European Commission

January 2021

Advanced Technologies for Industry – Product Watch

Synthetic fuels

This report was prepared by Alexander Schwarz and Sven Wydra (Fraunhofer ISI).

EUROPEAN COMMISSION

Executive Agency for Small and Medium-sized Enterprises (EASME)
Unit A.1.2 — COSME
E-mail: EASME-COSME-ENQUIRIES@ec.europa.eu

Directorate General for Internal Market, Industry, Entrepreneurship and SMEs
Unit F.1 — Industrial Strategy and Value Chains
Unit F.2 — Social Economy
E-mail: GROW-ATI@ec.europa.eu

European Commission
B-1049 Brussels

LEGAL NOTICE

Print	ISBN 978-92-9460-360-9	doi: 10.2826/812610	EA-04-20-717-EN-C
PDF	ISBN 978-92-9460-361-6	doi: 10.2826/588887	EA-04-20-717-EN-N

January 2021

Section 1

Section 2

Section 3

Section 4

Section 5

Section 1

1. Introduction

Background

The Product Watch Reports have been developed in the framework of the ‘Advanced Technologies for Industry’ project and serve to identify and analyse 15 promising advanced technology (AT)-based products and their value chains, with an assessment of the strengths and weaknesses of the EU positioning.

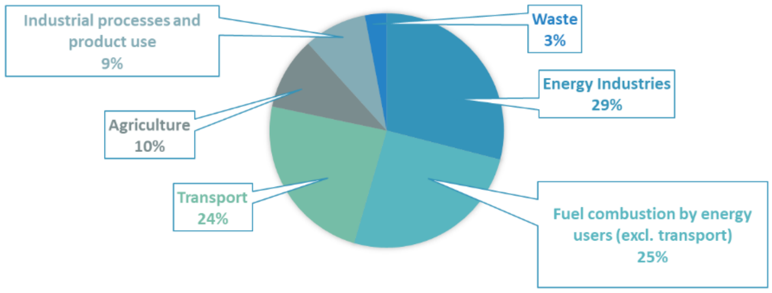
Promising AT-based products can be defined as “*enabling products for the development of goods and services enhancing their overall commercial and social value; embedded by constituent parts that are based on AR/VR, Big Data & Analytics, Blockchain, Cloud, Artificial Intelligence, the Internet of Things (IoT), Mobility, Robotics, Security & Connectivity, Nanotechnology, Micro-nanoelectronics, Industrial Biotechnology, Advanced Materials and/or Photonics; and, but not limited to, produced by Advanced Manufacturing Technologies*”.

1.1. Background of this report

Product description

Climate change has become one of the most urgent global challenges[1] and as such it drives economic[2], public[3] and political agendas[4] alike. A significant part of climate gas emissions stems from our mobility regime, which is mainly based on the combustion of fossil-fuels such as gasoline or kerosene[5]. Within the European Union (EU), the transport sector accounted for almost $^{1}/_{4}$ of greenhouse gas emissions in 2017 as shown in Figure 1.

Figure 1: Share of EU greenhouse gas emissions by source in 2017



Source: Eurostat, 2020

Decarbonising transportation is hence considered crucial for a sustainability transition of the European wider energy system[6]. In addition to social innovations like bike friendly cities, various technology options like battery electric vehicles or new transport vehicle designs could contribute to the necessary

---

[1] United Nations. (n.d.). Climate Change. Retrieved April 2020, from: https://www.un.org/en/sections/issues-depth/climate-change/. United Nations. (n.d.). Goal 13: Take urgent action to combat climate change and its impacts. Retrieved April 2020, from: https://www.un.org/sustainabledevelopment/climate-change/.

[2] McKinsey Global Institute. (2020). Climate risk and response: Physical hazards and socioeconomic impacts.

[3] Fridays For Future. (n.d.). Map of Climate Striking and Actions. Retrieved April 2020, from: https://fridaysforfuture.org/action-map/map/.

[4] UNFCCC. (2015). The Paris Agreement. Retrieved April 2020, from: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement. European Commission. (n.d.). A European Green Deal. Retrieved April 2020, from: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

[5] United States Environmental Protection Agency. (n.d.). Global Greenhouse Gas Emissions Data. Retrieved April 2020, from: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data.

[6] Fuel Cells and Hydrogen Joint Undertaking. (2019). Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition. Retrieved April 2020, from https://www.hydrogeneurope.eu/news/hydrogen-roadmap-europe-has-been-published.

transition. One particularly intuitive solution is the use of greener fuel types such as "synthetic fuels" (synfuels)[7].

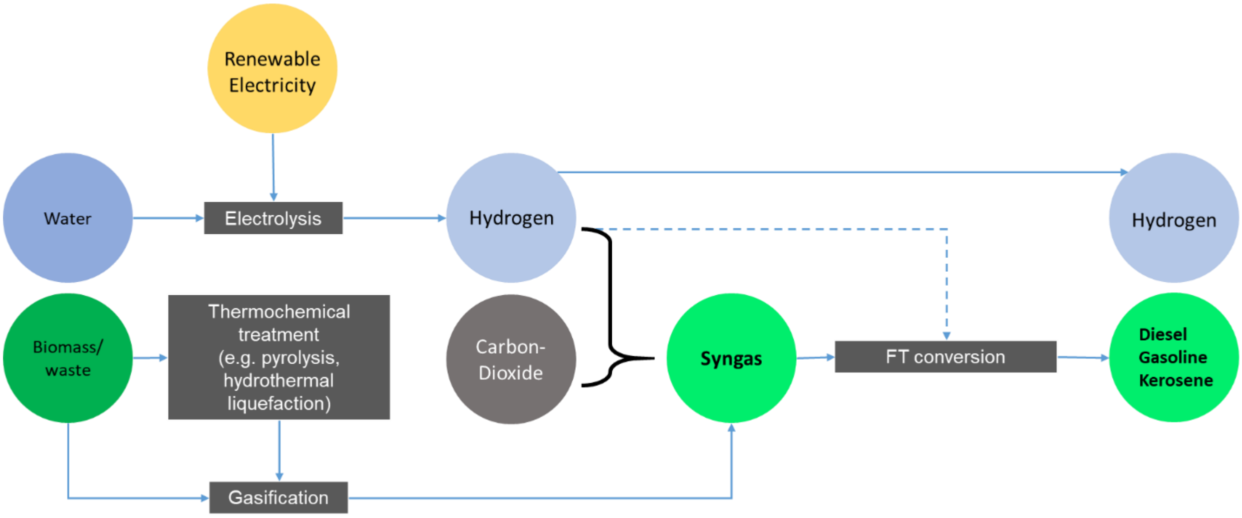
Among different synfuel types, hydrogen generated via electrolysis (PtG-hydrogen) from renewable energy (green hydrogen) seems a particularly promising solution, which has recently garnered political momentum at the EU[8] as well as at Member State level[9]. One of its key potentials is that it could contribute to a wider energy transition[10] by storing intermittent clean energy in chemical form and to thus integrating the different fields energy, heating, chemical production (as feedstock) and mobility (as fuel)[11]. Following the Hydrogen Roadmap Europe, the ambitious deployment of green and low-carbon hydrogen could translate into a €130 bn industry for EU fuel[12] and equipment companies by 2030 that could reach €820 bn by 2050. Moreover, net exports could amount to €50 bn[13].

Power-to-Liquid (PtL) fuels constitute another promising type of synfuels. PtL fuels derive from the reaction between hydrogen with carbon oxide during Fischer-Tropsch-Synthesis. PtL can thus be considered as a secondary product of green hydrogen. PtL fuels are drop-ins, i.e. substances chemically identical to fossil-based transport fuels like kerosene. They hence seem a way to store renewable hydrogen in a convenient liquid form.

In contrast to hydrogen and PtL, Biomass-to-Liquid (BtL) fuels make use of biological input, which is first gasified and subsequently converted into drop-ins via Fischer-Tropsch-Synthesis (like PtL fuels). Unlike bio-based alternatives such as Bio-Ethanol, thanks to their drop-in nature, BtL fuels do not require adaptation in motor technology.

These three synfuel types are technologically linked as shown in Figure 2.

