126]

Nevertheless, transporting compressed hydrogen through pipelines is considered to be the lowest-cost option for distances up to 3,000 km.[127] Retrofitting natural gas infrastructure can further decrease the costs of transporting compressed hydrogen by half.[128] However, such transport via gas pipelines has its limits. Uptake through retrofitting is estimated to not be able to pass 20% of the total pipeline volume and repurposing the pipelines for exclusive hydrogen usage is very expensive.[129]

Storing hydrogen in liquid form allows for an energy density that is up to 75% higher than that of compressed hydrogen, but also requires about 25-30% of the energy contained in the hydrogen for the liquefaction process.[130] Still, the volumetric density of liquefied hydrogen is about one fourth compared to kerosene.[131] Liquefied hydrogen can be transported by carriers that are akin to LNG carriers.[132] The shipping costs for liquefied hydrogen are still very high (15 $/kg from Saudi Arabia to Japan), but could fall to 1.7 $/kg by 2030 if scaled-up sufficiently (Figure 5).[133]

The economic feasibility of hydrogen import depends strongly on the utilization rate of import infrastructure, particularly for pipeline infrastructure. In combination with the existing natural gas infrastructure, which allows for imports in the magnitude of 30 Mt of hydrogen annually, and the low costs of transporting compressed hydrogen over short distances, this makes it likely that a bulk of the import of hydrogen will come in its pure form rather than through one of its derivatives – methanol, ammonia or LOHCs.[134]

123 Rivard, Trudeau, and Zaghib, "Hydrogen Storage for Mobility," 12.

124 Joint Research Centre, "Assessment of Hydrogen Delivery Options" (European Commission, 2021), 2, https://ec.europa.eu/jrc/sites/default/files/jrc124206_assessment_of_hydrogen_delivery_options.pdf.

125 Rivard, Trudeau, and Zaghib, "Hydrogen Storage for Mobility," 12.

126 Patrick Molloy, "Run on Less with Hydrogen Fuel Cells," RMI, February 10, 2019, https://rmi.org/run-on-less-with-hydrogen-fuel-cells/.

127 Joint Research Centre, "Assessment of Hydrogen Delivery Options," 3.

128 Joint Research Centre, 2.

129 Entsog, Gas Infrastructure Europe, and Hydrogen Europe, "How to Transport and Store Hydrogen – Facts and Figures," n.d.

130 International Renewable Energy Agency, "Green Hydrogen Cost Reduction," 47.

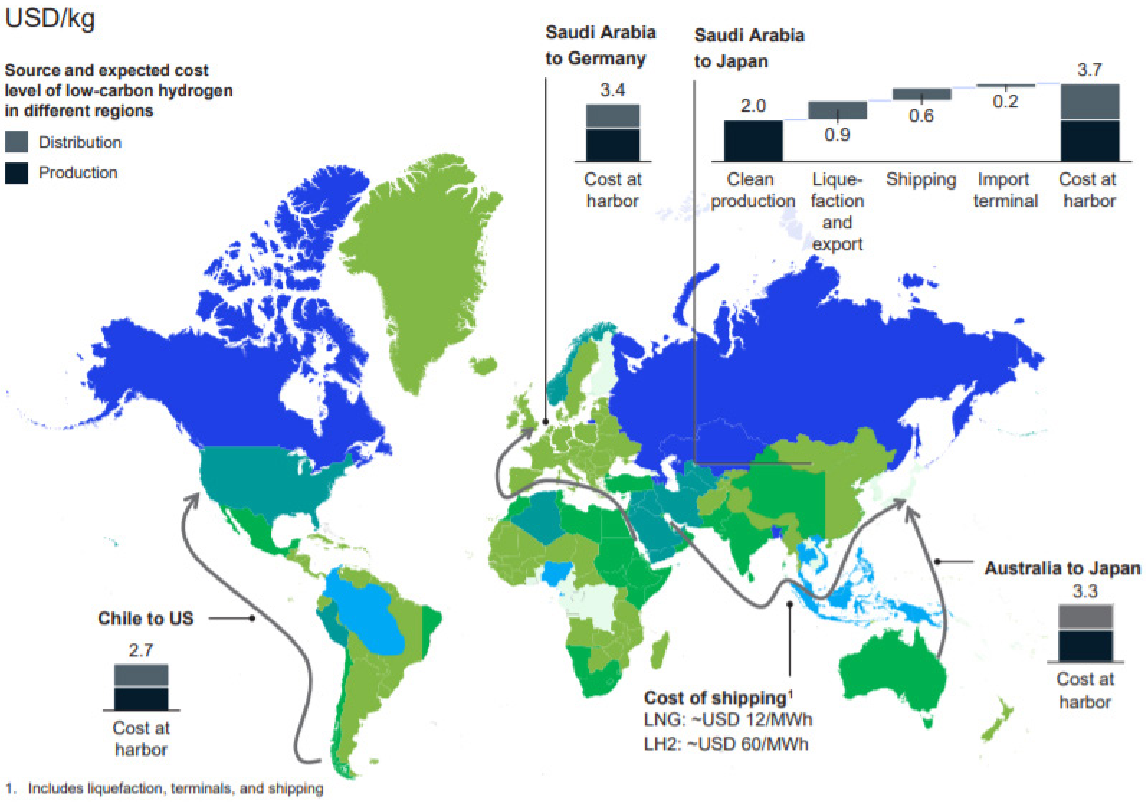
131 Rivard, Trudeau, and Zaghib, "Hydrogen Storage for Mobility," 5.

132 Joint Research Centre, "Assessment of Hydrogen Delivery Options," 2–3.

133 "Path to Hydrogen Competitiveness: A Cost Perspective" (The Hydrogen Council, January 20, 2020), 26, https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf.

134 "Decarbonised hydrogen imports into the European Union," 31.

Figure 5. Costs of shipping liquid hydrogen across regions in 2030[135]



Methanol

Methanol can serve as a low-carbon energy carrier as well as source of energy. It can be produced from a wide array of sources, but it is currently mainly produced by natural gas.[136] Methanol can also be made emission-free by combining green hydrogen with CO_2 (green e-methanol).[137] As such, increasing the production of green e-methanol is strongly dependent on pressing down the costs of green hydrogen and having sufficient CO_2 available.

Methanol has a number of strong suits as an energy carrier. The molecule is easy to transport and store due to its liquid form at ambient temperature, its compatibility with existing infra-structure and ability to be blended with conventional fuels.[138] Methanol can be transported through oil pipelines and its refueling stations are almost identical to those of gasoline or diesel, as well as significantly cheaper than those of hydrogen or LNG.[139] Methanol has a higher volumetric energy density than liquefied or compressed hydrogen, but it remains only at about half of the volumetric energy density of diesel and gasoline.[140]

135 "Path to Hydrogen Competitiveness: A Cost Perspective," 27.

136 Nils Landstrand, "The Benefits of Methanol," MAN Energy Solutions, accessed December 1, 2021, https://www.man-es.com/discover/the-benefits-of-methanol.

137 International Renewable Energy Agency and Methanol Institute, "Innovation Outlook: Renewable Methanol," 4.

138 International Renewable Energy Agency and Methanol Institute, 5.

139 International Renewable Energy Agency and Methanol Institute, 30.

140 International Renewable Energy Agency and Methanol Institute, 25.

Despite the potential that methanol harbors, observers are skeptical about a large-scale ramp-up of (clean) methanol production, citing high costs and lacking demand as primary fuel.[141] This is reflected in the European Green Deal and climate policies at large, which do not give any particular role to methanol.

Ammonia

Ammonia is a molecule consisting of nitrogen and hydrogen, widely used as a fertilizer. Reflecting the production process of the hydrogen used for ammonia production, the industry distinguishes between different colors of ammonia, such as grey, green and blue. While there are some green ammonia projects in operation, they all are very small scale.[142] The expansion of green ammonia production depends first and foremost on the cost reduction of green hydrogen, which in turn is largely determined by the costs of renewable energy.[143]

Ammonia carries significant potential to be used in the shipping and power generation sectors, but is also considered to be a promising hydrogen carrier.[144] Ammonia has a substantially higher energy density than liquid hydrogen – but slightly less than fossil fuels[145]- and can already be stored at -33 C instead of -253 C, as is the case for liquid hydrogen.[146] Its volumetric energy density is also significantly higher than that of liquid hydrogen.[147] These properties make ammonia an attractive energy carrier, which is amplified by the fact that much ammonia storage and transport infrastructure in the form of ammonia ships are already in place.[148] Moreover, ammonia is considered to be the cheapest option to for long distance transport of hydrogen, adding only 0.3-0.5 $/kg.[149] Converting hydrogen into ammonia is furthermore a well-developed technology. Potential drawbacks of ammonia as an energy carrier are the high costs of reverting it into hydrogen, adding 1-2 $/kg to the total costs, and its toxicity that restricts storage and transport options.[150]

141 "Methanol Production Capacity May Quintuple on Decarbonized Industry Transformation: Study," IHS Markit, January 29, 2021, https://cleanenergynews.ihsmarkit.com/research-analysis/methanol-production-capacity-may-quintuple-on-decarbonized-ind.html.

