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The key implications of EU legislation for establishing economically feasible Power-to-X fuel production

OTMU2501-3003 Ympäristöoikeus murroksissa

Master's Thesis

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23.9.2024

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Abstract

Master's thesis

Subject: Environmental Law
Author: Eeva Karvonen
Title: The key implications of EU legislation for establishing economically feasible Power-to-X fuel production
Supervisor: Aleksi Heinilä
Number of pages: 67 pages
Date: 23.9.2024

This thesis examines the implications of the European Union's legislative framework on establishing economically feasible and functional PtX fuel production. The principal EU acts studied in this thesis are the Renewable Energy Directive and its Delegated Acts, the Hydrogen and Gas market Package and the EU Emissions Trading System, which will be analysed using legal dogmatics and regulatory theory as the methods.

This thesis examines the regulatory framework concerning the production of renewable hydrogen and carbon dioxide, the principal raw materials of PtX fuels, and gives *de lege ferenda*-recommendations on how the legislation could be revised to better foster the ramp-up of production. The key issues of producing PtX fuels are that they are not cost competitive in comparison to traditional fossil fuels, and that the production of RFNBOs must fulfil strict requirements in order for them to be considered renewable in the context of the EU legislation.

This thesis examines the EU policies that are in place to create demand for PtX fuels, as well as the different support schemes such as the EU Hydrogen Bank, Modernisation Fund and the Horizon Europe, that aim to direct funds to green transition projects. This thesis also suggests widening the scope of the legislative framework from RFNBOs and strictly renewable hydrogen to facilitate the production and uptake of low-carbon hydrogen and fuels during the transitional period.

Key words: Power-to-X, PtX, renewable fuels of non-biological origin, RFNBO, the Renewable Energy Directive, the Hydrogen and Gas Market Package, Hydrogen, Carbon Dioxide

TURUN YLIOPISTO
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Tiivistelmäsivu

Tutkielma

Oppiaine: Ympäristöoikeus
Tekijä: Eeva Karvonen
Otsikko: The key implications of EU legislation for establishing economically feasible Power-to-X fuel production
Ohjaaja: Aleksi Heinilä
Sivumäärä: 67 sivua
Päivämäärä: 23.9.2024

Tässä tutkielmassa tarkastellaan Euroopan unionin sääntelykehikon vaikutuksia taloudellisesti toteuttamiskelpoiselle ja toimivalle PtX-polttoainetuotannolle. Tärkeimmät EU:n säädökset, joita tutkielmassa tarkastellaan, ovat uusiutuvan energian direktiivi III, uusiutuvan energian direktiivin delegoidut säädökset, vety- ja kaasumarkkinapaketti sekä EU:n päästökauppajärjestelmä, joita analysoidaan lainopin sekä ohjaus- ja arviointikeinotutkimuksellisten metodien avulla.

Tutkielmassa tarkastellaan uusiutuvan vedyn ja hiilidioksidin, PtX-polttoaineiden pääraaka-aineiden, valmistusta koskevaa sääntelykehystä ja annetaan *de lege ferenda*-suosituksia siitä, miten lainsäädäntöä voitaisiin muuttaa tuotannon käynnistämisen edistämiseksi. PtX-polttoaineiden valmistamisen keskeiset haasteet liittyvät ensinnäkin siihen, etteivät ne ole taloudellisesti kilpailukykyisiä perinteisiin fossiilisiin polttoaineisiin verrattuna, minkä lisäksi RFNBO-tuotannon on täytettävä tiukat vaatimukset, jotta niitä voidaan pitää EU-sääntelyn mukaan uusiutuvina.

Tässä tutkielmassa tarkastellaan EU:n sääntelykeinoja, joilla pyritään luomaan kysyntää PtX-polttoaineille, sekä erilaisia tukijärjestelmiä, joita ovat esim. Euroopan Investointipankin European Hydrogen Bank, Modernisation Fund ja Horizon Europe -ohjelmat, joilla pyritään ohjaamaan varoja vihreän siirtymän hankkeisiin. Tässä tutkielmassa ehdotetaan myös, että lainsäädäntökehyksen soveltamisalaa laajennetaan RFNBO:ista ja puhtaasti uusiutuvasta vedystä, jotta vähähiilisen vedyn ja polttoaineiden tuotantoa ja käyttöönottoa voitaisiin kannustaa siirtymäkauden aikana.

Avainsanat: Power-to-X, PtX, muuta kuin biologista alkuperää oleva polttoaine, RFNBO, Uusiutuvan Energian Direktiivi, vety- ja kaasumarkkinapaketti, vety, hiilidioksidi

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List of Abbreviations

BAT	Best Available Techniques
CCU	Carbon Capture and Utilisation
CCUS	Carbon Capture, Utilisation and Storage
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DA	Delegated Act
DAC	Direct Air Capture
EEA	European Environmental Agency
EIB	European Investment Bank
ESS	Energy Storage System
ETS	Emissions Trading System
GHG	Greenhouse Gas
ICAO	International Civil Aviation Organization
NZIA	Net-Zero Industry Act
PPA	Power-Purchase Agreement
PtA	Power-to-Ammonia
PtH	Power-to-Hydrogen
PtM	Power-to-Methanol
RES	Renewable Energy Source
RCF	Recycled Carbon Fuel
RFNBO	Renewable Fuel of Non-Biological Origin
SAF	Sustainable Aviation Fuel
TEN-T	Trans-European Transport Network

1 Introduction

1.1 Background

This thesis examines the implications of the European Union's regulatory framework on establishing economically feasible Power-to-X fuel production. Power-to-X fuels (also called PtX fuels) are synthetic and sustainable fuels produced by converting energy into an energy carrier such as hydrogen.[1] These fuels can be used as alternatives to fossil energy in multiple sectors, including the transport sector, which currently accounts to about 25 % of greenhouse gas (GHG) emissions in the EU.[2] PtX fuels are an alternative to using polluting fossil fuels, especially in so-called hard-to-abate sectors such as maritime transport and aviation. This thesis examines the regulatory framework concerning the production of these fuels from the perspective of their principle raw materials, hydrogen and carbon dioxide. Currently, most of the hydrogen used in industrial processes is produced from fossil raw materials like natural gas, which causes high GHG emissions.[3] However, it can be produced sustainably with renewable energy in a process called electrolysis. Furthermore, although carbon dioxide has a reputation as the primary GHG emission driving climate change, it can be obtained sustainably from the atmosphere or directly from industrial point sources, and then used in the production of sustainable fuels.[4]