Figure 2: Considered synfuel production pathways



Source: adapted from The Royal Society, 2019

PtL and BtL fuels are currently less of interest for research and industry than green hydrogen, judging by the available information. Nonetheless, for their drop-in qualities, BtL and PtL synfuels are especially considered as means to green airplanes or ships, which are hard to come by with hydrogen-based power trains. Moreover, the market volumes of their fossil-based counterparts suggest significant economic

---

[7] As there is no common understanding of the term, this report deals with three prominent alternatives.

[8] European Commission. (n.d.). Clean energy – an EU hydrogen strategy. Retrieved April 2020, from: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12407-A-EU-hydrogen-strategy.

[9] Bundesministerium für Wirtschaft und Energie. (2020). Die Nationale Wasserstoffstrategie. Retrieved on June 2020, from: https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/die-nationale-wasserstoffstrategie.html.

[10] This also applies to a wider geographic scope than the EU, since synfuels could constitute a means to store electricity produced under more economic conditions abroad and trade it with actors like the EU.

[11] Fuel Cells and Hydrogen Joint Undertaking. (2019). Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition. Retrieved April 2020, from https://www.hydrogeneurope.eu/news/hydrogen-roadmap-europe-has-been-published. International Renewable Energy Agency. (2018). Hydrogen from renewable power - Technology outlook for the energy transition.

12 Please note that it could also be the case that importing renewable energy into the EU, e.g. in the form of hydrogen or biomethane, would be economically more attractive than EU-internal production.

[13] Fuel Cells and Hydrogen Joint Undertaking. (2019). Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition. Retrieved April 2020, from https://www.hydrogeneurope.eu/news/hydrogen-roadmap-europe-has-been-published.

potential. For example, according to market research, the global market for kerosene amounted to about €254 to 295 bn in 2018 and is expected to grow annually around 5% in the coming years[14][15] .

1.2. Objectives of this report

Next to the adoption of sustainable social behaviour, the global mitigation of climate change calls for a timely adoption of innovative sustainable technologies. As it is a large climate gas source in the EU, to make the mobility sector more sustainable could significantly contribute to climate change abatement. Synthetic fuels could facilitate its greening.

This report therefore aims to provide an overview of relevant stakeholders with an analytical and empirical base to see how ATI based products can help EU industry to stay ahead of global competition. The objective is to map the EU synfuel industry and its interactions in the value chain, as well as to identify its strengths and weaknesses. Due to the difference between green hydrogen, PtL and BtL fuels regarding their current importance for research and industry, the report foregrounds hydrogen as the furthest developed option. Analyses are based on desk-research, the internal expertise of Fraunhofer ISI and on expert interviews.

---

[14] Values were converted from USD into EUR, using the European Commission's official monthly conversion rate for November 2020 ($ 1.0 = € 0.85441) as provided by European Commission. (2020c).

[15] Own calculations, based on:
Fortune Business Insights. (2019). Aviation Fuel Market Size Share and Industry Analysis By Fuel (Jet Fuel (Aviation Turbine Fuel), Avgas, Bio Jet Fuel), By End User (Commercial, Private, Military) And Regional Forecast 2019-2026, Retrieved April 2020, from: https://www.fortunebusinessinsights.com/industry-reports/aviation-fuel-market-100427.
Reports And Data. (2019). Aviation Kerosene Market, Share & Trends Analysis Report by Fuel Type (Jet A & Jet A1, Jet B), by Application (Commercial, Defense, General Aviation), by Region, Competitive Strategies and Segment Forecasts, 2016-2026, Retrieved April 2020, from: https://www.reportsanddata.com/report-detail/aviation-kerosene-market.
Quince Market Insights. (2019). Global Aviation Kerosene Market, By Type (Jet A, Jet A-1, Jet B, Others), By Application (Civil Aviation, Military Aviation), By Region (North America, Western Europe, Eastern Europe, Asia Pacific, Middle East, Rest of the World) – Market Size & Forecasting (2016-2028), Retrieved April 2020, from: https://www.quincemarketinsights.com/industry-analysis/aviation-kerosene-market/58716.

Section 2

2. Value chain analysis

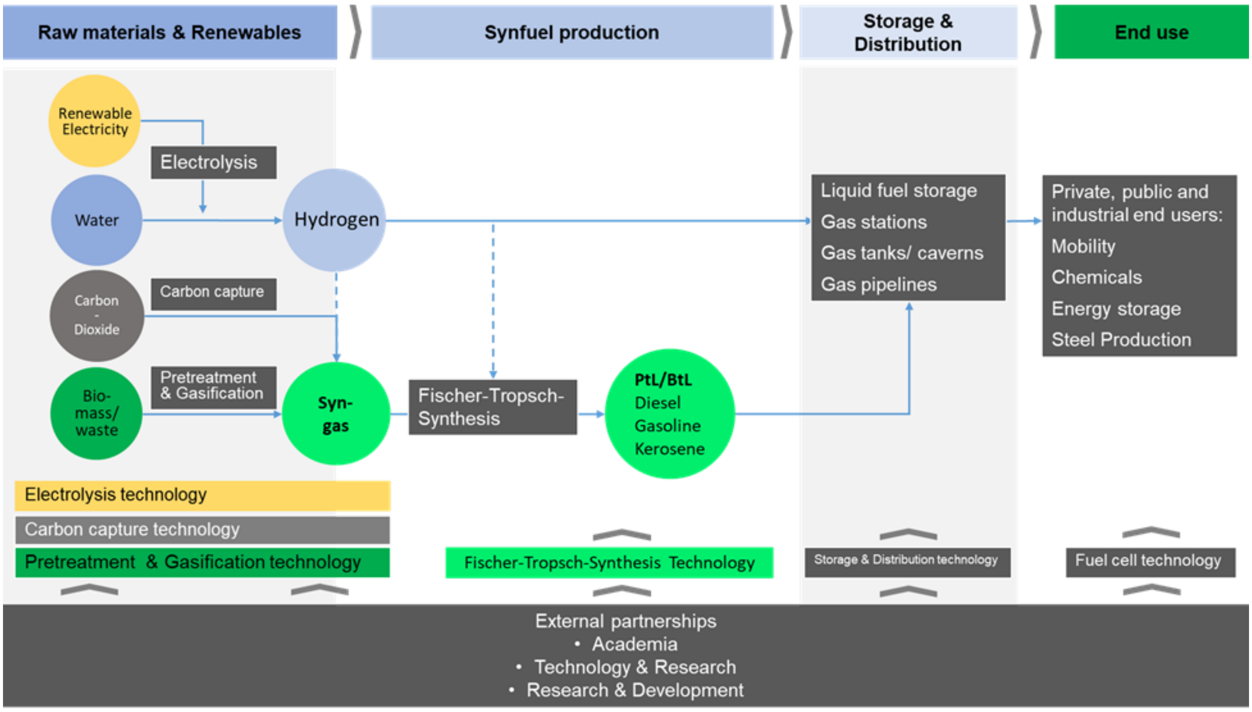
The following chapter explores the value chain of green hydrogen including the key actors and the current state of play of cross-chain linkages. In addition, it covers PtL and BtL synfuel application where data was available.

2.1 Value chain structure

The core of the EU hydrogen value chain is somewhat fragmented and consists mainly of relatively small organisations specialists either in final application assembly or in components, but rarely in both. It is global and expected to remain so. Europe seems to occupy a strong position, with almost 300 involved companies and more than 250 supporting knowledge-based actors being listed by the Fuel Cells and Hydrogen Joint Undertaking of the EU (FCH-JU) [16].

Figure 3 depicts the hydrogen value chain, which comprises four main elements: input provision, fuel production, storage and distribution and end use. Links to PtL and BtL synfuels are indicated.

Figure 3: Joint value chain for hydrogen, PtL and BtL synfuels



Source: Fraunhofer ISI; The Royal Society, 2019

Input provision. Clean energy is at the heart of green hydrogen production. Various EU businesses, among them large (fossil) energy incumbents such as German RWE[17], have started to engage in renewable energy production. To further convert hydrogen into PtL fuels requires the provision of gaseous carbon, which may stem from different sources like factory emissions absorbed via carbon capture and utilisation (CCU)[18]. Concerning BtL production, biomass is a core input, which may stem from different sources like agriculture or forestry.