142 Alexander H. Tullo, "Is Ammonia the Fuel of the Future? Industry Prepares Ammonia for a Second Life as a Fuel for the Future," Chemical & Engineering News, August 3, 2021, https://cen.acs.org/business/petrochemicals/ammonia-fuel-future/99/i8.

143 "Ammonia: Zero-Carbon Fertiliser, Fuel and Energy Store" (The Royal Society, February 2020), 14, https://royalsociety.org/-/media/policy/projects/green-ammonia/green-ammonia-policy-briefing.pdf.

144 Aliaksei Patonia and Rahmatallah Poudineh, "Ammonia as a Storage Solution for Future Decarbonized Energy Systems," November 2020, 5, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/11/Ammonia-as-a-storage-solution-for-future-decarbonized-systems-EL-42.pdf.

145 "Ammonia: Zero-Carbon Fertiliser, Fuel and Energy Store," 7.

146 Tullo, "Is Ammonia the Fuel of the Future? Industry Prepares Ammonia for a Second Life as a Fuel for the Future."

147 Patonia and Poudineh, "Ammonia as a Storage Solution for Future Decarbonized Energy Systems," 6.

148 Hydrogen Council and McKinsey & Company, "Hydrogen Inisghts - A Perspective on Hydrogen Investment, Market Development and Cost Competitiveness," February 2021, 23, https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021-Report.pdf.

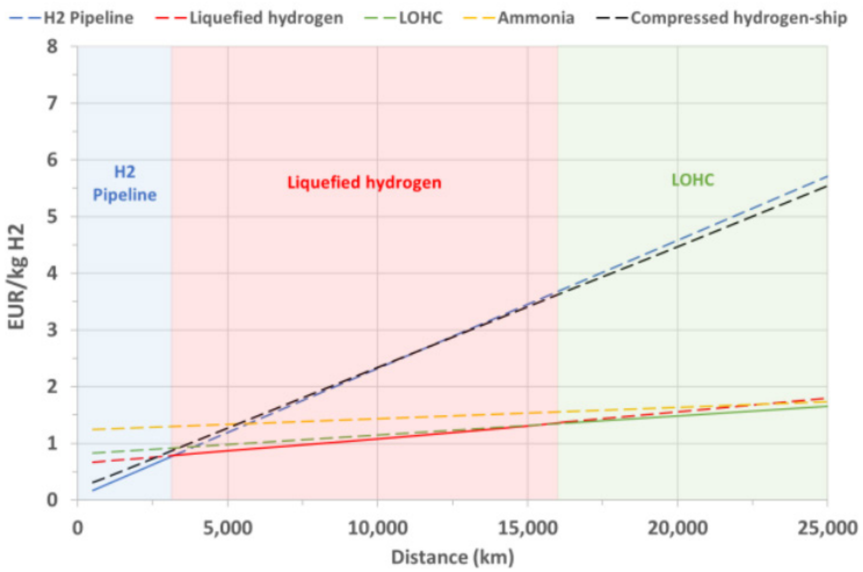
149 Hydrogen Council and McKinsey & Company, 6; "Ammonia: Zero-Carbon Fertiliser, Fuel and Energy Store," 24.

150 "Path to Hydrogen Competitiveness: A Cost Perspective," 26.

Liquid Organic Hydrogen Carrier (LOHC)

An LOHC is a stable organic liquid carrier that can bind hydrogen, such as n-ethylcarbazole, methyl-cyclohexane or benzyltoluene. LOHCs are liquid at ambient temperature and pressure, making it easier and less costly to transport them than pure hydrogen.[151] LOHCs can be non-flammable and non-toxic, making it easier to safely handle them than ammonia. They can also use existing diesel and gasoline storage units as well as shipping infrastructure for distribution and transport.[152] LOHCs furthermore have higher volumetric and gravimetric densities than compressed and liquefied hydrogen, although compared to fossil fuels the density remains low. On the long term, the transport of LOHCs is expected to become cheaper and more convenient than the other hydrogen carriers on long distances, as seen in Figure 6.[153] On the other hand, the dehydrogenation process requires large amounts of heat and therefore energy.[154] While LOHC technologies are not ready to be implemented on a large-scale, they are a promising option for shipping hydrogen at large distances.

Figure 6. Hydrogen delivery costs for 1 Mt hydrogen and a low-cost electricity scenario[155]



151 "LOHC Technology," Umicore, accessed December 2, 2021, https://www.umicore.com/en/newsroom/news/lohc-technology/.

152 "Path to Hydrogen Competitiveness: A Cost Perspective," 27.

153 Hydrogeit, "LOHC – Hydrogen Transport Made Easy," *H2-International* (blog), November 15, 2020, https://www.h2-international.com/2020/11/15/lohc-hydrogen-transport-made-easy/; Hydrogen Council and McKinsey & Company, "Hydrogen Inisghts - A Perspective on Hydrogen Investment, Market Development and Cost Competitiveness," 23.

154 Hydrogen Council and McKinsey & Company, "Hydrogen Inisghts - A Perspective on Hydrogen Investment, Market Development and Cost Competitiveness," 23.

155 Joint Research Centre, "Assessment of Hydrogen Delivery Options."

6.3. **Electrification & battery storage**

Electrification is at the heart of Europe's decarbonization, prospected to meet 36-39% of its energy demand by 2050. More than 80% of electricity will be provided by variable renewable energy (VRE) sources. Next to hydrogen storage, electricity storage can be essential in providing the necessary backup capacity when those VRE sources are not producing sufficient electricity. Electricity storage primarily comes in the form of battery storage.[156] Batteries are used in different sectors. They can be used for electronic devices, but also in the transport sector and to store grid electricity. The future development of battery storage in both the transport and electricity sectors holds important implications for the European tank storage sector.

As of 2020, there is little battery capacity for grid electricity storage deployed, standing at 17 GW globally. According to the IEA, this capacity would have to reach 580 GW by 2030 to be on track to reach net-zero according to the Net Zero Emissions scenario.[157] By 2050, battery storage capacity should reach 3 TWh.[158] A possible indication of whether stationary battery storage is going to grow this substantially could be the cost development of these batteries, of which the lithium-ion (Li-ion) battery is most widely used.[159] Since 2010, Li-ion battery costs for EVs and for stationary applications have dropped by more than 90% and two thirds, respectively.[160] These cost reductions have largely resulted from an increase in the production scale, suggesting that a continued reduction in costs is possible.[161]

Flow batteries offer an alternative to Li-ion batteries, storing energy in the form of liquid electrolytes in tanks. Moreover, flow batteries account for less energy density, have longer life cycles (up to 10,000 charging cycles)[162] and therefore function well for the electricity supply of thousands of households.[163] However, the materials used to produce such batteries are either costly materials like vanadium or contain toxic substances. [164] Vanadium is considered a critical mineral by the EU due to its high economic importance and expected supply risks in the next decades. Recent research has been focused on producing cheap, long-lived and safe flow batteries and there is promising progress going on. "A second wave of progress" could lead to replacements of vanadium with organic compounds.[165]

---

156 "Utility-Scale Batteries – Innovation Landscape Brief" (IRENA, 2019), 6, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Utility-scale-batteries_2019.pdf.

157 "Energy Storage – Analysis," IEA, November 2021, https://www.iea.org/reports/energy-storage.

158 IEA, "World Energy Outlook 2021," 30.

159 "Utility-Scale Batteries – Innovation Landscape Brief," 6.

160 "Innovation in Batteries and Electricity Storage – Analysis," IEA, 5, accessed November 10, 2021, https://www.iea.org/reports/innovation-in-batteries-and-electricity-storage.

161 Simon Moores, "The Global Battery Arms Race: Lithium-Ion Battery Gigafactories and Their Supply Chain" (The Oxford Institute for Energy Studies, 2021), 3, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2021/02/THE-GLOBAL-BATTERY-ARMS-RACE-LITHIUM-ION-BATTERY-GIGAFACTORIES-AND-THEIR-SUPPLY-CHAIN.pdf.