During the past years, the European Union has set ambitious decarbonisation targets across different sectors to reduce emissions and mitigate climate change. These include e.g. the European Green Deal, the Fit for 55, and the REPowerEU Plan. The European Green Deal, presented in 2019, reset the Commission's commitment to tackling climate and environmental-related challenges. It is a growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy with no net GHG emissions in 2050 and where economic growth is decoupled from resource use.[5] The ambitions of the Green Deal were written into law in Regulation (EU) 2021/1119 of the European Parliament and of the Council of 11 December 2019 (European Climate Law), which sets a target of reducing the Union's net emissions by at least 55 % by 2030 compared

[1] Bossmann– Fournié– Humberset – Khallouf, 2018, p. 5.
[2] European Commission, Transport and the Green Deal, Accessed 9 August 2024.
[3] H2 Cluster, 2021, p. 6.
[4] European Commission, Final report, Task 1, 2022, p. 13.
[5] COM(2019) 640 final, p. 2.

to 1990, as well as the becoming the first climate neutral continent by 2050. The Fit for 55 launched by the Commission on 14 June 2021 contains a set of inter-connected legislative proposals to make the EU fir for the 55 % emissions reduction target by encouraging and implementing change across sectors. Targets for additional renewables production as well as renewable hydrogen production are set in the REPowerEU Plan, launched on 18 May 2022 by the Commission as a response to Russia's war on Ukraine, which has disrupted the world's energy systems.[6] The production of net-zero technologies, also linked to hydrogen production, is further promoted with the Regulation (EU) 2024/1735 of the European Parliament and of the Council of 13 June 2024 on establishing a framework of measures for strengthening Europe's net-zero technology manufacturing ecosystem (the Net-Zero Industry Act, NZIA).

This thesis will centre on renewable fuels of non-biological origin, which are also considered PtX fuels, because the EU's regulatory framework is largely focused on them as well.[7]. The most important piece of EU legislation concerning the production of PtX fuels is the Directive on the promotion of the use of energy from renewable sources (Renewable Energy Directive, RED), which was first adopted in 2009 (Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 (RED I). Since its adoption, the Directive has been recast on 11 December 2018 (RED II) and on 18 October 2023 (RED III). The Renewable Energy Directive sets the framework for the promotion of energy from renewable sources by setting targets for the share of renewable energy in the energy mix, and setting rules for financial support, guarantees of origin, regional cooperation, administrative procedures and on information and training. More detailed rules related to the production of RFNBOs are set in two delegated acts adopted under RED II. Other important legislative elements examined in this thesis are the Hydrogen and Gas Market Package (consisting of a Directive and a Regulation) concerning the uptake of so-called low-carbon hydrogen, the Emissions Trading System (ETS), the ReFuelEUAviation Regulation, FuelEUMaritime Regulation and the Alternative Fuels Infrastructure Regulation (AFIR).

Furthermore, this thesis has a special focus on RFNBO production potential in Finland, as hydrogen production is a key element of the clean energy transition in Finland. Goals for the ramp-up of a hydrogen economy in Finland are laid out in the current Governmental Programme

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[6] COM(2022) 230 final, p. 1.
[7] Talus – Pinto – Gallegos, 2024, p. 17.

from 2023.[8] The Programme lays out an objective for Finland to account for 10% of the Union's clean hydrogen production and at least 10% of hydrogen use.[9] PtX production facilities are already under construction in Finland; Hycamite TCD Technologies Oy is constructing a pyrolysis plant in Kokkola, PtX solutions Oy's Green hydrogen facility is under construction in Harjavalta and Neste Oyj has proceeded to the basic engineering phase in a green hydrogen production facility in Porvoo. Furthermore, a great number of projects on e.g. green hydrogen production, electrolyser and ammonia production, e-methane and e-methanol production are in planning phase or under feasibility study. However, the number of full-scale investment decisions remains moderate, as issues related to economic feasibility of production hinder the interest in such projects.[10]

1.2 Research questions

This thesis examines the implications of the EU legislative framework on the production of RFNBOs and other PtX fuels. The principal focus is on the recast Renewable Energy Directive (RED III) and the Delegated Acts adopted under RED II, the Hydrogen and Gas Market Package as well as the EU ETS Directive, but other acts such as the FuelEU Maritime and the ReFuelEU Aviation are delved into as well. This thesis analyses and assesses how the legislative framework regulates the production of the principle raw materials of these fuels, which are hydrogen and carbon dioxide. A special characteristic related to the legislative framework is that for a large part, both the regulations, as well as the technology and methods of producing these fuels is fairly new. This means that the legislation concerning them should be assessed comprehensively.

Furthermore, this thesis examines how the legislative framework concerning these fuels supports their production from a market perspective, as these fuels are currently not cost competitive with traditional fossil fuels, and their production is costly. The legislative framework should facilitate production in a manner which creates incentives to launch and invest to new projects. This thesis assumes that the requirements set for the production of RFNBOs in the legislative framework are too strict to allow the large-scale ramp-up of RFNBO

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[8] Publications of the Finnish Government 2023:60, p. 149–150. In the Programme, the Government expresses its commitment to reaching the emission-reduction targets, as well as reaching carbon neutrality and eventually carbon negativity. A goal to draw up a programme by the end of 2024 to reverse the emissions debt that has accumulated since the start of the decade is set in the Governmental Programme

[9] Publications of the Finnish Government 2023:60, p. 158–159.

[10] H2Cluster, Projects, accessed 15 July 2024.

production, and thus examines alternative policies to support production, such as looser requirements for hydrogen in the transitional phase as well as financial support. The primary research question and the supporting questions are as follows:

What are the key implications of EU legislation for establishing economically feasible Power-to-X fuel production?

1. How must the production RFNBO raw materials be organized to adhere to current EU standards?

2. What EU policy measures are in place to support the production of Power-to-X fuels?

3. What issues can be identified with regards to Power-to-X fuel production within the current legislative framework?

4. How could the EU regulatory framework be revised to better foster the ramp-up of PtX fuel production?

The legislation should be assessed and reviewed accordingly, keeping in mind the special characteristics of the sector. However, what comes to revising new legislation, it should be kept in mind that rapid changes in legislation do not create strong trust among investors and project developers, who are necessary for the execution of the green transition projects. It is also important to assess whether the legislative measures set in the RED and the Delegated Acts facilitate projects to reach the targets set in the legislation. The legislative framework should simultaneously foster a paradigm shift towards the large-scale uptake of renewable fuels in the transport sector, while creating a suitable environment for project development, investments, and further research and development. So far, the production of these fuels is still not economically viable either at all, or in comparison to the production of their fossil comparators. This thesis also examines the financial support mechanisms that are offered for PtX products and their raw materials, as they are key to the initial ramp-up of production. When assessing how the EU regulatory framework should and could be amended to better foster the production ramp-up of hydrogen and its derivatives, I shall examine if the legislator should broaden the scope of legislation to cover other types of hydrogen than strictly renewable (in EU terms), at least for the transitional period, as otherwise the ambitious targets might not be reachable in the established schedule.