---

[16] Fuel Cells and Hydrogen Joint Undertaking. (2018). Value added of the hydrogen and fuel cell sector in Europe. Retrieved April 2020, from: https://www.fch.europa.eu/page/FCH-value-chain.
A map of actors of the European hydrogen supply chain is accessible under: https://www.fch.europa.eu/page/FCH-value-chain

[17] RWE AG. (2019). Die neue RWE: klimaneutral bis 2040 und eines der global führenden Unternehmen bei Erneuerbaren Energien. Retrieved April 2020, from: https://www.group.rwe/presse/rwe-ag/2019-09-30-die-neue-rwe.

[18] Viebahn et al. (2018).Freudendahl, D. (2016).

Synfuel production. In contrast to grey (from fossil fuels e.g. via steam methane reforming) and blue (from fossil resources combined with carbon capture and utilisation)[19], green hydrogen is produced from renewable energy-driven water electrolysis. In PtL and BtL production, Fischer-Tropsch-Synthesis is a core step.

Distribution. Unlike PtL or BtL fuels, which match established storage and distribution infrastructures, hydrogen requires different storage and distribution solutions, such as liquefaction, specialised storage vessels or (partly) dedicated gas grids.

End use. Whereas the end use for PtL and BtL fuels will mostly take place in the mobility sector, hydrogen may as well be used in additional sectors and for different applications, e.g. as feedstock for chemicals and steel, as a means to store energy, or as a synfuel or as precursor for PtL fuels . End users thus may be individual, public or industrial. Using hydrogen in mobility requires fuel cells as complementary technology, while PtL and BtL fuels can be readily used in combustion engines.

2.2 Key actors in the value chain

In this section, major European and non-European actors are highlighted for each chain step in non-exhaustive lists. Where data was available, potentially important stakeholders are mentioned regarding PtL and BtL fuels.

Hydrogen

Electrolysis technology. Green hydrogen is typically produced via electrolysis, which is why electrolysers are a key technology and a bottleneck in upscaling production. Electrolysis technology matured decades ago, and various alternative options exist today, which feature different maturities such as Atmospheric Alkaline (high), Solid Oxide (low) or Proton Exchange Membrane (PEM) (high). Alternative hydrolysis concepts, which e.g. use photo- or thermochemical routes remain in a nascent state. PEM electrolysers largely constitute the most developed option. Table 1 provides a non-exhaustive illustration of important electrolyser manufacturers.

Currently, providers of electrolysis technology like McPhy Energy, ThyssenKrupp or Nel Hydrogen as well as manufacturers of technical gases like Linde and Air Liquide appear among the prime producers of green hydrogen. Some actors are active in several stages of the value chain, e.g. Nel and Hydrogenics also offer electrolysers as well as refuelling equipment. Although large oil incumbents like BP, Shell or Total and energy suppliers such as RWE, Vattenfall or E.ON seem to show interest in the technology and engage in experiments, they have not yet entered hydrogen production on a large scale and may act more as integrators.

Table 1: Electrolyser manufacturers[20]

Company	Headquarters	Related products	Website
Areva H_2Gen	Germany	Electrolysers	https://www.arevah2gen.com/de/
Enapter	Italy	Electrolysers	https://www.enapter.com/
Erre Due	Italy	Electrolysers	https://www.erreduegas.it/en/
Giner	United States of America	Electrolysers Fuel Cells	https://www.ginerinc.com/
Green Hydrogen	Denmark	Electrolysers	https://greenhydrogen.dk/
Hitachi Zosen	Japan	Hydrogen generators	https://www.hitachizosen.co.jp/english/index.html
Hydrogenics	Canada	Electrolysers Hydrogen refuelling Fuel cells	https://www.hydrogenics.com/
ITM Power	United Kingdom	Electrolysers	https://www.itm-power.com/

---

[19] International Renewable Energy Agency. (2019). Hydrogen: A renewable energy perspective.

[20] Companies that are also active in other steps of the green hydrogen value chain are only mentioned once.

Company	Headquarters	Related products	Website
MAN Energy Solutions	Germany	Power-to-Gas plants	https://www.man-es.com/
McPhy Energy	France	Electrolysers Storage solutions Hydrogen stations	https://mcphy.com/en/
Mitsubishi Power	Japan	Energy Storage Systems	https://power.mhi.com
Nel Hydrogen	Norway	Electrolysers Hydrogen fuelling equipment	https://nelhydrogen.com/
Proton on Site	United States of America	Hydrogen generators	https://www.protononsite.com/
Siemens	Germany	Electrolysers	https://new.siemens.com/de/de.html
Sun Hydrogen	United States of America	Electrolysers	https://sunhydrogen.com
Teledyne Energy Systems	United States of America	Electrolysers Fuel cells	http://www.teledynees.com/
ThyssenKrupp	Germany	Electrolysis plants	https://www.thyssenkrupp.com/

Source: Frost & Sullivan, 2018; Markets and Markets, 2019a; Market Research Future, 2020b; Persistence Market Research, 2020

Storage & Distribution technology. Storage and distribution solutions may vary in dependence on the given infrastructure and the amount of produced hydrogen. As hydrogen can be injected into existing natural gas grids in low amounts e.g. storage considerations would be less pronounced in case of low or medium quantities and direct consumption. Likewise, available natural storage capacities like underground caverns imply less need for artificial storage devices. Conversely, on-site production and consumption at fuel stations could require dedicated technical storage. Today physical storage, hydrogen compression or liquefaction, is technologically mature and deployed for industrial applications, in contrast to chemical storage methods like metal hydrides. Table 2 provides a non-exhaustive list of relevant companies that provide hydrogen storage solutions.

Table 2: Storage and distribution solution providers

Company	Headquarters	Related products	Website
Air Liquide	France	Technical gases	https://www.airliquide.com
HBank Technologies	Taiwan	Hydrogen storage solutions	http://www.hbank.com.tw/
Hexagon composites	Norway	Hydrogen storage tanks	https://www.hexagongroup.com/
INOXCVA	India	Gas transportation, storage, and distribution solutions	http://www.inoxcva.com/
Linde	Germany	Technical gases Industrial engineering	https://www.linde.de/de/
Praxair	United States of America	Technical gases	merged with Linde

Company	Headquarters	Related products	Website
VRV[21]	United States of America	Hydrogen storage solutions	https://www.vrv.com/
Worthington Industries	United States of America	Gas cylinders	https://worthingtonindustries.com/Home

Source: Global Market Insights, n.d.; Grand View Research, 2016b; Markets and Markets, 2019b; Markets and Markets, 2017

Fuel cell technology. While hydrogen can be utilised for heating or as feedstock without notable technological adaptation using it in the mobility requires a switch from combustion engines to fuel cells. Thus, fuel cells are a core complementary technology. Table 3 provides a non-exhaustively lists notable fuel cell manufacturers.

Table 3: Fuel cell manufacturers

Company	Headquarters	Related products	Website
Ballard Power Systems	Canada	Fuel cells	https://www.ballard.com/
FuelCell Energy	United States of America	Fuel cells	https://www.fuelcellenergy.com/
Nedstack	The Netherlands	Fuel cells	https://nedstack.com/en
Plug Power	United States of America	Fuel cells Refuelling solution	https://www.plugpower.com/
Power Cell	Sweden	Fuel cells	https://www.powercell.se/en
SFC Energy	Germany	Fuel cells	https://www.sfc.com/

Source: Grand View Research, 2020; Mordor Intelligence, n.d.a; Mordor Intelligence, n.d.b

Fuel cell and hydrogen research. The FCH-JU joins stakeholders along the value chain. The public private partnership between the European Commission and Hydrogen Europe (Research) features about 240 members from industry and research[22]. The FCH-JU aims "to demonstrate by 2020 fuel cell and hydrogen technologies as one of the pillars of future European energy and transport systems, making a valued contribution to the transformation to a low carbon economy by 2050"[23]. FCH-JU funds research, development and demonstration. From 2014 to 2020 it has a budget of €1.33 bn. A second phase, which inter alia aims at technology upscaling and market entry, is planned to last until the end of 2024.