162 Queensland Government, "Types of Battery Energy Storage | Battery Energy Storage," Text (corporateName=The State of Queensland; jurisdiction=Queensland), accessed February 18, 2022, https://www.qld.gov.au/housing/buying-owning-home/energy-water-home/solar/battery-energy-storage/types-of-battery-energy-storage.

163 Robert F. Service, "New Generation of 'flow Batteries' Could Eventually Sustain a Grid Powered by the Sun and Wind," Science.org, October 31, 2018, https://www.science.org/content/article/new-generation-flow-batteries-could-eventually-sustain-grid-powered-sun-and-wind; Environmental and Energy Study Institute, "Fact Sheet | Energy Storage (2019) | White Papers | EESI," February 22, 2019, https://www.eesi.org/papers/view/energy-storage-2019.

164 Service, "New Generation of 'flow Batteries' Could Eventually Sustain a Grid Powered by the Sun and Wind."

165 Service.

The development of organic flow batteries is an opportunity for the European tank storage sector to contribute to the transition towards sustainable electrification of several sectors. Companies like Vopak and Elestor have signed a Joint Development Agreement for the development of a hydrogen bromine flow battery.[166] The ambition is to increase electricity storage capacity of flow batteries from 200 kWh to 3000 kWh within two years and in the long term to bring it to the industrial level.[167]

Another option for sustainable energy storage is saltwater battery.[168] Saltwater batteries conduct and store electricity using sodium. This kind of battery is a very safe option because there is no toxic metal used, also making the recycling process easier.[169] The main issue is, similar to flow batteries, that the production is more costly than Li-ion batteries.[170] Nevertheless, efforts are being made to increase the production of saltwater batteries. The Austrian energy company Bluesky Energy is planning to build large saltwater battery production sites in Austria, starting in late 2022.[171]

Batteries with lower energy density, which is the case for both saltwater and flow batteries, require a larger physical battery and therefore have additional materials needs and associated costs. Since Li-ion battery prices continue to decrease, production prices pose the biggest challenge for battery storage alternatives.[172] Given that most batteries, regardless of the technology, contain critical minerals such as lithium, cobalt and vanadium, the extent to which prices will decrease is also impacted by the supply risk. Global shortages will undoubtedly increase the price of the minerals, leading to uncertain price developments for these technologies.

Overall, a continuous decrease in costs and concomitant accelerating deployment of grid battery storage can be expected. It is clear for the EU that stationary battery storage will inevitably play an important role as the share of renewable energy increases drastically, pumped hydropower has geographical limits to be expanded and as Europe seeks to minimize its fossil fuel usage in the long-term.[173] At the same time, the importance of stationary battery storage in 2050 will strongly depend on the scale of deployment of green hydrogen, which can also provide necessary storage capacity.[174]

166 Elestor, "ELESTOR Enters Cooperation with Vopak for Scaling HBr Flow Battery Technology," Elestor, May 6, 2021, https://www.elestor.nl/elestor-enters-cooperation-with-vopak-for-scaling-hbr-flow-battery-technology/.

167 Elestor.

168 EnergySage, "Saltwater Batteries: What You Need To Know | EnergySage," Solar News, April 9, 2020, https://news.energysage.com/saltwater-batteries-what-you-need-to-know/.

169 EnergySage.

170 EnergySage.

171 Bluesky Energy, "The Saltwater Battery," BlueSky Energy I Stromspeicher Batterien, accessed February 18, 2022, https://www.bluesky-energy.eu/en/saltwater_battery/.

172 EnergySage, "Saltwater Batteries."

173 Christopher Andrey et al., "Study on Energy Storage: Contribution to the Security of the Electricity Supply in Europe" (Publications Office of the European Union, 2020), 9, https://data.europa.eu/doi/10.2833/077257.

174 Andrey et al., 10.

6.4. **Carbon storage**

Carbon capture, utilization and storage (CCUS) refers to a range of technologies that are centered around capturing CO_2 and subsequently either store or use it.[175] These technologies are considered to be a critical contributor to net-zero targets in three ways.[176] First, CCUS allows abating emissions from sectors where moving away from fossil fuels is challenging or even technologically limited, such as in the production of cement or steel.[177] In this sense, CCUS is particularly attractive as many existing industrial facilities and power plants are likely to remain in operation. Second, CCUS is critical to the production of blue hydrogen, which remains the cheapest option to produce low-cost hydrogen for the upcoming years.[178] Third, CCUS allows for negative emissions by removing CO_2 from the atmosphere.[179]

Like other technologies that are supposed to carry the energy transition, the deployment of CCUS remains highly limited. As of 2019, the total CO_2 abatement by CCUS amounted to 40 Mt annually.[180] The projects that are under development are gathering momentum. By the end of 2020 a total of 75 Mt of capacity was under development. This grew to 111 Mt by September 2021 – a 48% increase within less than a year.[181] About 5,600 Mt of abatement capacity would have to be in operation by 2050 to limit the temperature increase to 2 degrees.[182]

Most CCUS technologies are at an "early adoption" stage. This means that they are fully developed and can commercially operate, but still require supportive policies and regulatory frameworks to enable their large-scale deployment.[183] Nevertheless, in the IEA's SDS scenario, almost two thirds of the cumulative emission reductions up to 2070 resulting from the usage of CCUS stem from technologies that are still at the prototype or demonstration stage.[184]

The costs of CCUS depends on the technology used. For instance, separating CO_2 from natural gas can generally be done at a relatively low cost of about 15-25 $/t CO2, while for other usages it can range from 40-100 $/t CO_2.[185] Capturing CO_2 from the atmosphere – Direct Air Capture (DAC) – is particularly expensive, with costs ranging between 250-600 $/t CO_2.[186]

CCUS has both upsides and downsides. Some consider it to be a means of 'locking-in' and perpetuating the usage of fossil fuels, emphasizing that CCUS usage is not entirely carbon

175 IEA, "A New Era for CCUS – CCUS in Clean Energy Transitions – Analysis," 2020, 19, https://www.iea.org/reports/ccus-in-clean-energy-transitions/a-new-era-for-ccus.

176 IEA, 3.

177 Krysta Biniek et al., "Driving CO2 Emissions to Zero (and beyond) with Carbon Capture, Use, and Storage," June 30, 2020, https://www.mckinsey.com/business-functions/sustainability/our-insights/driving-co2-emissions-to-zero-and-beyond-with-carbon-capture-use-and-storage.

178 IEA, "A New Era for CCUS – CCUS in Clean Energy Transitions – Analysis," 17.

179 IEA, 18.

180 Jaylene Salas, "The Future of Carbon Capture," The Aspen Institute, October 9, 2020, https://www.aspeninstitute.org/blog-posts/the-future-of-carbon-capture/.

181 "Global Status of CCS 2021" (Global CCS Institute, 2021), 9, https://www.globalccsinstitute.com/wp-content/uploads/2021/11/Global-Status-of-CCS-2021-Global-CCS-Institute-1121.pdf.

182 "Global Status of CCS 2021," 12.

183 IEA, "A New Era for CCUS – CCUS in Clean Energy Transitions – Analysis," 94–95.

184 IEA, 96.

185 IEA, 101.

186 Katie Lebling et al., "Direct Air Capture: Resource Considerations and Costs for Carbon Removal," World Resource Institute, January 6, 2021, https://www.wri.org/insights/direct-air-capture-resource-considerations-and-costs-carbon-removal.

neutral. On the other hand, proponents of CCUS argue that climate targets simply cannot be met without capturing CO_2 from existing industries as well as from the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) also contends in its 2018 report that about 5-10 Gt of CO_2 must be removed from the atmosphere annually from 2050 to 2100 to remain below a 1.5-degree temperature increase.[187] Moreover, the majority of governments have included CCUS as a critical part of their long-term emission reduction strategies.[188] The IEA also projects that the decarbonization of the petrochemical sector will predominantly come from the application of CCUS.[189]

All in all, CCUS is likely to play an increasingly important role in the mid and long term to enable the widescale production of low-carbon hydrogen and to decarbonize the industrial sector. Meanwhile, CCUS also has its role to play in the long-term due to the importance of DAC to reach the climate targets. This could represent an opportunity for tank storage companies to expand their services beyond liquid fuel storage toward gaseous CO_2, although developments remain uncertain.