1.3 Method and scope

The methods used in this thesis are pluralist, consisting of a combination of legal dogmatics and regulatory theory, as well as some *de lege ferenda* -recommendations and law and economics- contemplations. Traditional legal dogmatics is used to interpret and systemize the legislation, and I will use it to examine how RFNBO producers must organize their activities to adhere to EU standards. This is done especially with regards to how hydrogen must be produced and how carbon dioxide must be obtained in accordance with the delegated acts of the RED. Furthermore, I will analyse how the new Hydrogen and Gas Market Package defines so-called low-carbon hydrogen and low-carbon fuels, with the aim to facilitate their market uptake. Finally, the Emissions Trading System is examined with focus on how it affects RFNBO production and how it addresses carbon capture and utilization technologies to avoid double counting of emissions. The thesis shall contain some law and economics-related reflections as well, as the economic feasibility of RFNBO production and the necessity of financial support mechanisms to direct funds into these projects are assessed.

I will use a regulatory-theoretical approach to examine the occasionally contradicting goals that the legislative framework must balance between. Regulatory theory is related to the law and economics approach, as it evaluates legislation from the perspective of on the markets.[11] In this thesis, I will analyse the legislation against a framework of what kind of targets it should seek to achieve in order to facilitate economically feasible PtX production while maintaining other goals. These targets are often contradictory with one another. The markets and systems of the PtX economy are in constant change, meaning that open communication between the legislator and market players should be favoured. Facilitating participation may increase the legitimacy and acceptance of the legislative outcomes,[12] and together with transparency it can increase the predictability of the legislative outcome to market players. Although market actors may call for regulations that allow for more leeway, the legislator must set some kind of standards and rules for the market in order to achieve not only a level playing field, but also long-terms climate goals to mitigate climate change. Additionally, the legislation should be sufficiently technology neutral – at least among clean technologies – as it allows the regulation of functions and effects rather than the means; it avoids discrimination and hindering technological innovations, and it endures the test of time.[13] However, as truly technology neutral legislation is not very specific

[11] Kokko, 2014, p. 300.
[12] Baumgart – Lavrijssen, 2024, p. 147–148.
[13] Giljam, 2018, p. 237.

about the subject matter which it regulates, the law can in practice become insufficiently clear.[14] Therefore, a balance between a flexible yet sufficiently guiding regulatory solution must be struck. It can be difficult to find a balance between these contradicting goals, especially when the technologies and the decarbonisation targets are all relatively new. Therefore, this thesis examines how different targets are met within the regulatory framework of PtX fuels. Furthermore, I aim to provide *de lege ferenda* -recommendations based on the previous phases of the research and suggest alternative legislative measures to support the production ramp-up of PtX fuels. I shall analyse the implications of the legislation from a producer's point of view to give the reader a better understanding of how the regulation affects setting up production.

The sources and material used for this thesis are somewhat multidisciplinary. To examine the legislative angle of the research question, sources used range from legal literature to communications of legal bodies, like the EU Commission and the Finnish Government. To get an understanding of the economic viewpoint of scaling PtX fuel production, I utilize non-legal literature as well as reports and occasionally news. Finally, technical reports are used to address technical aspects.

PtX fuels can be used for a variety of purposes, but the scope is narrowed to cover RFNBOs and PtX fuels for use in the transport sector. Although the term RFNBO covers different end-products, this thesis is focused on the upstream production phase of RFNBOs, namely on the production of hydrogen with electrolysis and carbon dioxide via carbon capture. This is because it is vital to smooth the path for the early stages of these value chains to scale production on the necessary level to reach EU targets, so it should be critically examined whether the legislative framework achieves this or not. The same legislative elements partially cover other sustainable fuels than RFNBOs, such as recycled carbon fuels (RFC) and biofuels, but the further assessment of these fuels is excluded from the scope of this thesis.

1.4 Structure

The structure of the thesis is tied to the research questions in order to maintain a logical order and to help the reader in following along. In the first chapter, I will shortly explain the thematic background of this thesis, containing an explanation of PtX fuels and what they can be used for. The topicality of this subject is explained in the introduction through a general overview of

[14] Giljam, 2018, p. 237.

the climate targets, policy goals, and existing hydrogen projects as well as the key legislative elements in the EU. Furthermore, in the first chapter, I introduce and reason the research questions of the thesis, the methodological approaches as well as the scope.

The second chapter introduces the reader to the topic in a more profound manner to give a good understanding of the topic, especially considering the fact that the PtX thematic is not generally familiar to legal scholars. I shall explain in further detail what PtX fuels and RFNBOs are, what they are made of and what they can be used for. I shall also delve into the advantages and challenges of these fuels, as they are essential in understanding the topic. The transport sector, including maritime transport and aviation, is currently among the highest pollutants in the EU,[15] and there are targets to lower these emissions through the use of alternative fuels like RFNBOs. I shall approach the regulation concerning the production of RFNBOs from the perspective of their main raw materials: renewable hydrogen and carbon dioxide, explaining how renewable hydrogen is produced, and what carbon capture and utilization (CCU) means. I will not go into detail of how these raw materials are regulated yet in the second chapter, but rather focus on the technology aspect.

In the third chapter, I will delve into the regulatory framework of the EU, introducing the Fit for 55-package, the RED and its revisions, as well as the Delegated Acts adapted under RED II. First, I shall lay out the background of the regulatory framework by introducing the Green Deal as well as the Fit for 55, which sets major climate goals, and then introduce the original renewable energy directive and its revisions (RED II and RED III), with the focus on matters related to hydrogen production. The Delegated Acts of RED aim to clarify some uncertainties of the Directive with regards to the requirements for considering hydrogen renewable. In this section, I will explain what additionality as well as temporal and geographical correlation mean, and introduce the methodologies set for greenhouse gas (GHG) accounting. Furthermore, the recently revised Hydrogen and Gas Market package, consisting of a Directive and a Regulation, is introduced and its provisions concerning the definition of "low-carbon" hydrogen and "low-carbon" fuels are examined, as they could be used in the decarbonisation of the transport sector as well. Finally, the EU ETS Directive, which has been revised as well is assessed in chapter three, with regards to its scope having been widened to cover the maritime and aviation sectors,

[15] The transport sector accounts to about 25 % of all EU GHG emissions (European Commission, Transport and the Green Deal, Accessed 9 August 2024).

and the accounting methods that are related to CCU. The principal method used in this chapter is legal dogmatics, as I am going to systemize the legislative framework.