PtL and BtL specifics

Carbon capture and utilisation technology and research. As stated above PtL production from green hydrogen requires the addition of gaseous carbon like carbon dioxide. Therefore, PtL fuels constitute a subclass of CCU. However, although carbon capture technologies vary between low to high technological maturity[24] they have not yet been widely deployed[25]. Moreover, although some actors engage in CCU many of them seemingly pursue approaches different from the above-devised. That is, instead of Fischer-Tropsch-PtL fuels, respective actors aim to produce e.g. chemical compounds like Dutch Photanol, construction materials like Belgian Recoval, or gas like German Electrochea. Likewise research does not seem specifically targeted at PtL but rather at a broad range of ways to utilise carbon. Table 4 provides a non-exhaustively lists of actors and networks which deal with CCU.

---

[21] Acquired by Chart industries in 2018.

[22] Hydrogen Europe Industry. (n.d.). Member directory. Retrieved April 2020, from: https://www.hydrogeneurope.eu/directory/Research.

[23] Fuel Cells and Hydrogen Joint Undertaking. (n.d.). FCH JU Projects. Retrieved April 2020, from: https://www.fch.europa.eu/page/fch-ju-projects.

[24] Bui et al., 2018.

[25] Freudendahl, 2016.

Table 4: CCU related actors and networks

Initiative	Headquarters/ involved countries	Short description	Website
Aker Solutions/ **Aker Carbon Capture**	Norway	Carbon Capture technology	https://www.akersolutions.com/
Carbon Recycling International (CRI)	Iceland	Methanol	https://www.carbonrecycling.is/
European Carbon Dioxide Capture and Storage Laboratory Infrastructure	Europe	Permanent pan-European distributed research infrastructure (5 operations centres in France, Italy, the Netherlands, UK and Norway). Objective: to enable low to zero CO2-emissions from industry and power generation to combat climate change.	https://www.eccsel.org/about/eccsel-eric/mission/
Fluor Corporation	United States of America	Carbon Capture technology	https://www.fluor.com/
Linde	Germany	Carbon Capture technology	https://www.linde.de/de/
Mineral Carbonation International	Australia	Cement and others	https://www.mineralcarbonation.com
Phoenix Initiative	Flanders France Germany The Netherlands	Umbrella initiative linking national and European RD&I activities with respect to CO2 valorisation, jointly supported by Flanders, France, Germany, the Netherlands, and the European Chemical Industry Council.	https://www.phoenix-co2-valorisation.eu/
The P2X Kopernikus project	Germany	Power-to-X (chemicals, gas, liquids)	https://www.kopernikus-projekte.de/en/projects/p2x/ptx_industrial_plants

Source: Dechema, 2020; Fraunhofer ISI; Fortune Business Insights, 2020; Grand View Research, 2016a; Market Research Future, 2020a; Markets and Markets, 2020

PtL producers and research. Due to its link with the hydrogen value chain, the aforementioned actors can also be considered important for the PtL value chain. Moreover, Original Equipment Manufacturers like Audi and large oil companies like Aral also partially engage in PtL. At large, however, there seems to be less market interest on the European level than is the case regarding H2 or BtL. For example, the think tank *CO_2 Value Europe* covers the topic on the European level, but only among other topics[26]. Likewise, EU PtL research would not feature a counterpart to the FCH-JU. Eventually, no company could be identified that would only specialise in PtL as defined initially. Table 5 provides a non-exhaustive list of companies that could prove relevant for PtL production.

Table 5: Companies potentially important for PtL production

Company	Headquarters	Link to PtL	Website
Sunfire	Germany	(Co)electrolysers to produce H2 and syngas	https://www.sunfire.de/de/
NewCO2Fuels	Israel	Technology platform to produce syngas	http://www.newco2fuels.co.il/
LanzaTech	United States of America	Technology platform to recycle carbon	https://www.lanzatech.com/
Royal Dutch Shell	United Kingdom The Netherlands	Fischer-Tropsch-Synthesis	https://www.shell.com/

Source: Viebahn et al., 2018

BtL producers and research. There is only limited economic activity regarding BtL fuels. Globally, only Red Rock Biofuels and Sundrop fuels could be identified as potentially important[27]. Regarding research in the EU, a Technology and Innovation Platforms (ETIP) exists, which explores BtL production among others. ETIPs are considered core industry-led communities to develop and implement the research and innovation priorities of the European Strategic Energy Technology Plan, aiming to facilitate the realisation of low-carbon energy technology innovation[28].

2.3 Linkages along the value chain

Due to the emergent state of synfuel technologies, value chain links exist but seem rather loose at some points. Yet, cooperation between different companies seems to work at large. Judging by the existence of joint initiatives and similar, the hydrogen chain features many links which mirrors in cooperation like the FCH-JU on the EU level, H2 Mobility in Germany or the HySetCo project in France. Some companies operate on several parts of the chain like McPhy Energy (electrolysis, storage) and Nel Hydrogen (electrolysers, fuelling equipment). Regarding BtL fuels, the ETIP Bioenergy seems to indicate cooperation. Concerning PtL biofuels no dedicated joint cooperation activity was found, albeit individual actors like the German Deutsche Energie-Agentur argue for a cross-industry platform[29]. Beyond that one can expect large incumbents from the energy (e.g. Aral) or adjacent industries (e.g. Audi, Daimler) to engage in synfuel chains. Yet some incumbents may find it difficult to fully commit to synfuels given e.g. lacking political de-risking or the lacking economic competitiveness of synfuels.

---

[26] CO2 Value Europe. (n.d.). About us. Retrieved August 2020, from: https://www.co2value.eu/about/.

[27] Frost & Sullivan. (2015). Technologies Enabling Biomass-To-Bioenergy (TechVision).

[28] ETIP Bioenergy. (n.d.). ETPs and ETIPs - an overview. Retrieved July 2020, from: https://www.etipbioenergy.eu/supporting-initiatives-and-platforms/related-european-technology-platforms-and-jtis/etp-overview.

[29] Deutsche Energie-Agentur. (2017). E-Fuels sind notwendig, um EU-Klimaschutzziele des Verkehrssektors zu erreichen. Retrieved April 2020, from: https://www.dena.de/newsroom/meldungen/2017/e-fuels-sind-notwendig-um-eu-klimaschutzziele-des-verkehrssektors-zu-erreichen/.

Section 3

3. Analysis of EU competitive positioning

Figure 4 provides an overview of these key strengths, opportunities, challenges and risks for the synfuel value chain. BtL and PtL-specific aspects are highlighted in cursive.

Figure 4: Strengths, opportunities, challenges and risks for the synfuel value chain

Strengths
- Industrial basis
- Strong technological competences
- *Drop-in nature*
- *Reliance on established technologies*

Challenges
- Cost competitiveness to fossil-based products
- Upscaling and production capacities

Opportunities
- Improved sustainability
- Natural feedstock limitations
- Increased product range

Risks
- International competition
- Unclear long-term consumer acceptance
- *Drop-ins may foster lock-ins*

Source: Fraunhofer ISI

The further analysis focuses on green hydrogen. Due to their complementarity PtL can be expected to share the basic issues of hydrogen.

3.1 Strengths

Sustainability gains. Green hydrogen bears the potential to significantly increase the sustainability of the EU. Since it is produced from renewable energies it could be considered carbon-neutral[30]. Similarly, combusting hydrogen yields energy and water instead of climate gas. Beyond this, hydrogen could help storing intermittent renewable energies thus allowing to smoothen energy supply over longer periods of time as well as between regions with abundant renewable supply and areas with major energy demand[31]. Moreover, it might help to integrate different sectors as shown in Figure 2, thus reaching even those where de-fossilisation is hard to reach by electrification like long haul transportation or chemical production. The Hydrogen Roadmap Europe states that ambitious deployment of green and low carbon hydrogen could help reducing about 560 Mt of CO_2 emissions by 2050[32].