6.5. **Biofuels**

Biofuels are derived from biomass products like corn, soy, switchgrass, wood, waste and vegetable oil.[190] There are two types of biofuels: Liquid biofuels, namely ethanol, biodiesel, advanced biodiesel and biokerosene; and gaseous biofuels like biogas and biomethane.[191] They are often used for fuel blends with high-carbon fuels, especially for the decarbonization of the transport sector. They contribute to the reduction of emissions by mitigating the pure use of heavy fossil fuels. Similar to carbon storage, however, biofuels offer an in-between solution to the problem of the fossil fuel use: they contribute to the reduction of emissions but do not entirely avoid these emissions.

As most growth in demand is expected to come from advanced biofuels, the future of conventional biofuel is not promising. [192] Conventional biofuels based on food crops are unsustainable due to the requirement of land and agricultural production to sustain biomass.[193] To overcome this challenge, the EU defines advanced biofuels based on the type of biomass that is used to produce them, which tends to be non-food-based and sustainable, such as algae, biowaste, industrial waste, straw or animal manure.[194]

Advanced biofuels could reduce lifecycle GHG emissions by at least 50% in comparison to fossil fuels.[195] Advanced technology for liquid biofuel production like the usage of woody feed-

187 "Global Status of CCS 2021," 10.

188 "Global Status of CCS 2021," 11.

189 IEA, "European Union 2020 - Energy Policy Review," 118.

190 Massachuchetts Government, "Advanced Biofuels," accessed December 8, 2021, https://www.mass.gov/service-details/advanced-biofuels.

191 International Energy Agency, "Net Zero by 2050 - A Roadmap for the Global Energy Sector," May 2021, 107, iea.li/nzeroadmap.

192 Green Car Congress, "RaboResearch: EU Biofuel Demand to Halve by 2050," Green Car Congress, November 4, 2021, https://www.greencarcongress.com/2021/11/20211104-rabo.html.

193 Raj Shah, "Future Trends in Biofuel | Biofuels International Magazine," Biofuel News, March 10, 2021, https://biofuels-news.com/news/future-trends-in-biofuel/.

194 "Directive (EU) 2018/ 2001 of the European Parliament and of the Council - of 11 December 2018 - on the Promotion of the Use of Energy from Renewable Sources" (European Union, December 11, 2018), Annex IX, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001.

195 Massachuchetts Government, "Advanced Biofuels."

stock will grow substantially up to 2050.[196] Synthetic fuels refer to biomass-based products that are hydrogenated and therefore carbon-free.[197] Since the global demand for renewable fuels will increase in the future, the demand for synthetic fuels from renewable hydrogen and CO_2 (known as Power-to-X (PtX)) will expand as well.[198] The global demand for PtX could meet 20,000 TWh in 2050.[199] Synthetic fuels will most likely play a role in the future fuel supply for the transport sector.

According to the IEA's Net Zero Scenario, from 2030 onwards biofuels are mostly expected to supply heavy road freight, shipping and aviation instead of the light transport sector. Aviation and maritime transport will be increasingly dependent on renewable and low-carbon liquid and gaseous fuels due to the lack of zero-emission alternatives.[200] Initiatives like the ReFuelEU Aviation and FuelEU Maritime are promoting the use of sustainable aviation and maritime fuels.[201] Contrastingly, by 2030 biodiesel is projected to drop by 10%[202] and after 2045, most of the EU vehicle fleet will be powered by electricity and hydrogen, which will lead to a decline of biofuel demand for road transport.[203]

The global aviation sector is expected to incorporate 15% and 45% in 2030 and 2050, respectively, of SAFs such as hydrogenated esters and fatty acids (HEFA), as well as biomass gasification using the Fischer-Tropsch process (bio-FT).[204] Especially in regard to the growing aviation industry, which is expected to increase from 4 billion to 8 billion passengers by 2050, SAFs offer a low-carbon fuel alternative.[205]

6.6. **Circular approaches in industry**

Global demand for industrial products is likely to increase over the upcoming decades due to the expected demographic growth and industrialization and urbanization of emerging markets. In the IEA's APS scenario as well as NZE scenario, demand for petrochemical products increases until at least 2030 globally, followed by an increase concentrated in Asia Pacific.[206]

196 International Energy Agency, "Net Zero by 2050 - A Roadmap for the Global Energy Sector," 106.

197 UTV Independent Tank Farm Association, "E-Fuels and Biofuels :: UTV - Independent Tank Storage Association," accessed December 8, 2021, https://www.tanklagerverband.de/themen/e-fuels-und-biofuels.

198 UTV Independent Tank Farm Association.

199 UTV Independent Tank Farm Association.

200 European Commission, "Sustainable and Smart Mobility Strategy – Putting European Transport on Track for the Future," 2021, 5, https://transport.ec.europa.eu/transport-themes/mobility-strategy_en.

201 European Commission, 5.

202 European Commission. Directorate General for Agriculture and Rural Development., *EU Agricultural Outlook for Markets and Income 2020-2030.* (LU: Publications Office, 2020), 4, https://data.europa.eu/doi/10.2762/252413.

203 Green Car Congress, "RaboResearch."

204 International Energy Agency, "Net Zero by 2050 - A Roadmap for the Global Energy Sector," 107.

205 Air bp, "What Is Sustainable Aviation Fuel (SAF) and Why Is It Important? | News and Views," Air bp, accessed January 6, 2022, https://www.bp.com/en/global/air-bp/news-and-views/views/what-is-sustainable-aviation-fuel-saf-and-why-is-it-important.html.

206 IEA, "World Energy Outlook 2021" (Paris: IEA, 2021), 132–33, https://www.iea.org/reports/world-energy-outlook-2021; IEA "The Future of Petrochemicals: Towards More Sustainable Plastics and Fertilisers" (Paris: IEA, 2018), 71, https://iea.blob.core.windows.net/assets/bee4ef3a-8876-4566-98cf-7a130c013805/The_Future_of_Petrochemicals.pdf.

The industrial sector accounts for almost 40% of global energy use as of 2020.[207] In turn, oil and gas each account for about 20% of total industrial energy usage, with coal being the most widely used fuel at almost 30%. The remainder is mainly provided by electricity, but also by a small amount of bioenergy and heat.[208] The three biggest industrial consumers globally are the chemicals, steel and cement industries. Coal is predominantly used for the production of steel and to a lesser extent cement, while oil accounts for almost half of the energy provided to the chemical industry.[209]

Petrochemical products –products derived from oil or natural gas – account for 90% of total chemical feedstock.[210] Ammonia, so-called high-value chemicals (HVCs) and methanol are the most widely used products within the petrochemical industry, together accounting for two thirds of its total energy demand.[211] Ammonia, principally produced from natural gas, serves as a basis for all synthetic nitrogen fertilizers, which in turn are used for more than half of global food production. HVCs are used for the production of plastics, rubber and synthetic fibers.[212] Methanol is mainly used for the production of certain plastics and coatings. Methanol can also be used as an intermediary for certain high-value chemicals when there is no oil to serve as a feedstock.[213]

An important development that could influence feedstock demand in the industrial sector is recycling. The market of industrial waste recycling and services is expected to grow by $6.98 bn during 2021-2025.[214] Many countries around the world have taken measures to reduce the usage of single-use plastics and are increasingly investing in waste management and recycling. Accordingly, IEA's STEPS scenario sees a slight increase in the global recycle rate from 17% to 20% by 2030, while the APS scenario and the NZE scenario entail a slightly higher recycling rate at 23% and 27% respectively.[215]

There are two types of conversion processes.[216] One way to recycle waste materials, for example plastic, is through pyrolysis. Pyrolysis means that waste (or plastic) is thermally cracked in the absence of oxygen, which fragments it into smaller hydrocarbon molecules and hence leads to the production of so-called pyrolysis oil.[217] Gasification poses a second option for feedstock recycling.[218] In this thermo-chemical process, biomass is burned at extremely high temperatures, in the presence of oxygen, creating combustible gas, also called

207 Tiffany Vass et al., "Tracking Industry 2021 – Analysis," IEA, November 2021, https://www.iea.org/reports/tracking-industry-2021.

208 Vass et al.

209 "Final Energy Demand of Selected Heavy Industry Sectors by Fuel, 2019 – Charts – Data & Statistics," IEA, September 19, 2020, https://www.iea.org/data-and-statistics/charts/final-energy-demand-of-selected-heavy-industry-sectors-by-fuel-2019.

210 IEA, "The Future of Petrochemicals: Towards More Sustainable Plastics and Fertilisers," 17.

211 IEA, 17.

212 IEA, 17.

213 Tiffany Vass et al., "Chemicals - Fuels & Technologies," IEA, November 2021, https://www.iea.org/fuels-and-technologies/chemicals.