The fourth chapter examines the policy measures regarding financial support for production and uptake of PtX fuels. I shall introduce the legislative measures of the EU of creating demand and incentives for PtX production. The goals set in the ReFuelEU Aviation Regulation, the FuelEU Maritime Regulation the Alternative Fuels Infrastructure Regulation (AFIR) are necessary for creating demand for RFNBOs, as they are not yet economically feasible to produce. I will introduce the modelled investment needs of the envisioned hydrogen economy, in relation to the needed renewables capacity, electrolyser producing as well as production capacity of hydrogen. Finally, I will assess the existing policy measures and investment support schemes that direct funds towards PtX projects, such as Horizon Europe and the European Hydrogen Bank. The goal of this chapter is to give the reader an understanding on the feasibility of RFNBO production within the current legislative framework, and the necessary investment needed to realize the necessary production capacity.

In the fifth chapter, I will explain what kinds of issues the legislative framework should seek to address, from facilitating innovations and being sufficiently flexible to being stable enough to attract investors. I will use a regulatory theory approach to analyse the legislation against the framework introduced previously. Furthermore, I will clarify what requirements RFNBO production facilities must meet for the products to be considered renewable in light of the Delegated Acts of RED II. In this chapter, I aim to provide an answer to the research questions on what issues can be identified with regards to Power-to-X fuel production within the current legislative framework, as well as how could the EU regulatory framework be revised to better foster the ramp-up of PtX fuel production. I argue that the legislative framework is too strict to allow for the necessary production ramp-up of RFNBOs in the established timeframe. In the final section of the fifth chapter, I will argue that the focus of the legislative framework should be widened to cover low-carbon hydrogen and low-carbon fuels to reach the goals that are set for the future production capacities.

In the concluding chapter, all research questions and their conclusions are reviewed once more. I am going to go over the suggested legislative measures that could be taken to foster the ramp-up of PtX fuel production and the uptake of these fuels, in spite of the economic and regulatory challenges that they face. Finally, the need for further research on the legislative framework of

CCU and the definition of low-carbon fuels and low-carbon hydrogen is recognized in the concluding chapter.

2 The technological framework of PtX fuels

This chapter gives an overview of PtX fuels, and especially on renewable fuels of non-biological origin, in order for the legislation concerning them to be analysed later on in this thesis. The chapter starts with defining of key terms, followed by a description of the advantages and opportunities that PtX fuels have. The primary raw materials, hydrogen and carbon dioxide and their production pathways, are introduced in further detail. Finally, the chapter covers the main issues that the production of these fuels faces, namely the high price of production and the lack of a stable policy framework.

2.1 Definitions

Renewable fuels of non-biological origin (RFNBOs) are liquid and gaseous fuels the energy content of which is derived from renewable sources other than biomass, as defined in Article 2(36) of the Directive 2009/28/EC on the promotion of the use of energy from renewable sources (The Renewable Energy Directive, RED). In order for a fuel to be considered an RFNBO, it must fulfil the criteria set in the RED III, namely it must account for at least 70 % GHG savings in comparison to its fossil fuel comparators. It is important that the feedstock is of non-biological origin, as otherwise the fuel would be considered a biofuel or a biogas,[16] therefore not being able to be calculated for the target shares set for RFNBOs in different sectors. Renewable hydrogen is the simplest RFNBO, but also more complex fuels like e-kerosene are RFNBOs.[17]

RFNBOs are included in the wider category of so-called Power-to-X fuels (also referred to as P2X fuels). PtX refers to the conversion of electrical power into another energy carrier, where the “X” symbolizes the energy carrier.[18] These energy carriers can be gaseous or liquid substances such as hydrogen (Power-to-Hydrogen), ammonia (Power-to-Ammonia), methane (Power-to-Methane). Power-to-Gas and Power-to-Liquid refer to PtX fuels based on their state. Power-to-Liquid products have the highest use potential in the transport sector, as the sector currently holds the largest share of fossil liquids.[19] PtX fuels is an umbrella term for multiple types of fuels, including Renewable Fuels of Non-Biological Origin (RFNBOs). The

[16] According to RED Article 2(33), biofuel means liquid fuel for transport produced from biomass, and according to Article 2(28), biogas means gaseous fuels produced from biomass.
[17] Delarue – Meus – Moncada – Valkering – Verbist, 2024, p. 3.
[18] Bossmann– Fournié– Humberset – Khallouf, 2018, p. 5.
[19] Bossmann– Fournié– Humberset – Khallouf, 2018, p. 14.

EU legislation on alternative fuels is largely focused on RFNBOs, but other types of PtX fuels also exist, such as Recycled Carbon Fuels.[20]

E-fuels (also known as electrofuels or eFuels) are electricity-based fuels that are used as an alternative to conventional liquid fuels in the transport and heating markets. The production of e-fuels is based on hydrogen extracted with electrolysis, which is then processed further with e.g. the Fischer-Tropsch synthesis process and combined with CO_2 extracted from the air and converted into a liquid energy carrier, the e-Fuel. E-fuels are climate neutral, as their production uses renewable energy, and only as much CO_2 is emitted during their use as is bound from air during their production. [21]

EU legislation classifies hydrogen into different categories based on its production method. As a general rule, renewable hydrogen means hydrogen that is produced with renewable electricity -powered electrolysis, but the rules laid out in the Delegated Act 2023/1184 of RED II for the counting the electricity used as renewable are set more complex requirements that will be introduced in detail later. Article 2 (11) of the recast Hydrogen and Gas Market Directive (EU) 2024/1788 defines low-carbon hydrogen as hydrogen, the energy content of which is derived from non-renewable sources, which meets the greenhouse gas (GHG) emissions reduction threshold of 70 % in comparison to the fossil fuel comparator for RFNBOs. Fossil hydrogen, in turn, refers to hydrogen that is produced from fossil fuel like natural gas or coal.[22] Low-carbon fuels, in turn, are defined in Article 2(13) of the Hydrogen and Gas Market Directive as RFCs as defined in Article 2 (35) of the RED,[23] low-carbon hydrogen and synthetic gaseous and liquid fuels the energy content of which is derived from low-carbon hydrogen that meets the GHG emissions reduction target.