Technological readiness and R&D capabilities. Relevant technologies for the production, storage and distribution of green hydrogen like PEM or hydrogen liquefaction or distribution are largely mature and work reliably. What is more, the EU features competent research institutions and well-developed R&D and deployment schemes at various regional levels. Likewise, there are notable R&D activities throughout the EU such as those funded by the Fuel Cells and Hydrogen Joint Undertaking[33].

Company experience and excellence. The EU harbours relevant companies regarding the production, storage and distribution of green hydrogen. As stated above, research on the EU hydrogen supply chain identified around 300 actors engaged in the investigated chain steps alone[34]. EU companies are considered to feature particular experience excellence in mechanical and plant engineering and some EU enterprises already operate hydrogen distribution assets at industrial scale such as e.g. hydrogen pipelines to serve industrial customers.

---

[30] Office of Energy Efficiency and Renewable Energy. (n.d.). Hydrogen Production: Electrolysis. https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis

[31] Fuel Cells and Hydrogen Joint Undertaking. (n.d.). FCH JU Projects. Retrieved April 2020, from: https://www.fch.europa.eu/page/fch-ju-projects.

[32] Fuel Cells and Hydrogen Joint Undertaking. (2019). Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition. Retrieved April 2020, from: https://www.hydrogeneurope.eu/news/hydrogen-roadmap-europe-has-been-published. International Renewable Energy Agency. (2018). Hydrogen from renewable power - Technology outlook for the energy transition.

[33] Fuel Cells and Hydrogen Joint Undertaking. (n.d.). FCH JU Projects. Retrieved April 2020, from: https://www.fch.europa.eu/page/fch-ju-projects.

[34] Fuel Cells and Hydrogen Joint Undertaking. (2018). Value added of the hydrogen and fuel cell sector in Europe. Retrieved April 2020, from: https://www.fch.europa.eu/page/FCH-value-chain.

Committed institutional framework. The EU has various dedicated energy-related strategies, like the Energy Union strategy, the Energy Roadmap, the European Green Deal or the European Hydrogen Strategy[35]. Moreover, the FCH-JU aims to directly support the development of the EU (green) hydrogen sector. In addition, individual Member States feature national initiatives of varying extents such as:

- France: Hydrogen Deployment Plan for Energy Transition[36]
- Germany: National hydrogen strategy, National Innovation Programme Hydrogen and Fuel Cell Technology, Hydrogen Power Storage & Solutions East Germany[37]
- Spain: National Policy Framework to support the deployment of hydrogen in transport[38]
- The Netherlands: Government Strategy on Hydrogen[39]

Infrastructures. Throughout the EU, (natural) gas infrastructures with high transmission, distribution or storage capacities exist, which can at least partially be used for hydrogen. Moreover, a hydrogen value chain might use infrastructures currently used for fossil fuels. For instance, oil and gas platform pipelines could be repurposed to transport hydrogen produced by large offshore wind generators to the land. Beyond that, a European network of hydrogen refuelling stations is planned[40], which could lay the basis for larger fuel cell mobility applications and thus trigger hydrogen production.

3.2 Opportunities

The expansion of renewable energies. Most of the renewable energy within the EU stems from intermittent sources like wind and photovoltaic. Therefore, the EU increasingly requires large, flexible, mid- to long-term (seasonal) energy storage technologies such as green hydrogen. Consequently, an increasing systemic pervasion of renewable energies as well as the decentralisation of their production could benefit the development of green hydrogen technologies.

Sector integration. Integration efforts for different sectors like chemicals or heating would expand the potential hydrogen market. Apart from that, complementarities between green hydrogen and other industries are not yet fully harnessed. For example, in addition to hydrogen, electrolysis yields high-grade O2, which could be used for industrial purposes like oxy-fuels. Similarly, a stronger crossover between green hydrogen and fuel cell manufacturing could decrease production costs, e.g. for PEM.

Political momentum. As mentioned initially, climate change has become one of the most urgent challenges for global societies and as such driving economic, public and political agendas. With its Green Deal, the EU provided a high-profile answer to tackle climate change. Moreover, the most recent plans of the EU Commission to provide impulses in response to the economic breakdown caused by Covid-19 include considerations to promote sustainable technologies[41].

3.3 Risks

Lacking clear regulatory framework. Realising the hydrogen economy requires significant up-front investment, not least due to the linked necessary mobility infrastructures such as hydrogen refuelling stations. Yet, as a coherent political design of the former does not fully exist yet, private actors may refrain from necessary investments due to high risks. In a similar vein, the coordination process among gas and electricity players is not yet complete and, there seem to be legal barriers, e.g. regarding standardisation or hydrogen transport.

Low economic competitiveness. Green hydrogen is said to lack economic competitiveness compared to conventional ways of hydrogen production like steam methane reforming. The market for green

---

[35] European Commission. (2020a). A hydrogen strategy for a climate-neutral Europe.

[36] Ministère de l'économie, des finances et de la relance. (2020). Stratégie nationale pour le développement de l'hydrogène décarboné en France. Retrieved November 2020, from: https://www.entreprises.gouv.fr/fr/actualites/industrie/politique-industrielle/strategie-nationale-pour-developpement-de-l-hydrogene.

[37] Bundesministerium für Bildung und Forschung. (n.d.). Nationale Wasserstoffstrategie. Retrieved November 2020, from: https://www.bmbf.de/de/nationale-wasserstoffstrategie-9916.html.
Projektträger Jülich. (n.d.). Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie (NIP). Retrieved November 2020, from: https://www.ptj.de/nip.
Hypos. (n.d.). Landing page. Retrieved November 2020, from: https://www.hypos-eastgermany.de/de/.

[38] HyLaw. (n.d.). Policy paper - Spain. Retrieved November 2020, from: https://www.hylaw.eu/info-centre.
Binnie. (2020).

[39] Government of the Netherlands. (2020). Government Strategy on Hydrogen. Retrieved November 2020 from : https://www.government.nl/binaries/government/documents/publications/2020/04/06/government-strategy-on-hydrogen/Hydrogen-Strategy-TheNetherlands.pdf.

[40] Hydrogen Mobility Europe. (n.d.). Landing page. Retrieved July 2020, from: https://h2me.eu/.
H2 MOBILITY Deutschland. (n.d.). Landing page. Retrieved July 2020, from: https://h2.live/.

[41] European Commission. (2020b). Europe's moment: Repair and prepare for the next generation. Retrieved June 2020, from: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_940.

hydrogen has remained small so far, which has prevented companies from realising scale economic effects. Likewise, some parts of the industry like electrolyser providers can be considered rather fragmented with little supply chain optimisation.

Technology optimisation and knowledge. Green hydrogen production largely relies on mature technologies. Yet, there is room for improvement. For example, further developments in solid electrolytes, stack sealing materials, compression or purification are needed. At large, the challenge remains to increase the energy efficiency of green hydrogen production while reducing capital and operating costs. Likewise using underground aquifers/empty gas fields for hydrogen storage remains challenging and more specific know-how like on electrochemical compression is not yet industrialised.

Weak access to infrastructures and resources. Although important infrastructure already exists, some challenges remain. For instance, existing hydrogen pipelines are privately owned, and not necessarily accessible to third parties. Moreover, massive underground storage is not possible everywhere as it depends on onsite geology considerations. What is more, some primary materials of the hydrogen value are sourced outside EU and/or are subject to local protectionism.

3.4 Challenges

Techno-economic insecurity. There is the risk that further R&D as well as upscaling will not bring down the production costs of green hydrogen as expected. Thus, it may remain less cost-competitive than fossil or alternative renewable fuels. In a similar vein, alternatives like batteries or smart grid technologies could develop faster, rendering hydrogen production a less interesting field of activity.

International competition. The EU faces strong international competition. Especially Asia (Japan, Korea, China) can be considered a key competitor. Some foreign markets like the Chinese tend to mature fast, thus e.g. facilitating technology development or the upscaling of the hydrogen economy. This rising competition bears the danger that the EU and European companies may fall behind their competitors if they do not manage to successfully scale up activities in time.