214 Businesswire, "Europe Industrial Waste Recycling and Services Market Report 2021-2025 - Growing Industrial Waste and Growing Investments in Smart Waste Recycling - ResearchAndMarkets.Com," December 21, 2021, https://www.businesswire.com/news/home/20211221005563/en/Europe-Industrial-Waste-Recycling-and-Services-Market-Report-2021-2025---Growing-Industrial-Waste-and-Growing-Investments-in-Smart-Waste-Recycling---ResearchAndMarkets.com.

215 IEA, "World Energy Outlook 2021," 217.

216 Circular Economy Guide, "Feedstock Recycling," Circular Economy Guide, accessed February 3, 2022, https://www.ceguide.org/Strategies-and-examples/Dispose/Feedstock-recycling.

217 Carina Oliveira, "Technology Factsheet: Pyrolysis Oil Production from Plastic Waste" (TNO, September 28, 2020), https://energy.nl/wp-content/uploads/2020/09/Pyrolysis-oil-production-from-plastic-waste_28-09-2020.pdf.

218 Circular Economy Guide, "Feedstock Recycling."

syngas.[219] The main difference is that during pyrolysis oxygen is absent while gasification happens in an oxygen-rich environment.[220]

Chemical waste recycling contributes to the move from a linear economy to a circular one.[221] The recycled elements can be reused as virgin material alternatives in manufacturing new industrial polymers.[222] This way plastic waste can become a source for circular carbon, even having the same quality carbon as in the original product.[223] Further benefits lay in the reduced costs, the conservation of natural resources, the reduction of GHG emissions and consequently a better public perception of the industry and companies of the sector.[224] The continuous increase in the global consumption of plastics makes it is very likely that in the long term the role of recycling will become indispensable. An industrial solution for the recycling of plastic is required, which is why tank storage companies should work with other stakeholders to adapt their capacities and offer services that align with recycling demand.

219 Madhu, "Difference Between Pyrolysis and Gasification," Compare the Difference Between Similar Terms, August 29, 2019, https://www.differencebetween.com/difference-between-pyrolysis-and-gasification/; Circular Economy Guide, "Feedstock Recycling."

220 Madhu, "Difference Between Pyrolysis and Gasification"; Circular Economy Guide, "Feedstock Recycling."

221 CEFIC, "Circular Carbon," accessed February 4, 2022, https://cefic.org/a-solution-provider-for-sustainability/circular-carbon/.

222 Circular Economy Guide, "Feedstock Recycling."

223 CEFIC, "Circular Carbon."

224 Blue Corona Team, "The Basics of Industrial Recycling," CleanUp News, March 25, 2021, https://www.cleanupnews.org/home/industrial-recycling-basics.

7. Observations and conclusions

The European energy mix of 2050 will look vastly different from the one we have today. While the pace of the energy transition in the next decades is uncertain, especially at the global level, the European ambition is clear: reaching net zero. Europe is leading the energy transition and the war in Ukraine has brought even more urgency to accelerating the path to climate neutrality. The private sector, investors and governments, need to work together to ensure a smooth and accelerated energy transition. Tank storage sector can contribute to this goal. The pathway to 2050 is determined by many variables, two of the main ones being governance and technological developments.

7.1. Governance, policy support and investments

Europe is heading for a climate neutral future. For a smooth phase out of fossil fuels and replacement with affordable and available supplies of low-carbon energy, governments need to support domestic industries in their transition and in setting up new supply chains. So far, insufficient action has been taken to achieve climate goals and the world seems to be headed toward a relatively pessimistic direction. To prevent a situation in which the energy transition, instability and uncertainty continue for longer than anticipated (i.e., beyond 2050), governments need to take the lead in the fight against climate change and focus on constructive cooperation domestically and internationally.

As a large part of (green) hydrogen supplies will be imported from North Africa or the Middle East, European ports and industrial clusters need to be able to handle the significant amount of new energy carriers. In the case of some hydrogen carriers, varying energy densities mean that more storage and larger scale infrastructure will be necessary to provide the same amount of energy as fossil fuels. Spatial constraints may become an issue for Europe as ports and industrial hubs will require significantly more physical space than now for storing and processing energy carriers. While it is unlikely that one hydrogen carrier will become dominant, companies need a degree of clarity and support regarding the direction that their government is taking. Investors need incentives to fund new projects. With the proper policy support, current energy hubs and industrial clusters can be the drivers of the transition, thus avoiding a complete spatial shift and redesign of the energy system.

The new system should continue supporting the European economy. Europe aims not only to transition, but to remain prosperous and enhance its strategic autonomy in doing so. Upholding modern, robust and well developed infrastructure is a precondition to this ambition. Policy support in this area can enhance the trading function of Europe, which is now fulfilled by ports through import terminals. It can further prevent disruptions in the future energy supply, which is inherently uncertain as new markets and trade relations are slowly being established.

7.2. Technological developments

Tank storage companies are part of Europe's energy infrastructure. Important opportunities are arising for them to expand their services, facilities and expertise in order to continue being reliable providers of energy to the European society. These opportunities align with the goals of the European Taxonomy and may bring in significant investments for storage companies. Expanding services further than storage, handling and blending into the transport, trade and conversion/reconversion, is a key area of development. Broadening expertise into hydrogen, its various energy carriers and recycled oils is essential. Widening areas of work from liquids and into gases for carbon storage, hydrogen and biofuels, as well different types of non-liquid electricity storage, can be a productive approach as well.

Safety will continue being an important prerequisite of energy infrastructure. Tank storage companies can support safety procedures by offering their expertise of storing toxic and hazardous substances. In the case of storing substances like ammonia or methanol, tank storage companies have been active for years. If increasing amounts of such substances will be required, safely storing and handling it will be a relatively routine activity for tank companies. Contrastingly, less mature technologies like battery or carbon storage will bring additional safety requirements, which will require the expansion of expertise and development of protocols.

Green hydrogen will likely see the largest increase in production and demand, driven by the versatility of hydrogen as an energy carrier, its ability to decarbonize hard-to-abate sectors and the strong policy support it enjoys. Nevertheless, the enormous amount of renewable energy needed for its production and the varying costs of production per region – dependent on the costs of renewable energy[225] - means that a significant part of green hydrogen will be imported.[226]

As such, significant storage volumes will be needed to accommodate hydrogen, which can be stored underground or in tanks. The Netherlands and Germany have among the biggest

225 "Path to Hydrogen Competitiveness: A Cost Perspective," 21.

226 European Commission, A hydrogen strategy for a climate-neutral Europe, 2.

underground storage capacity of the EU.[227] With total annual EU production expected to reach 333 TWh already by 2030, this is likely to fall short of what is needed.[228] In combination with the geographic difficulties of transporting hydrogen to underground storages and the advantages of embedding hydrogen in an industrial cluster, this makes tank storage an attractive option to store hydrogen as well.

Another pertinent question is the form in which hydrogen will be stored and transported. There are currently little indications that one energy carrier will dominate. Up to 2030, liquid hydrogen is argued to be the lowest-cost option for shipping due to the maturity of its technology.[229] Still, significant upscaling would be needed to further reduce its costs. Moreover, ammonia and LOHCs have properties that could make them more appealing once their reconversion processes are mature, as well as well-developed infrastructures. Other technologies such as storing hydrogen in solid form (e.g. magnesium or metal hybrids) could also become promising in the future, although their current application is limited. As each energy carrier has its strong suits and drawbacks, they will likely be used in tandem for different circumstances and end users.

The future of battery storage has potentially significant implications for Europe's energy transition. The costs of stationary batteries will continue to decrease, especially for Li-ion batteries but perhaps also for organic flow batteries and saltwater batteries. However, it is unclear at what rate and to what extent this decrease will happen and what the trade-off with hydrogen will be.

On the other hand, the future of CCUS seems more predictable, being essential to blue hydrogen in the mid-term and to capturing CO_2 from the atmosphere in the long-term. For the tank storage sector this could provide an additional incentive to cooperate more closely with local industrial complexes and refineries to develop CCUS facilities.

Biofuels are set to become more important in the long-term, with the global supply of biofuels prospected to increase four- to sixfold according to the NZE. Whereas for road transport biofuels are seen as an intermediate solution before complete electrification, the decarbonization of the aviation and maritime sectors are highly dependent on advanced biofuels, leading to a significant increase in demand in the long-term.