Carbon dioxide (CO_2) is an essential feedstock for RFNBOs. Carbon capture, utilization and storage (CCUS, or just CCU when referring to only Carbon Capture and Utilization; and CCS

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[20] Recycled Carbon Fuels (RFC) are regulated in the same EU Delegated Acts as RFNBOs. According to Article 2(35) of the RED, recycled carbon fuels mean liquid and gaseous fuels that are produced from liquid or solid waste streams of non-renewable origin which are not suitable for material recovery, or from waste processing gas and exhaust gas or non-renewable origin which are produced as an unavoidable and unintentional consequence of the production process in industrial installations. RFCs are regulated in the same legislative acts as RFNBOs, but their further assessment is ruled out of the scope of this thesis.
[21] eFuel alliance, What are eFuels? (Accessed 28 August 2024).
[22] COM(2020) 301 final, 8.7.2020, p. 1.
[23] Article 2 (35): ‘recycled carbon fuels’ means liquid and gaseous fuels that are produced from liquid or solid waste streams of non-renewable origin which are not suitable for material recovery in accordance with Article 4 of Directive 2008/98/EC, or from waste processing gas and exhaust gas of non-renewable origin which are produced as an unavoidable and unintentional consequence of the production process in industrial installations.

when referring to Carbon Capture and Storage) refers to technologies that capture CO_2 either directly from industrial point sources (i.e. underlying industrial processes), or from the atmosphere. Moreover, in carbon capture and utilization, the captured carbon is used or refined into more valuable products, such as e-fuels, chemicals or building material. However, if the fuel uses CO_2 as a feedstock, the CO_2 is released back to the atmosphere in the use-phase, meaning that the fuel is not carbon negative, but carbon neutral. In carbon capture and storage, the carbon is transported and stored permanently into a suitable geological formation[24], thus preventing emissions to the atmosphere.[25]

2.2 Advantages, opportunities and strengths of PtX-fuels

PtX fuels have multiple advantages and opportunities for use when compared to fossil fuels. However, contrary to the early conceptualization of the so-called "hydrogen economy", researchers have concluded that hydrogen-based solutions shall be complementary elements of the so-called "electric economy", rather than act as the primary energy carrier. *Electrification of the energy sector is going to be at the core of the energy transition.* This entails a massive ramping of solar power, wind power and electrolyser capacities. Regardless, about 40 % of the final energy and feedstock demand cannot be directly electrified, such as fuels for the maritime and aviation sectors, chemicals and steel manufacturing.[26]

Hydrogen shall be produced with energy coming from renewable sources, and it will function as the primary balance for the energy-industry system as a whole, because it indirectly balances the inelastic power demand in flexible operation of low-cost electrolysers and underground hydrogen storage.[27] Hydrogen can be produced in multiple different ways, but in order for it to be considered renewable under EU standards, it must comply with the criteria set in the RED III and the Delegated Acts of RED II. Furthermore, hydrogen can be used in seasonal electricity balancing and heating, but its role is going to be minor, as batteries are becoming the most important electricity storage solution with up to 90 % of direct electricity storage.[28] Hydrogen may not become the central energy carrier, but rather complement the

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[24] Technologies for the storage of CO2 into geological formations include trapping it in rock formations, dissolving it into water which is found inn geological formations or including chemical reactions with rock formations to produce minerals.
[25] European Commission: About Industrial Carbon Management, (Accessed 16 July 2024).
[26] Bogdanov – Breyer – Lopez – Laaksonen, 2024, p. 352–354.
[27] Bogdanov – Breyer – Lopez – Laaksonen, 2024, p. 353–354.
[28] Bogdanov – Breyer – Lopez – Laaksonen, 2024, p. 353.354. The lithium-ion battery is the most dominating battery technology.

system as an electricity-based intermediate energy carrier, which can be converted into different products using power-to-hydrogen-to-X technologies.[29]

According to the European Environmental Agency (EEA), road transport constitutes the largest part of overall transport emissions, emitting up to 76% of all GHG emissions from transport in 2021. Emissions from transport decreased by 13.5% between 2019 and 2020 due to the COVID-19 -pandemic, but have since rebounded 8.6% in 2021, and 2.7% in 2022. According to the EEA report from 2023, transport-related emissions were to peak in 2023, with the trend reversed by implementing transport-related measures in the Member States.[30] Road transport emissions are expected to decrease faster than other modes of transport.[31] As those PtX fuels that can be regarded as RFNBOs must account for at least 70 % GHG savings, their large-scale uptake would therefore account to significant GHG emissions reductions. Furthermore, the use of hydrogen in vehicles does not cause any GHG emissions, unlike the combustion of some other fuels.[32] Hydrogen can be used in hydrogen fuel cell vehicles, the only emissions being water vapor and hot air, with no harmful downstream emissions.[33] Road transport can be decarbonised by electrifying cars and road vehicles, leaving the use of PtX fuels to support the electrification of road transport. Regardless, heavy-duty transport modes such as aviation and maritime transport (so-called hard-to-abate-sectors) are not easy to electrify, and PtX fuels are expected to be used to decarbonise these transport modes.

Furthermore, PtX projects have positive economic implications. Finland has multiple competitive advantages when it comes to PtX-fuel production, which are key in achieving a high-value hydrogen economy. The current Governmental Programme sets ambitious goals for a Finnish hydrogen economy; Finland is set out to become a major producer of clean hydrogen, producing no less than 10 % of clean hydrogen in the EU.[34] In order to reach the target of carbon neutrality by 2035, the emissions from fossil fuels must be tackled. Hydrogen is a key substance in this transition, as it can be used by itself as well as in the production processes of other

[29] Bogdanov – Breyer – Lopez – Laaksonen, 2024, p. 356.
[30] EEA, 24 October 2023, accessed 26 June 2024.
[31] EEA, 24 October 2023, accessed 26 June 2024.
[32] Hydrogen Cluster Finland, 2021, p. 6.
[33] Havukainen – Horttanainen – Patel – Soukka – Tuomaala, 2024, p 993.
[34] Governmental Programme, 2023, p. 143.

renewable fuels.[35] Furthermore, the ramp-up of the PtX economy has positive implications to the employment rate, as PtX projects create job opportunities along the value chain.[36]