Infrastructure investment needed. Lacking upscaling constitutes a major weakness of the EU and the challenge to demonstrate at large scale the feasibility of hydrogen technologies remains. Especially hydrogen-based transportation would require ambitious upscaling in the form of infrastructure construction. While existing energy infrastructure should be used to its maximum potential, investments in new technology and infrastructures are also needed[42]. For example, the authors of the Hydrogen Roadmap Europe estimate the scale-up of the green and low carbon hydrogen industry to require about €8 bn of annual investments until 2030 in the case of ambitious targets[43].

---

[42] Masterplan for a Competitive Transformation of EU Energy-intensive Industries Enabling a Climate-neutral, Circular Economy by 2050 – Report (2019). Retrieved September 2020, from: https://ec.europa.eu/docsroom/documents/38403

[43] Fuel Cells and Hydrogen Joint Undertaking. (2019). Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition. Retrieved April 2020, from: https://www.hydrogeneurope.eu/news/hydrogen-roadmap-europe-has-been-published.

4. Conclusion & Outlook

4.1 Conclusion

Synfuels might help to increase the sustainability of the European economy. Concerning green hydrogen, the European industry seems in a promising starting position with dedicated research and development initiatives like the FCH-JU, political commitment[44] and many competent firms[45]. Moreover, actors can rely on largely proven technologies like PEM electrolysis. Nonetheless, the sector seems to remain in an emerging state with interlinked challenges that need to be addressed. Moreover, not least the significant international competition seems to increase overall urgency.

Providing long-term political clarity and leveraging political momentum. Policy makers and industry could contribute to ramping-up the hydrogen economy by devising dedicated long-term pathways to decarbonise all sectors. Such a step, including a clear political vision of the production and use of green hydrogen and a corresponding legal framework, may help to de-risk and therefore incentivise private economic investments. To start with, public procurement could favour fuel cell electric vehicles. The European Hydrogen Strategy, which was adopted in July 2020, and which lays out a strategic roadmap towards a hydrogen transition, could play a crucial role in this respect. What is more, the Covid-19 crisis could bring further momentum as green hydrogen may benefit from parts of the funds that aim to support the EU economy vis-a-vis the pandemic[46].

Increasing economic competitiveness. As already stated, green hydrogen lacks economic competitiveness. One possible remedy would be to increase the availability of renewable energy, the key input in hydrogen production. This could be done by expanding renewables or by reducing tariffs and levies on electricity. Similarly, regulators could exempt the use of electrolysers for balancing the energy grid from grid fees. Doing so might help rendering hydrogen cheaper and thus more competitive. Alternatively, market-based mechanisms that contribute to internalising the external cost of fossil technologies could raise the competitiveness of hydrogen. Beyond that, further research and development efforts could also support the development of the hydrogen value chain.

Enabling upscaling. As mentioned above, currently green hydrogen is not yet produced on industrial scale. However, upscaling would allow hydrogen actors to realise monetary and non-monetary scale effects, e.g. regarding fix costs or learning curves. Therefore, hydrogen production could become cheaper and more competitive. One way to support upscaling could be by providing tailored funding or to increase the growth of the green hydrogen market. This could be done. by creating complementary infrastructures like hydrogen refuelling stations to make mobility more convenient to customers and convince them of green hydrogen, thus increasing the market demand for hydrogen. Another important issue will be the location. Potential plants at reloading sites like ports or airports may provide logistic advantages and a starting point for subsequent processing to synfuels for aircraft or shipping.

Focus. Following the FHC-JU, a particular strength of the industry is the production of hydrogen and distribution equipment so that EU actors might achieve shares between 75 to 90% in domestic revenues as well as 25% in third countries[47]. These parts of the value chain could prove a promising focus.

Due to the close bond between hydrogen and PtL synfuels, it seems reasonable to assume that the abovementioned points largely apply to PtL too. One marked difference is that PtL (and BtL) fuels could benefit from their drop-in nature as they comply with existing infrastructures. They hence could become a promising means to green airplanes or ships, which are hard to come by with hydrogen-based power trains. Since PtL and BtL fuels technically compete for the same applications, their respective development may partly depend on the other.

---

[44] European Commission. (2019). Hydrogen. Retrieved April 2020, from: https://ec.europa.eu/energy/topics/energy-system-integration/hydrogen_en

[45] Fuel Cells and Hydrogen Joint Undertaking. (2018). Value added of the hydrogen and fuel cell sector in Europe. Retrieved April 2020, from: https://www.fch.europa.eu/page/FCH-value-chain.

[46] European Commission. (2020a). A hydrogen strategy for a climate-neutral Europe.

[47] Fuel Cells and Hydrogen Joint Undertaking. (2019). Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition. Retrieved April 2020, from https://www.hydrogeneurope.eu/news/hydrogen-roadmap-europe-has-been-published.

4.2 Outlook

Overall, synfuels seem an intuitive means to contribute to a sustainability transition of European mobility and thus the EU energy system. Green hydrogen, as the furthest developed of the considered synfuels, could particularly benefit from increasing public momentum, which may increase in the aftermath of Covid-19. Yet, the EU hydrogen economy still needs to address a variety of technological and non-technological challenges. The latter seem even larger for PtL or BtL fuels, which have not yet been commercialised on a notable scale.

Overall, it must be noted that any synfuel type is only a part of a larger systemic transition and should hence not be considered a silver bullet without context.

4.3 Covid-19 – impact on synfuels

It seems prudent to ask whether EU synfuel actors might be affected by the economic downturn caused by the pandemic as well.

According to Hydrogen Europe the European green hydrogen sector faces three potential key risks as a result of Covid-19:

1. Short-term liquidity shortages among small technology providers
2. Markedly decreasing investments by large companies
3. Dropping funding from investors

In addition to reasons like companies rethinking or abandoning clean tech investments or investors being less inclined to take the risk of financing the growth of the sector, Hydrogen Europe sees the danger of lasting low fossil fuel prices, which might decrease the competitiveness of green alternatives. Similarly, governments facing the challenge to restart their economies may either run out of financial resources or may be tempted to de-prioritise environmental policy altogether. It seems reasonable to assume that the above-said may apply to BtL and PtL fuels likewise. For instance, lastingly depressed demand for air travel or low kerosene prices may hamper efforts targeted at developing synthetic kerosene. For the moment, however, synfuel actors seem rather less affected by Covid-19, which might be partly attributed to the small production scale or their pre-commercial state respectively.

Nonetheless, the European Commission's current emphasis of the topics of climate and sustainability, e.g. via its European Green Deal, might indicate chances for synfuel technologies. Moreover, more recent statements by the EU Commission on how to allocate Covid-19 recovery assistance funds seem back up the interpretation that the pandemic may eventually facilitate a sustainability transition by prompting sustainable investments[48].

---

[48] European Commission. (2020b). Europe's moment: Repair and prepare for the next generation. Retrieved June 2020, from: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_940.
Simon. (2020). 'Do no harm': EU recovery fund has green strings attached. Retrieved June 2020, from: https://www.euractiv.com/section/energy-environment/news/do-no-harm-eu-recovery-fund-has-green-strings-attached/.

Section 5

5. Annexes

5.1 List of interviewees

Interviewee	Position
Werner Diwald	Secretary, Deutscher Wasserstoff- und Brennstoffzellen-Verband
Reinhardt Rauch	Professor, Engler-Bunte-Institute at the Karlsruhe Institute of Technology
Christian von Olshausen	Chief Technical Officer, sunfire GmbH

5.2 Bibliography

Binnie, Isla. (2020). Spain approves hydrogen strategy to spur low-carbon economy. Retreieved November 2020, from: https://www.reuters.com/article/us-spain-energy-hydrogen-idUSKBN26R2AF.

Bioökonomie.de. (2020). Pandemie als Chance für die Bioökonomie. Retrieved April 2020, from: https://biooekonomie.de/nachrichten/pandemie-als-chance-fuer-die-biooekonomie.

Bui, M.; Adjiman, C.; Bardow, A.; Anthony, E.; Boston, A.; Brown, S.; Fennell, P.; Fuss, S.; Galindo, A.; Hackett, L.; Hallett, J.; Herzog, H.; Jackson, G.; Kemper, J.; Krevor, S.; Maitland, G.; Matuszewski, M.; Metcalfe, I.; Petit, C.; Puxty, G.; Reimer, J.; Reiner, D.; Rubin, E.; Scott, S.; Shah, N.; Smit, B.; Trusler, J.; Webley, P.; Wilcox, J.; Mac Dowell, N. (2018). Carbon capture and storage (CCS): the way forward. In Energy & Environmental Science 11, pp. 1062-1176. DOI: 10.1039/c7ee02342a.