Finally, circularity is essential for promoting sustainable practices in industry. The global consumption of petrochemicals, including plastics, will continue increasing, although largely outside of Europe. Nonetheless, ramping up the recycling of plastics and waste brings enormous opportunities to decrease emissions and the consumption of fossil fuels as feedstock. European countries could become important hotspots for plastic recycling and even hubs for waste trade. Tank storage companies can strongly support this process.

227 "Europe: Hydrogen Underground Storage Capacity by Country," Statista, accessed November 23, 2021, https://www.statista.com/statistics/1267919/potential-hydrogen-storage-capacity-in-europe-by-country/.

228 European Commission, A hydrogen strategy for a climate-neutral Europe, 6.

229 "Path to Hydrogen Competitiveness: A Cost Perspective," 27.

References

Air bp. “What Is Sustainable Aviation Fuel (SAF) and Why Is It Important? | News and Views.” Air bp. Accessed January 6, 2022. https://www.bp.com/en/global/air-bp/news-and-views/views/what-is-sustainable-aviation-fuel-saf-and-why-is-it-important.html.

“Ammonia: Zero-Carbon Fertiliser, Fuel and Energy Store.” The Royal Society, February 2020. https://royalsociety.org/-/media/policy/projects/green-ammonia/green-ammonia-policy-briefing.pdf.

Andrey, Christopher, Paul Barberi, Luc van Nuffel, Frank Gérard, João Gorenstein Dedecca, Koen Rademaekers, Yacine El Idrissi, Morgan Crenes, and Luiza Lacombe. “Study on Energy Storage: Contribution to the Security of the Electricity Supply in Europe.” Publications Office of the European Union, 2020. https://data.europa.eu/doi/10.2833/077257.

Beukel, Jilles van den, and Lucia van Geuns. “Russia’s Unsustainable Business Model: Going All In on Oil and Gas.” HCSS Geo-Economics. The Hague Centre for Strategic Studies, January 2021. https://hcss.nl/sites/default/files/files/reports/Russias%20Unsustainable%20Business%20Model.pdf.

Biniek, Krysta, Kimberly Henderson, Matt Rogers, and Gregory Santoni. “Driving CO2 Emissions to Zero (and beyond) with Carbon Capture, Use, and Storage,” June 30, 2020. https://www.mckinsey.com/business-functions/sustainability/our-insights/driving-co2-emissions-to-zero-and-beyond-with-carbon-capture-use-and-storage.

Blue Corona Team. “The Basics of Industrial Recycling.” CleanUp News, March 25, 2021. https://www.cleanupnews.org/home/industrial-recycling-basics.

Bluesky Energy. “The Saltwater Battery.” BlueSky Energy I Stromspeicher Batterien. Accessed February 18, 2022. https://www.bluesky-energy.eu/en/saltwater_battery/.

Bundhun, Rebecca. “How India’s 2070 Net-Zero Ambitions Will Boost Green Energy Sector in the Country.” *The National News*, November 7, 2021, sec. Road to Net Zero. https://www.thenationalnews.com/business/energy/2021/11/07/how-indias-2070-net-zero-ambitions-will-boost-green-energy-sector-in-the-country/.

Businesswire. “Europe Industrial Waste Recycling and Services Market Report 2021-2025 - Growing Industrial Waste and Growing Investments in Smart Waste Recycling - ResearchAndMarkets.Com,” December 21, 2021. https://www.businesswire.com/news/home/20211221005563/en/Europe-Industrial-Waste-Recycling-and-Services-Market-Report-2021-2025---Growing-Industrial-Waste-and-Growing-Investments-in-Smart-Waste-Recycling---ResearchAndMarkets.com.

Calvo Ambel, Carlos. “How to Decarbonise European Transport by 2050,” November 27, 2018. https://www.transportenvironment.org/discover/how-decarbonise-european-transport-2050/.

Caspersen, Michael. “The Hydrogen Trajectory.” KPMG, March 2, 2021. https://home.kpmg/xx/en/home/insights/2020/11/the-hydrogen-trajectory.html.

CEFIC. “Circular Carbon.” Accessed February 4, 2022. https://cefic.org/a-solution-provider-for-sustainability/circular-carbon/.

Cerny, Ondrej, Frank Gerard, Simon Minett, and Shahane Bakhshyan. “Implications of the Energy Transition for the European Storage, Fuel Supply and Distribution Infrastructure.” Trinomics, 2021.

Circular Economy Guide. “Feedstock Recycling.” Circular Economy Guide. Accessed February 3, 2022. https://www.ceguide.org/Strategies-and-examples/Dispose/Feedstock-recycling.

“Decarbonised hydrogen imports into the European Union: challenges and opportunities,” October 2021. https://www.weltenergierat.de/publikationen/studien/hydrogen-imports-into-the-eu/.

"Decarbonising End-Use Sectors: Practical Insights on Green Hydrogen." IRENA Coalition for Action, May 2021. https://www.irena.org/publications/2021/May/Decarbonising-end-use-sectors-green-hydrogen.

"Decarbonization Pathways for the Indusrial Cluster of the Port of Rotterdam." Wuppertal Institut, 2016.

Deloitte. "Decarbonizing Aviation: Clear for Take-Off." Accessed December 14, 2021. https://www2.deloitte.com/xe/en/pages/energy-and-resources/articles/decarbonizing-aviation.html.

Detz, Remco, Sebastiaan Hers, Caroline Schipper, and Richard Westerga. "Ruimtelijke Effecten van de Energietransitie: Casus Haven Rotterdam." TNO & Smartport, September 2021.

"Directive (EU) 2018/ 2001 of the European Parliament and of the Council - of 11 December 2018 - on the Promotion of the Use of Energy from Renewable Sources." European Union, December 11, 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001.

EIA. "Annual Energy Outlook," 2021. https://www.eia.gov/outlooks/aeo/pdf/AEO_Narrative_2021.pdf.

———. "EIA Projects Renewables Share of U.S. Electricity Generation Mix Will Double by 2050 - Today in Energy - U.S. Energy Information Administration (EIA)," February 8, 2021. https://www.eia.gov/todayinenergy/detail.php?id=46676.

Eirik Woerness. "Energy Perspectives 2021." October 6, 2021. https://www.equinor.com/en/sustainability/energy-perspectives.html.

Elestor. "ELESTOR Enters Cooperation with Vopak for Scaling HBr Flow Battery Technology." Elestor, May 6, 2021. https://www.elestor.nl/elestor-enters-cooperation-with-vopak-for-scaling-hbr-flow-battery-technology/.

Enerdata. "The United Arab Emirates Targets Carbon Neutrality by 2050." Energdata, October 8, 2021. https://www.enerdata.net/publications/daily-energy-news/united-arab-emirates-targets-carbon-neutrality-2050.html.

EnergySage. "Saltwater Batteries: What You Need To Know | EnergySage." Solar News, April 9, 2020. https://news.energysage.com/saltwater-batteries-what-you-need-to-know/.

Entsog, Gas Infrastructure Europe, and Hydrogen Europe. "How to Transport and Store Hydrogen – Facts and Figures," n.d.

Environmental and Energy Study Institute. "Fact Sheet | Energy Storage (2019) | White Papers | EESI," February 22, 2019. https://www.eesi.org/papers/view/energy-storage-2019.

Equinor. "Energy Perspectives 2021 Long-Term Macro and Market Outlook," 2021. https://www.equinor.com/en/sustainability/energy-perspectives.html.

———. "Energy Perspectives 2021 Speakers Notes Erik Woerness Senior Vice President and Chief Economist," October 6, 2021. https://www.equinor.com/en/sustainability/energy-perspectives.html.

———. *Exploring an Uncertain Energy Future: Equinor Energy Perspectives 2021*, 2021. https://www.youtube.com/watch?v=YSd4kLpom38.

European Chemical Industry Council. "How Can Europe's Chemical Industry Help Deliver on the Green Deal?" cefic.org, April 28, 2021. https://cefic.org/policy-matters/chemical-industry-green-deal/how-can-europes-chemical-industry-help-deliver-on-the-green-deal/.

European Commission. "A Clean Planet for All A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy," November 28, 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0773.

———. "A European Green Deal," 2020. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

———. A hydrogen strategy for a climate-neutral Europe, Pub. L. No. COM/2020/301, COM(2020) 301 (2020). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301.

———. "Fit for 55": delivering the EU's 2030 Climate Target on the way to climate neutrality, COM(2021) 550 § (2021). https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0550&from=EN.