Furthermore, especially the production of green hydrogen[37] is an important upstream product in the value chain of many different hydrogen-based products, which are not limited to fuels for the transport sector. It is therefore important to ramp-up the production of renewable hydrogen in the large-scale to accelerate the production and market uptake of more sustainable alternatives across different sectors, like transport, chemicals industry and steelmaking.[38] RFNBOs and other PtX fuels can be used for different purposes across sectors, not only in the transport sector. They may work as feedstock or as a source of energy in industrial and chemical processes and in maritime transport and aviation. PtX fuels can be used in decarbonizing sectors where direct electrification is not technologically possible or commercially competitive. They may also play a significant role in system integration, as it is possible to use these fuels for energy storage to balance the energy system.[39]

The competitive advantages that Finland has are related to multiple sources of biogenic CO_2, as well as the opportunities for scaling of cost-effective wind power, both onshore and offshore. Building new renewables capacity is essential, as the renewable electricity used in the production of RFNBOs must be additional. In addition to the good potential regarding additional renewables capacity, Finland has a strong and effective electricity transmission network. Finland possesses strong technical competencies covering the whole energy value chain[40] as well as the maritime sector and has potential to expand PtX fuel production by increasing renewable electricity production.[41] What comes to CCU, Finland has potential to use CCU and capture carbon dioxide emissions from the industry. Finland has an abundance of biogenic CO_2, which provides a further competitive advantage.[42]

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[35] H2 Cluster, 2021, p. 6.
[36] EU report (Clean Energy Technology Centre), 2023, p. 5–6.
[37] Green hydrogen refers to hydrogen produced with renewable electricity.
[38] Bogdanov – Breyer – Lopez – Laaksonen, 2024, p. 353.
[39] RED III, recital (75), p. 19.
[40] The generation of clean electricity, power electronics and power conversion technologies, control and optimization of energy distribution systems, energy and process industry equipment, end.to-end digitalization and the design and engineering required for turn-key project deliveries (H2 Cluster, 2021, p. 9).
[41] H2 Cluster, 2021, p. 6–9.
[42] H2 Cluster, 2021, p. 10.

2.3 Raw materials of RFNBOs

The RFNBO production process uses renewable electricity. If the hydrogen (which can itself be considered an RFNBO if it fulfils the requirement) is processed further into another RFNBO, the production process also uses carbon dioxide as feedstock. The hydrogen used for the must fulfil the requirements set in RED III for it to be considered renewable, primarily meaning that it has been produced via electrolysis which uses renewable electricity. The CO_2 used for RFNBO production is mostly obtained by capturing, either from an industrial point source or from the atmosphere (direct air capture, DAC). The production process of RFNBOs starts with forming a mixture of hydrogen and CO_2 into so-called syngas,[43] which can then be processed further via various conversion steps such as methanation, Fischer-Tropsch and methanol synthesis.[44] Both the regulation as well as the technology for producing or obtaining of hydrogen and CO_2 are very different, so they will be handled separately in the text as well.

2.3.1 Hydrogen

Hydrogen is the most important raw material of RFNBOs. It can be produced sustainably with renewable energy via a process called electrolysis, which breaks down water (H_2O) into hydrogen and oxygen.[45] Hydrogen can be used as it is, but it is often refined to be used for other fuels, which may have better storage or utilization characteristics. For example, conversion to methanol (PtM) or ammonia (PtA) increases the energy density of a fuel.[46] As mentioned earlier, producing renewable hydrogen is an important upstream product in the production process of many different fuels. Therefore, the regulation concerning its production is under special scrutiny, as bottlenecks in hydrogen production can hinder the production of other fuels.

Currently, of all hydrogen produced, 42 % is used in oil refineries, 35 % in ammonia production and 15 % in methanol production.[47] About 96 % of the hydrogen produced in Europe in 2020 was produced with steam methane reforming using either coal or natural gas.[48] In the energy-industry of the future, hydrogen emerges as the central intermediate energy carrier, and its relevance is driven further by significant cost reductions in renewable electricity capacity

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[43] European Commission, Final report, Task 1, 2022, p. 13.
[44] European Commission, Final report, Task 1, 2022, p. 16.
[45] European Commission, Final report, Task 1, 2022, p. 16.
[46] Daoutis – Palys, 2022, p. 2.
[47] Havukainen – Horttanainen – Patel – Soukka – Tuomaala, 2024, p. 992.
[48] European Parliament Briefing, EU rules for renewable hydrogen, April 2023, p. 2.

coming from solar and wind power, as well as the projected cost reductions of electrolysers.[49] The EU envisions that the share of hydrogen in the energy mix of the Union should grow from less than 2 % in 2020 to 13–14 % in 2050.[50] Research suggests that a massive ramping of electrolyser capacity is required from 2030 to 2050. When all hydrogen demand across the global energy-industry system is considered, the demand can be upwards of 61,737 TWh in 2050, of which up to 81% is for hydrogen used as intermediate for PtX products as part of a hydrogen-to-X route.[51]

For the past years the EU has categorized hydrogen into different "coloured" hydrogen in accordance with its production method. The EU is moving away from the colour scheme, and the new classification system is one where hydrogen production is classified based on the definitions for renewable and low carbon hydrogen. Green hydrogen means hydrogen which is produced with renewable electricity through electrolysis, and its new definition is "renewable hydrogen, sometimes referred to as "clean hydrogen." Blue hydrogen means hydrogen that is produced from natural gas with CCS and is now called low-carbon hydrogen. Grey hydrogen is produced from natural gas, brown from brown coal and black from black coal. These are all called fossil-based hydrogen (without CCS). Hydrogen produced via electrolysis with electricity taken from the grid is called yellow hydrogen, and it can fall into all the aforementioned categories, depending on the electricity mix that is used.[52] There are other colour definitions as well; pink hydrogen is produced by nuclear-powered electrolysis, and turquoise hydrogen is produced via a process called pyrolysis.[53] Hydrogen produced with nuclear energy is not encompassed in the definition of low-carbon hydrogen in the new Hydrogen and Gas Market Package.[54] The production of turquoise hydrogen is a thermochemical production process, which uses decomposition/pyrolysis on biogas, renewable methane or biomethane to turn it into hydrogen and solid carbon in high temperatures (using electricity). Depending on which feedstock is utilized, the pyrolysis process can be classified as either carbon neutral or carbon negative; the process causes no gaseous carbon which would need to be captured.[55]

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[49] Bogdanov – Breyer – Lopez – Laaksonen, 2024, p. 351–352.
[50] COM(2020) 301 final, p. 1.
[51] Bogdanov – Breyer – Lopez – Laaksonen, 2024, p. 354–355.
[52] European Parliament Briefing, EU rules for renewable hydrogen, April 2023, p. 3.
[53] Talus – Pinto – Gallegos, 2024, p. 7.
[54] Talus – Pinto – Gallegos, 2024, p. 7.
[55] Talus – Pinto – Gallegos, 2024, p. 11.