Bundesministerium für Bildung und Forschung. (n.d.). Nationale Wasserstoffstrategie. Retrieved November 2020, from: https://www.bmbf.de/de/nationale-wasserstoffstrategie-9916.html.

Bundesministerium für Wirtschaft und Energie. (2020). Die Nationale Wasserstoffstrategie. Retrieved June 2020, from: https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/die-nationale-wasserstoffstrategie.html.

Crowe, T. (2014). Synthetic Fuels: Investing Essentials. Retrieved April 2020, from: https://www.fool.com/investing/general/2014/08/05/synthetic-fuels-investing-essentials.aspx.

Dechema. (2020). DECHEMA’s erste virtuelle CO2-Weltreise – Fünf CCU-Anlagen, die man gesehen haben muss. Retrieved November 2020, from: https://nachrichten.idw-online.de/2020/07/22/dechemas-erste-virtuelle-co2-weltreise-fuenf-ccu-anlagen-die-man-gesehen-haben-muss/.

Deutsche Energie-Agentur. (2017). E-Fuels – The potential of electricity based fuels for low emission transport in the EU. Retrieved April 2020, from: https://www.dena.de/themen-projekte/projekte/mobilitaet/e-fuels-the-potential-of-electricity-based-fuels-for-low-emission-transport-in-the-eu/.

Deutsche Energie-Agentur. (2017). E-Fuels sind notwendig, um EU-Klimaschutzziele des Verkehrssektors zu erreichen. Retrieved April 2020, from: https://www.dena.de/newsroom/meldungen/2017/e-fuels-sind-notwendig-um-eu-klimaschutzziele-des-verkehrssektors-zu-erreichen/.

European Commission. (2020a). A hydrogen strategy for a climate-neutral Europe.

European Commission. (2020b). Europe's moment: Repair and prepare for the next generation. Retrieved June 2020, from: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_940.

European Commission. (2020c). Exchange rate (InforEuro). Retrieved March 2020, from: https://ec.europa.eu/info/funding-tenders/how-eu-funding-works/information-contractors-and-beneficiaries/exchange-rate-inforeuro_en.

European Commission. (2019). Hydrogen. Retrieved April 2020, from: https://ec.europa.eu/energy/topics/energy-system-integration/hydrogen_en.

European Commission. (n.d.). A European Green Deal. Retrieved April 2020, from: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

European Commission. (n.d.). Clean energy – an EU hydrogen strategy. Retrieved April 2020, from: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12407-A-EU-hydrogen-strategy.

Eurostat. (2020). Shedding light on energy in the EU. 2020 edition. Retrieved July 2020, from: https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-4a.html.

ETIP Bioenergy. (n.d.). ETPs and ETIPs - an overview. Retrieved July 2020, from: https://www.etipbioenergy.eu/supporting-initiatives-and-platforms/related-european-technology-platforms-and-jtis/etp-overview.

Fortune Business Insights. (2020). Carbon Capture and Sequestration Market Size, Share & COVID-19 Impact Analysis, By End Use (Enhanced Oil Recovery (EOR) and Dedicated Storage), By Capture Source (Chemicals, Natural Gas Processing, Power Generation, Fertilizers Production, and Others), and Regional

Forecast, 2020-2027. Retrieved November 2020, from: https://www.fortunebusinessinsights.com/industry-reports/carbon-capture-and-sequestration-market-100819.

Fortune Business Insights. (2019). Aviation Fuel Market Size, Share and Industry Analysis By Fuel (Jet Fuel (Aviation Turbine Fuel), Avgas, Bio Jet Fuel), By End User (Commercial, Private, Military) And Regional Forecast 2019-2026, Retrieved April 2020, from: https://www.fortunebusinessinsights.com/industry-reports/aviation-fuel-market-100427.

Freudendahl, D. (2016). Carbon Capture and Usage. Retrieved April 2020, from https://www.int.fraunhofer.de/content/dam/int/de/documents/EST/EST-1216-Carbon-Capture-and-Usage.pdf.

Frost & Sullivan. (2015). Technologies Enabling Biomass-To-Bioenergy (TechVision).

Frost & Sullivan. (2018). Innovations in Power-to-X Technology – Futuretech TechVision Opportunity Engine.

Fridays For Future. (n.d.). Map of Climate Striking and Actions. Retrieved April 2020, from: https://fridaysforfuture.org/action-map/map.

Global Market Insights. (n.d.). Hydrogen Storage Market Size, Industry Analysis Report, Regional Outlook, Application Development, Competitive Market Share and Forecast, 2020 - 2026. Retrieved April 2020, from: https://www.gminsights.com/industry-analysis/hydrogen-storage-market.

Government of the Netherlands. (2020). Government Strategy on Hydrogen. Retrieved November 2020 from : https://www.government.nl/binaries/government/documents/publications/2020/04/06/government-strategy-on-hydrogen/Hydrogen-Strategy-TheNetherlands.pdf.

Grand View Research. (2016a). Carbon Capture And Storage (CCS) Market Analysis By Application (EOR, Industrial & Agriculture), By Capture Technology (Pre-Combustion, Industrial, Oxy-Firing & Post-Combustion), Competitive Strategies, And Segment Forecasts, 2018 - 2025. Retrieved November 2020 from : https://www.grandviewresearch.com/industry-analysis/carbon-capture-storage-ccs-market.

Grand View Research. (2016b). Hydrogen Storage Market Size, Share & Trends Analysis Report By Type (Physical Based, Material Based), By Application (Stationary Power, Portable Power, Transportation), By Competitive Landscape, And Segment Forecasts, 2018 - 2025. Retrieved April 2020, from: https://www.grandviewresearch.com/industry-analysis/hydrogen-storage-market.

Grand View Research. (2020). Fuel Cells Market by Type (Proton Exchange Membrane Fuel Cell, Phosphoric Acid Fuel Cell, Alkaline Fuel Cell, Microbial Fuel Cell), Application (Transport, Stationary, Portable), End-User, Region - Global Forecast to 2024. Retrieved September 2020, from: https://www.marketsandmarkets.com/Market-Reports/fuel-cell-market-348.html.

H2 Mobility Deutschland. (n.d.). Landing page. Retrieved July 2020, from: https://h2.live/.

Hydrogen Europe Industry. (n.d.). Member directory. Retrieved April 2020, from https://www.hydrogeneurope.eu/directory/Research.

Hydrogen Mobility Europe. (n.d.). Landing page. Retrieved July 2020, from: https://h2me.eu/.

HyLaw. (n.d.). Policy paper - Spain. Retrieved November 2020, from: https://www.hylaw.eu/info-centre.

Hypos. (n.d.). Landing page. Retrieved November 2020, from: https://www.hypos-eastgermany.de/de/.

International Renewable Energy Agency. (2018). Hydrogen from renewable power - Technology outlook for the energy transition. Retrieved April 2020, from: https://irena.org/-/media/Files/IRENA/Agency/Publication/2018/Sep/IRENA_Hydrogen_from_renewable_power_2018.pdf.

International Renewable Energy Agency. (2019). Hydrogen: A renewable energy perspective. Retrieved April 2020, from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Hydrogen_2019.pdf.

McKinsey Global Institute. (2020). Climate risk and response: Physical hazards and socioeconomic impacts.

Market Research Future. (2020a). Global Carbon Capture and Storage (CCS) Market Research Report: Information by Technology (pre-combustion, post-combustion, oxy -fuel combustion), Applications (EOR, agriculture, industrial) End-Use (iron steel, oil & gas, chemical) and Region– Forecast till 2023. Retrieved November 2020, from: https://www.marketresearchfuture.com/reports/carbon-capture-storage-market-1862.