———. "Proposal for a Regulation on Ensuring a Level Playing Field for Sustainable Air Transport," July 14, 2021. https://ec.europa.eu/info/sites/default/files/refueleu_aviation_-_sustainable_aviation_fuels.pdf.

———. "Proposal for a Regulation on the Use of Renewable and Low-Carbon Fuels in Maritime Transport and Amending Directive 2009/16/EC." Brussels, July 14, 2021. https://ec.europa.eu/info/sites/default/files/fueleu_maritime_-_green_european_maritime_space.pdf.

———. "Reducing Emissions from the Shipping Sector." Accessed November 10, 2021. https://ec.europa.eu/clima/eu-action/transport-emissions/reducing-emissions-shipping-sector_en.

———. "Sustainable & Smart Mobility Strategy," September 12, 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789.

———. "Sustainable and Smart Mobility Strategy – Putting European Transport on Track for the Future," 2021. https://transport.ec.europa.eu/transport-themes/mobility-strategy_en.

European Commission. Directorate General for Agriculture and Rural Development. *EU Agricultural Outlook for Markets and Income 2020-2030.* LU: Publications Office, 2020. https://data.europa.eu/doi/10.2762/252413.

European Commission. Directorate-General for Energy. "Energy: Roadmap 2050." Publications Office, 2012. https://data.europa.eu/doi/10.2833/10759.

European Commission. "Press Conference on the REPowerEU Communication." Text, March 8, 2022. https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_22_1632.

European Parliament. "MEPs Demand Full Embargo on Russian Imports of Oil, Coal, Nuclear Fuel and Gas," July 4, 2022. https://www.europarl.europa.eu/news/en/press-room/20220401IPR26524/meps-demand-full-embargo-on-russian-imports-of-oil-coal-nuclear-fuel-and-gas.

Eurostat. "Oil and Petroleum Products - a Statistical Overview," August 2021. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Oil_and_petroleum_products_-_a_statistical_overview.

"FETSA." Accessed September 28, 2021. https://fetsa.eu/.

Fuels Europe. "Vision 2050: A Pathway for the Evolution of the Refining Industry and Liquid Fuels," 2018. https://www.fuelseurope.eu/wp-content/uploads/DEF_2018_V2050_Narratives_EN_digital.pdf.

Gandolfi, Alberto, Ajay Patel, Michele Della Vigna, Mafalda Pombeiro, and Mathieu Pidoux. "Green Hydrogen: The next Transformation Driver of the Utilities Industry," September 22, 2020. https://www.goldmansachs.com/insights/pages/gs-research/green-hydrogen/report.pdf.

Gerretsen, Isabelle. "Saudi Arabia Pledges Net Zero by 2060, but No Oil Exit Plan." *Climate Home News*, October 25, 2021, sec. Climate politics. https://www.climatechangenews.com/2021/10/25/saudi-pledges-net-zero-2060-no-oil-exit-plan/.

"Global Status of CCS 2021." Global CCS Institute, 2021. https://www.globalccsinstitute.com/wp-content/uploads/2021/11/Global-Status-of-CCS-2021-Global-CCS-Institute-1121.pdf.

Green Car Congress. "RaboResearch: EU Biofuel Demand to Halve by 2050." Green Car Congress, November 4, 2021. https://www.greencarcongress.com/2021/11/20211104-rabo.html.

Gross, Samantha. "The Challenge of Decarbonizing Heavy Industry." Brookings, June 24, 2021. https://www.brookings.edu/research/the-challenge-of-decarbonizing-heavy-industry/.

Hydrogeit. “LOHC – Hydrogen Transport Made Easy.” *H2-International* (blog), November 15, 2020. https://www.h2-international.com/2020/11/15/lohc-hydrogen-transport-made-easy/.

Hydrogen Council, and McKinsey & Company. “Hydrogen Inisghts - A Perspective on Hydrogen Investment, Market Development and Cost Competitiveness,” February 2021. https://hydrogen-council.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021-Report.pdf.

Hydrogenious - LOHC Technologies. “Hydrogen Stored as an Oil!” March 2020. https://www.hydrogen.energy.gov/pdfs/07-Schmidt-Liquid%20Organic%20Hydrogen%20Carriers.pdf.

IEA. “A New Era for CCUS – CCUS in Clean Energy Transitions – Analysis,” 2020. https://www.iea.org/reports/ccus-in-clean-energy-transitions/a-new-era-for-ccus.

———. “European Union 2020 - Energy Policy Review,” 2020. https://iea.blob.core.windows.net/assets/ec7cc7e5-f638-431b-ab6e-86f62aa5752b/European_Union_2020_Energy_Policy_Review.pdf.

———. “The Future of Hydrogen.” Technology report. Paris: IEA, 2019. https://www.iea.org/reports/the-future-of-hydrogen.

———. “The Future of Petrochemicals: Towards More Sustainable Plastics and Fertilisers.” Paris: IEA, 2018. https://iea.blob.core.windows.net/assets/bee4ef3a-8876-4566-98cf-7a130c013805/The_Future_of_Petrochemicals.pdf.

———. “World Energy Outlook 2021.” Paris: IEA, 2021. https://www.iea.org/reports/world-energy-outlook-2021.

IEA. “Energy Storage – Analysis,” November 2021. https://www.iea.org/reports/energy-storage.

IEA. “Final Energy Demand of Selected Heavy Industry Sectors by Fuel, 2019 – Charts – Data & Statistics,” September 19, 2020. https://www.iea.org/data-and-statistics/charts/final-energy-demand-of-selected-heavy-industry-sectors-by-fuel-2019.

IEA. “Global Hydrogen Review 2021 – Analysis.” Accessed November 8, 2021. https://www.iea.org/reports/global-hydrogen-review-2021.

IEA. “Hydrogen,” November 2021. https://www.iea.org/reports/hydrogen.

IEA. “Innovation in Batteries and Electricity Storage – Analysis.” Accessed November 10, 2021. https://www.iea.org/reports/innovation-in-batteries-and-electricity-storage.

IHS Markit. “Methanol Production Capacity May Quintuple on Decarbonized Industry Transformation: Study,” January 29, 2021. https://cleanenergynews.ihsmarkit.com/research-analysis/methanol-production-capacity-may-quintuple-on-decarbonized-ind.html.

International Energy Agency. “An Energy Sector Roadmap to Carbon Neutrality in China,” September 2021. https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf.

———. “India Energy Outlook 2021.” IEA, March 16, 2021. https://doi.org/10.1787/ec2fd78d-en.

———. “Net Zero by 2050 - A Roadmap for the Global Energy Sector,” May 2021. iea.li/nzeroadmap.

———. “Russia - Countries & Regions.” IEA, 2019. https://www.iea.org/countries/russia.

International Renewable Energy Agency. “Green Hydrogen Cost Reduction,” December 2020. https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction.

International Renewable Energy Agency, and Methanol Institute. “Innovation Outlook: Renewable Methanol,” 2021. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jan/IRENA_Innovation_Renewable_Methanol_2021.pdf.

IRENA. “Making the Breakthrough: Green Hydrogen Policies and Technology Costs,” 2021. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_Hydrogen_breakthrough_2021.pdf?la=en&hash=40FA5B8AD7AB1666EECBDE30EF458C45EE5A0AA6.

———. "Renewable Power Generation Costs in 2020." /publications/2021/Jun/Renewable-Power-Costs-in-2020, June 2021. https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020.

Joint Research Centre. "Assessment of Hydrogen Delivery Options." European Commission, 2021. https://ec.europa.eu/jrc/sites/default/files/jrc124206_assessment_of_hydrogen_delivery_options.pdf.

Krukowska, Ewa, and Alberto Nardelli. "Europe to Propose End of Combustion Engine Era in Green Overhaul," September 7, 2021. https://www.bloomberg.com/news/articles/2021-07-09/europe-to-propose-end-of-combustion-engine-era-in-green-overhaul.

Landstrand, Nils. "The Benefits of Methanol." MAN Energy Solutions. Accessed December 1, 2021. https://www.man-es.com/discover/the-benefits-of-methanol.

Lebling, Katie, Noah McQueen, Max Pisciotta, and Jennifer Wilcox. "Direct Air Capture: Resource Considerations and Costs for Carbon Removal." World Resource Institute, January 6, 2021. https://www.wri.org/insights/direct-air-capture-resource-considerations-and-costs-carbon-removal.

Madhu. "Difference Between Pyrolysis and Gasification." Compare the Difference Between Similar Terms, August 29, 2019. https://www.differencebetween.com/difference-between-pyrolysis-and-gasification/.