2.3.2 Carbon dioxide

Carbon dioxide used for the production of syngas must first be captured and potentially purified. Carbon capture from both industrial point sources or from the atmosphere requires high energy expenditure; in addition to which carbon capture facilities face an efficiency loss (also called an energy penalty or efficiency penalty) of up to 15%. According to the EU report on the potential of RFNBOs, this increased energy use can only be justified from an economic point of view, if the cost of emitting the CO_2 is higher than the cost of CCU.[56]

The demand of carbon dioxide in the global transport sector (for methanation and Fischer-Tropsch-fuel synthesis) is 3250 $MtCO_2$, and 1087 $MtCO_2$ for the power and heat sectors (for methanation).[57] At the moment, roughly only 0,1 % of all global CO_2 emissions (25 to 45 million tonnes/Mton) are captured. The International Energy Agency indicates that these levels should be drastically upscaled to more than 6000 Mton per year by 2050 to achieve the net-zero target. However, not all of the captured carbon is going to be utilized: rather, somewhere between 50 % and 95 % of the captured CO_2 is expected to be geologically stored, leaving the rest to be utilized for e-fuel production.[58] Although the decarbonisation of road vehicles can be done with just hydrogen, some sectors, like aviation and shipping are going to rely on more refined carbon-based fuels, as they have better use features for these sectors. Therefore, CCU technologies could create synergies between hard-to-abate upstream industries, and downstream carbon-based fuel producers.[59]

The CO_2 should be sustainable, which means that it should be either captured from a sustainable or an unavoidable point source such as pulp and paper mills, waste incineration, or via direct air capture (DAC). 2471 $MtCO_2$ could come from unavoidable point sources, which means that the rest of the demand should be filled by electricity-based CO_2 from DAC.[60] Direct air capture (DAC) technologies are the alternative to capturing CO_2 directly from a point source. The advantage of DAC is that it can be utilized pretty much anywhere, as it uses ambient air. Therefore, it is especially suitable for decentralized energy sources.[61]

[56]European Commission, Final report Task 1, 2022, p. 20.
[57] Bogdanov – Breyer – Lopez – Laaksonen, 2024, p. 354.
[58] Delarue – Meus – Moncada – Valkering – Verbist, 2024, p. 1.
[59] Delarue – Meus – Moncada – Valkering – Verbist, 2024, p. 3.
[60] Bogdanov – Breyer – Lopez – Laaksonen, 2024, p. 354.
[61] EU Final report. Task 1, 2022, p. 22.

As a major part of CO_2 emerges from different point sources, it is efficient to capture the CO_2 from those rather than the atmosphere. The technologies to capture the carbon from the flue gas from point sources can be divided into capture with post combustion, pre combustion and Oxyfuel combustion, as well as process-related CO_2 emissions sources. Pre combustion process removes the CO_2 before the combustion of the *solid* energy carrier via gasification or of gaseous energy carriers via reformation. The post combustion process treats the flue gas after the combustion of the energy carrier, as the CO_2 is separated from the flue gas generated in the combustion with air from the atmosphere. This is similar to the oxyfuel-combustion process, which uses oxygen instead of regular air. Process-related CO_2 emissions emerge from industrial processes as by-products. The actual extraction of carbon from the flue gas can be done via adsorption, absorption, use of membranes or chemical looping combustion systems, of which absorption technologies have the highest technology readiness levels, whereas adsorption and membrane technologies might achieve sufficient standards in the next decades.[62]

2.4 Challenges of PtX fuel production

The European Commission has commissioned a report on the potential of RFNBOs and RFCs in the transport sector. The report includes a categorization of the barriers for the production of RFNBOs and RCFs into economic, structural, regulatory and societal reasons.[63] Although the report concerns RFNBOs and RFCs and not PtX fuels in general, it is still useful for this thesis as it covers renewable hydrogen production.

The principal economic barrier of RFNBOs is their high price compared to fossil fuels, as they bring few benefits for their end users compared to current fuel alternatives. RFNBO prices are expected to be up to 2–6 times higher in 2030 in comparison to fossil fuels. End users like car owners, airlines or fleet operators are more likely to opt for the cheaper alternative, whichever it is. The principal cost drivers of RFNBOs are the operational costs for feedstock electricity.[64]

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[62]European Commission, Final report Task 1, 2022, p. 20–21. Adsorption and absorption are used to separate the CO_2 from other chemical elements in the flue gas. Adsorption process uses the adhesion of gaseous or liquid element or compound on the surface of another solid material, which is called “adsorbent” material. Absorption means a process where the gaseous or liquid element or compounds enters another liquid or solid material and concentrates within the volume of the “absorbent” material. Membrane technology takes advantage of the permeability of materials: the targeted material moves through the membrane, while other components are not able to pass the membrane.

[63] European Commission, Final report Task 1, 2022, p. 104.

[64] European Commission, Final report Task 1, 2022, p. 103–104.

The prices are driven up by the high initial investment costs of renewables projects as well as the variability of renewables production.[65]

Furthermore, RFNBO production faces technical and structural obstacles. The technology readiness level of production technology with the highest efficiency at the time of the publishing of the report in 2022 was not yet available on an industrial scale.[66] Above all, a lack of production capacities for electrolysers causes a hindrance to the PtX fuel market. The EC plans rely on green hydrogen exclusively, but this causes concern over whether it is possible to achieve the ambitious goals with just one technology, not to mention the additional electrolyser production capacity required to achieve this goal. According to a study published in 2022, the electrolyser capacity in the EU should be increased 900-fold until 2030.[67] The Net-Zero Industry Act adopted in 2024 seeks to address the problem related to the scaling of electrolyser capacities by establishing policies to support these industries.