Market Research Future. (2020b). Global Water Electrolysis Market Research Report: Information by Product Category (Proton Exchange Membrane, Alkaline Water Electrolysis and Solid Oxide Electrolyte (SOE)), End Users (Chemicals, Electronics & Semiconductor, Power Plants, Petroleum, Pharmaceuticals and others) and Region (North America, Europe, Asia–Pacific and Rest of the World) - Forecast till 2025, Retrieved July 2020, from: https://www.Market Research Future.com/reports/water-electrolysis-market-4133.

Markets and Markets. (2020). Partnership was the key strategies adopted by the market players to maintain growth in the global Carbon Capture, Utilization, and Storage Market. Retrieved November 2020, from: https://www.marketsandmarkets.com/ResearchInsight/carbon-capture-utilization-storage-market.asp.

Markets and Markets. (2019a). Power-to-gas Market by technology (Electrolysis and Methanation), Capacity (Less than 100 kW, 100–999kW, 1000 kW and Above), End-User (Commercial, Utilities, and Industrial), and Region (North America, Europe, Asia Pacific) - Global Forecast to 2024, Retrieved April 2020, from: https://www.marketsandmarkets.com/Market-Reports/power-to-gas-market-200568452.html?gclid=EAIaIQobChMIt7a9xaD16gIVDOd3Ch2PJQyqEAAYASAAEgK2uPD_BwE.

Markets and Markets. (2019b). Hydrogen Energy Storage Market by State (Liquid, Gas, Solid), Storage Technology (Compression, Liquefaction, Material based), End-User (Industrial, Commercial, Utilities), and Region - Global Forecast to 2024. Retrieved April 2020, from: https://www.marketsandmarkets.com/Market-Reports/hydrogen-energy-storage-market-107179995.html.

Markets and Markets. (2019c). Fuel Cells Market by Type (Proton Exchange Membrane Fuel Cell, Phosphoric Acid Fuel Cell, Alkaline Fuel Cell, Microbial Fuel Cell), Application (Transport, Stationary, Portable), End-User, Region - Global Forecast to 2024. Retrieved September 2020, from: https://www.marketsandmarkets.com/Market-Reports/fuel-cell-market-348.html.

Markets and Markets. (2017). Hydrogen Storage Market by Storage Form (Physical, Material-Based), Type of Storage (Cylinder, Merchant, On-Site, & On-Board), Application (Chemicals, Oil Refining, Industrial, Transportation, Metal Working), and Region - Global Forecast to 2026. Retrieved April 2020, from: https://www.marketsandmarkets.com/Market-Reports/hydrogen-storage-market15698551.html?gclid=EAIaIQobChMIwuK9ytvs6AIVUuWaCh0yBQXPEAAYASAAEgLPDfD_BwE.

Masterplan for a Competitive Transformation of EU Energy-intensive Industries Enabling a Climate-neutral, Circular Economy by 2050 – Report (2019). Retrieved September 2020, from: https://ec.europa.eu/docsroom/documents/38403

Ministère de l'économie, des finances et de la relance. (2020). Stratégie nationale pour le développement de l'hydrogène décarboné en France. Retrieved November 2020, from: https://www.entreprises.gouv.fr/fr/actualites/industrie/politique-industrielle/strategie-nationale-pour-developpement-de-l-hydrogene.

Mordor Intelligence. (n.d.a). Fuel Cell Market - Growth, Trends and Forecast (2020 - 2025). Retrieved September 2020, from: https://www.mordorintelligence.com/industry-reports/global-fuel-cell-market-industry.

Mordor Intelligence. (n.d.b). Automotive Fuel Cell System Market - Growth, Trends, and Forecast (2020 - 2025). Retrieved September 2020, from: https://www.mordorintelligence.com/industry-reports/automotive-fuel-cell-market.

Office of Energy Efficiency and Renewable Energy. (n.d.). Hydrogen Production: Electrolysis. https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis.

Persistence Market Research. (2020). Hydrogen Electrolyzer Market: Global Industry Analysis and Forecast, Retrieved July 2020, from: 2016-2026 https://www.persistencemarketresearch.com/market-research/hydrogen-electrolyzer-market.asp.

Projektträger Jülich. (n.d.). Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie (NIP). Retrieved November 2020, from: https://www.ptj.de/nip.

Quince Market Insights. (2019). Global Aviation Kerosene Market, By Type (Jet A, Jet A-1, Jet B, Others), By Application (Civil Aviation, Military Aviation), By Region (North America, Western Europe, Eastern Europe, Asia Pacific, Middle East, Rest of the World) – Market Size & Forecasting (2016-2028), Retrieved April 2020, from: https://www.quincemarketinsights.com/industry-analysis/aviation-kerosene-market/58716.

Reports And Data. (2019). Aviation Kerosene Market, Share & Trends Analysis Report by Fuel Type (Jet A & Jet A1, Jet B), by Application (Commercial, Defense, General Aviation), by Region, Competitive Strategies and Segment Forecasts, 2016-2026, Retrieved April 2020, from: https://www.reportsanddata.com/report-detail/aviation-kerosene-market.

RWE AG. (2019). Die neue RWE: klimaneutral bis 2040 und eines der global führenden Unternehmen bei Erneuerbaren Energien. Retrieved April 2020, from: https://www.group.rwe/presse/rwe-ag/2019-09-30-die-neue-rwe.

Simon, F. (2020). 'Do no harm': EU recovery fund has green strings attached. Retrieved June 2020, from: https://www.euractiv.com/section/energy-environment/news/do-no-harm-eu-recovery-fund-has-green-strings-attached/.

Fuel Cells and Hydrogen Joint Undertaking. (2018). Value added of the hydrogen and fuel cell sector in Europe. Retrieved April 2020, from: https://www.fch.europa.eu/page/FCH-value-chain.

Fuel Cells and Hydrogen Joint Undertaking. (2019). Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition. Retrieved April 2020, from https://www.hydrogeneurope.eu/news/hydrogen-roadmap-europe-has-been-published.

Fuel Cells and Hydrogen Joint Undertaking. (n.d.). FCH JU Projects. Retrieved April 2020, from: https://www.fch.europa.eu/page/fch-ju-projects.

The Royal Society. (2019). Sustainable synthetic carbon based fuels for transport. Retrieved April 2020, from: https://royalsociety.org/-/media/policy/projects/synthetic-fuels/synthetic-fuels-briefing.pdf.

UNFCCC. (2015). The Paris Agreement. Retrieved April 2020, from: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

United Nations. (n.d.). Climate Change. Retrieved April 2020, from: https://www.un.org/en/sections/issues-depth/climate-change/.

United Nations. (n.d.). Goal 13: Take urgent action to combat climate change and its impacts. Retrieved April 2020, from: https://www.un.org/sustainabledevelopment/climate-change/.

United States Environmental Protection Agency. (n.d.). Global Greenhouse Gas Emissions Data. Retrieved April 2020, from: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data.

Viebahn, P, Zelt, O., Fischedick, M., Hildebrand, J., Heib, S., Becker, D., Horst, J., Wietschel, M., Hirzel, S., Neumann, S. (2018). Technologien für die Energiewende. Politikbericht an das Bundesministerium für Wirtschaft und Energie (BMWi). Wuppertal, Karlsruhe, Saarbrücken.

About the 'Advanced Technologies for Industry' project

The EU's industrial policy strategy promotes the creation of a competitive European industry. In order to properly support the implementation of policies and initiatives, a systematic monitoring of technological trends and reliable, up-to-date data on advanced technologies is needed. To this end, the *Advanced Technologies for Industry* (ATI) project has been set up. It provides policymakers, industry representatives and academia with:

- Statistical data on the production and use of advanced technologies including enabling conditions such as skills, investment or entrepreneurship;
- • Analytical reports such as on technological trends, sectoral insights and products;
- • Analyses of policy measures and policy tools related to the uptake of advanced technologies;
- • Analysis of technological trends in competing economies such as in the US, China or Japan;
- • Access to technology centres and innovation hubs across EU countries.

More information about the 16 technologies can be found at: https://ati.ec.europa.eu

The project is undertaken on behalf of the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the Executive Agency for Small and Medium-sized Enterprises (EASME) by IDC, Technopolis Group, Capgemini, Fraunhofer, IDEA Consult and NESTA.

EA-04-20-717-EN-N

Publications Office
of the European Union