Malik Caline. "How Saudi Arabia, UAE can turn their decarbonization strengths to their advantage." *Arab News*, October 2, 2021. https://www.arabnews.jp/en/middle-east/article_56470/, https://www.arabnews.jp/en/middle-east/article_56470/.

Massachuchetts Government. "Advanced Biofuels." Accessed December 8, 2021. https://www.mass.gov/service-details/advanced-biofuels.

McKinsey & Company. "Europe's Path to Decarbonization." Accessed November 5, 2021. https://www.mckinsey.com/business-functions/sustainability/our-insights/how-the-european-union-could-achieve-net-zero-emissions-at-net-zero-cost.

Molloy, Patrick. "Run on Less with Hydrogen Fuel Cells." RMI, February 10, 2019. https://rmi.org/run-on-less-with-hydrogen-fuel-cells/.

Moores, Simon. "The Global Battery Arms Race: Lithium-Ion Battery Gigafactories and Their Supply Chain." The Oxford Institute for Energy Studies, 2021. https://www.oxfordenergy.org/wpcms/wp-content/uploads/2021/02/THE-GLOBAL-BATTERY-ARMS-RACE-LITHIUM-ION-BATTERY-GIGAFACTORIES-AND-THEIR-SUPPLY-CHAIN.pdf.

Nicosia, Rafiq Latta. "Qatar Petroleum Rebrands as QatarEnergy." Energy Intelligence, October 11, 2021. https://www.energyintel.com/0000017c-6fef-d080-a5fe-7fff20f30000.

Oliveira, Carina. "Technology Factsheet: Pyrolysis Oil Production from Plastic Waste." TNO, September 28, 2020. https://energy.nl/wp-content/uploads/2020/09/Pyrolysis-oil-production-from-plastic-waste_28-09-2020.pdf.

"Path to Hydrogen Competitiveness: A Cost Perspective." The Hydrogen Council, January 20, 2020. https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf.

Patonia, Aliaksei, and Rahmatallah Poudineh. "Ammonia as a Storage Solution for Future Decarbonized Energy Systems," November 2020. https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/11/Ammonia-as-a-storage-solution-for-future-decarbonized-systems-EL-42.pdf.

Patrahau, Irina, Michel Rademaker, Lucia Van Geuns, Sarah Ojukwu, and Philip Geurts. "European Tank Storage in Global Supply Chains: Outlook to 2030." The Hague Centre for Strategic Studies, 2022. https://hcss.nl/report/european-tank-storage-in-global-supply-chains-outlook-to-2030/.

Patrahau, Irina, Ankita Singhvi, Michel Rademaker, Hugo van Manen, René Kleijn, and Lucia van Geuns. "Securing Critical Materials for Critical Sectors: Policy Options for the Netherlands and the European Union." HCSS Geo-Economics. The Hague: The Hague Center for Strategic Studies, 2020.

Patrahau, Irina, Ankita Singhvi, Michel Rademaker, Hugo Van Manen, René Kleijn, and Lucia Van Geuns. "Securing Critical Materials for Critical Sectors Policy Options for the Netherlands and the European Union." The Hague Centre for Strategic Studies (HCSS), December 2020. https://hcss.nl/wp-content/uploads/2021/01/Securing-Critical-Materials-for-Critical-Sectors.pdf.

Potters, Ellie. "'Not Bonkers': Hydrogen Could Give US Nuclear Plants New Lease on Life." Accessed December 1, 2021. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/not-bonkers-hydrogen-could-give-us-nuclear-plants-new-lease-on-life-63423340.

Queensland Government. "Types of Battery Energy Storage | Battery Energy Storage." Text. corporateName=The State of Queensland; jurisdiction=Queensland. Accessed February 18, 2022. https://www.qld.gov.au/housing/buying-owning-home/energy-water-home/solar/battery-energy-storage/types-of-battery-energy-storage.

Reuters. "Russia Drafts New, More Ambitious Decarbonisation Strategy - Kommersant Newspaper." *Reuters*, October 7, 2021, sec. Environment. https://www.reuters.com/business/environment/russia-considering-more-ambitious-climate-targets-2021-10-06/.

Rivard, Etienne, Michel Trudeau, and Karim Zaghib. "Hydrogen Storage for Mobility: A Review." *Materials* 12, no. 12 (June 19, 2019). https://doi.org/10.3390/ma12121973.

Saba, Yousef, and Saeed Azhar. "Aramco Aims for Net Zero Emissions from Operations by 2050, CEO Says." *Reuters*, October 23, 2021, sec. COP26. https://www.reuters.com/business/cop/aramco-aims-net-zero-emissions-operations-by-2050-ceo-says-2021-10-23/.

Salas, Jaylene. "The Future of Carbon Capture." The Aspen Institute, October 9, 2020. https://www.aspeninstitute.org/blog-posts/the-future-of-carbon-capture/.

Service, Robert F. "New Generation of 'flow Batteries' Could Eventually Sustain a Grid Powered by the Sun and Wind." Science.org, October 31, 2018. https://www.science.org/content/article/new-generation-flow-batteries-could-eventually-sustain-grid-powered-sun-and-wind.

Shah, Raj. "Future Trends in Biofuel | Biofuels International Magazine." Biofuel News, March 10, 2021. https://biofuels-news.com/news/future-trends-in-biofuel/.

Simon, Nina, Mike McCurdy, and Heidi Larson. "Examining the Current and Future Economics of Hydrogen Energy." ICF, August 13, 2021. https://www.icf.com/insights/energy/economics-hydrogen-energy.

Statista. "Europe: Hydrogen Underground Storage Capacity by Country." Accessed November 23, 2021. https://www.statista.com/statistics/1267919/potential-hydrogen-storage-capacity-in-europe-by-country/.

"The European Strategy Is Undisputedly Green," January 15, 2021. https://www.enel.com/company/stories/articles/2021/01/europe-renewable-hydrogen.

The White House. "FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies." The White House, April 22, 2021. https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/.

TNO. "Blue Hydrogen Paves the Way for Green Hydrogen." Accessed November 22, 2021. https://www.tno.nl/en/focus-areas/energy-transition/roadmaps/towards-co2-neutral-industry/hydrogen-for-a-sustainable-energy-supply/blue-hydrogen-paves-the-way-for-green-hydrogen/.

Tullo, Alexander H. “Is Ammonia the Fuel of the Future? Industry Prepares Ammonia for a Second Life as a Fuel for the Future.” Chemical & Engineering News, August 3, 2021. https://cen.acs.org/business/petrochemicals/ammonia-fuel-future/99/i8.

Umicore. “LOHC Technology.” Accessed December 2, 2021. https://www.umicore.com/en/newsroom/news/lohc-technology/.

“Utility-Scale Batteries – Innovation Landscape Brief.” IRENA, 2019. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Utility-scale-batteries_2019.pdf.

UTV Independent Tank Farm Association. “E-Fuels and Biofuels :: UTV - Independent Tank Storage Association.” Accessed December 8, 2021. https://www.tanklagerverband.de/themen/e-fuels-und-biofuels.

Van den Beukel, Jilles, Lucia Van Geuns, Irina Patrahau, and Michel Rademaker. “The European Tank Storage Sector and the Global Energy Landscape.” HCSS, 2021.

Vass, Tiffany, Peter Levi, Alexandre Gouy, and Hana Mandová. “Chemicals - Fuels & Technologies.” IEA, November 2021. https://www.iea.org/fuels-and-technologies/chemicals.

———. “Tracking Industry 2021 – Analysis.” IEA, November 2021. https://www.iea.org/reports/tracking-industry-2021.

Weichenhain, Uwe. “Transporting the Fuel of the Future.” Roland Berger, April 11, 2021. https://www.rolandberger.com/en/Insights/Publications/Transporting-the-fuel-of-the-future.html.

World Nuclear Association, Martin Kaltschmitt, and Matthias Finkbeiner. “Hydrogen Production and Uses,” September 2020. https://www.world-nuclear.org/information-library/energy-and-the-environment/hydrogen-production-and-uses.aspx.

Zaken, Ministerie van Algemene. “Offshore Wind Energy - Renewable Energy - Government.Nl.” Onderwerp. Ministerie van Algemene Zaken, July 26, 2017. https://www.government.nl/topics/renewable-energy/offshore-wind-energy.

The Hague Centre
for Strategic Studies

HCSS
Lange Voorhout 1
2514 EA Hague

Follow us on social media:
@hcssnl

The Hague Centre for Strategic Studies
Email: info@hcss.nl
Website: www.hcss.nl