As the production process of PtX-fuels uses electricity, a significant ramp-up of renewable energy production capacity is needed. In comparison to fossil electricity, renewable electricity production is more unreliable due to the intermittent production capacity of renewable energy. E.g. wind and solar energy generation varies substantially due to changing weather conditions. The constantly changing production capacity increases prices of PtX-fuels, as production systems cannot operate at a steady state. According to Palys and Daoutidis, the systems require either a time-varying operation of at least some subsets or oversized process units or additional energy storage units, or a combination of those to meet production targets with intermittently available energy. The electricity generation must be balanced by using energy storage systems (ESS).[68] A proper infrastructure, including pipelines, storage facilities, transport routes etc. is also needed for RFNBOs as well as hydrogen and carbon.[69]

What comes to CCU, although DAC is expected to become one of the primary methods of acquiring CO_2 in a circular manner, it also faces some issues. The principal issue of DAC is its high energy expenditure: the regeneration process requires about 1,420 – 2,250 kWh heat per tonne CO_2, and other components of the system need about 366 – 764 kWh of electricity per

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[65] EU report (Clean Energy Technology Centre), 2023, p. 5–6.
[66] European Commission, Final report Task 1, 2022, p. 104.
[67] Ansari – Grinschgl – Pepe, 2022, p. 1–2.
[68] Daoutis – Palys, 2022, p. 1–2.
[69] European Commission, Final report Task 1, 2022, p. 104.

tonne CO_2.[70] The technology readiness level of DAC technologies is 5 or 6 out of 10. The technical risk for DAC is relatively low, but the economic risk is high due to the high energy consumption of the technology. Other uncertainties concerning the uptake of DAC technologies are: the short period to achieve carbon neutrality, large building of production capacities, lack of public and political discussion concerning the subject.[71] The cost of CO_2 direct air capture is projected to reduce in the future,[72] but reaching a technology readiness level of 9 and reducing the costs further requires several development and upscaling steps.[73] Despite having multiple advantages concerning the ramp-up of a hydrogen economy, Finland faces some weaknesses as well; the country is small and somewhat secluded, and funds are lacking.[74] What comes to CCUS technologies, Finland does not have the best opportunities for the permanent storage of CO_2.[75] However, many condensed sources of biogenic CO_2 exist, which are currently not used. These side streams should be taken advantage of.[76]

The regulatory obstacles that RFNBOs face include the lack of a stable policy framework and of long-term perspectives, as well as change in policy directions.[77] The European Union's regulatory framework concerning PtX fuels consists of multiple different acts, some of which may be revised within the next years.[78] This kind of regulatory uncertainty discourages investors and project promoters from action, as it makes it more difficult to calculate the expected economic outcomes of such projects as a change in regulation can make investments unprofitable. Long-term investments, in turn, are necessary to the production ramp-up of PtX fuels.

RFNBO production faces some societal opposition too. For example, the negative public perception of carbon dioxide as the primary GHG responsible for climate change, as well as the risks of carbon capture technologies (e.g. leaks during transport and storage) may hinder the

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[70] EU Final report. Task 1, 2022, p. 22.
[71] EU Final report. Task 1, 2022, p. 23.
[72] Bogdanov – Breyer – Lopez – Laaksonen, 2024, p. 352.
[73] European Commission, Final report Task 1, 2022, p. 23.
[74] H2 Cluster, 2021, p. 12.
[75] H2 Cluster, 2021, p. 6.
[76] H2 Cluster, 2021, p. 10–11.
[77] EU report (Clean Energy Technology Centre), 2023, p. 5–6.
[78] E.g. in accordance with Article 10 of the Delegated Act 2023/1184, By 1 July 2028, the Commission shall submit a report to the European Parliament and the Council assessing the impact of the requirements set out in this Regulation, including the impact of temporal correlation, on production costs, greenhouse gas emission savings and the energy system; and in accordance with the Commission's Industrial Carbon Management Strategy, the EU ETS is going to be reviewed in 2026.

uptake of fuels derived from captured CO_2.[79] This kind of prejudice is most likely caused by lack of information on the benefits of PtX fuels. Societal opposition is also caused with regards to the build-up of infrastructure including transmission lines as well as new renewables projects to add capacity, which are likely to face local opposition.[80]

[79] European Commission, Final report Task 1, 2022, p. 105.
[80] European Commission, Final report Task 1, 2022, p. 105.

3 Legislative framework of PtX fuels

The producers of PtX fuels, hydrogen and carbon dioxide must consider multiple EU acts when planning production. This chapters aims to provide an answer to the research question on how the production RFNBO raw materials must be organized to adhere to current EU standards. Many acts have been recast during the past years to better align them with the EU's target to reach a 55 % reduction of net emissions by 2030 in comparison to 1990 levels, set in the EU Green Deal and the Fit for 55 package. The Fit for 55 package strengthens eight already existing pieces of legislation [81] and presents five totally new initiatives[82] across different policy areas. The package tackles climate, energy, fuels, buildings, land use and forestry sectors and the policy mix used consists of pricing, targets, standards and support measures.[83] There are several legislative measures in place to decarbonise the transport sector, including but not limited to the Renewable Energy Directive and its Delegated Acts, the Hydrogen and Gas Market Package, and the EU Emissions Trading System, which will be covered in this chapter.

Discussion on the EU's dependency on energy imports is highlighted due to Russia's war against Ukraine. The development of a hydrogen market is one of the policy instruments to address the EU's dependency especially on natural gas imports. The import of green hydrogen from third countries is seen as a main pillar of the EU's strategy to address the challenges resulting from the war.[84] The REPowerEU Plan aims to rapidly phase out the Union's dependency on Russian fossil fuel imports with measures promoting energy savings, ensuring energy security[85] and substituting the use of fossil fuels with more sustainable alternatives. In addition, it includes targets for the ramp-up of hydrogen production and imports. According to the REPowerEUPlan, a massive speed-up and scale-up in renewable energy in power generation, industry, buildings and transport is going to accelerate the phasing-out of Russian fossil fuels.[86] To accelerate the uptake of renewable hydrogen, the REPowerEU sets targets to produce 10 million tonnes of renewable hydrogen domestically, and to import 10 million tonnes

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[81] The Emissions Trading System (ETS), the Energy Taxation Directive, the Effort Sharing Regulation, the Land Use Land Use Change and Forestry Regulation, the Renewable Energy Directive (RED) and the Energy Efficiency Directive.
[82] The Carbon Border Adjustment Mechanism (CBAM), the FuelEU Maritime, the ReFuelEU Aviation and the Alternative Fuels Infrastructure Regulation (AFIR).
[83] COM(2021) 550 final, p. 1–3.
[84] Baumgart – Lavrijssen, 2024, p. 137.
[85] COM(2022) 230 final, p. 1.
[86] COM(2022) 230 final, p. 6.

more by 2030.[87] Achieving these targets would not only decrease the Union's dependency on Russian energy, but simultaneously support the build-up of additional renewables capacity and renewable hydrogen production.

3.1 The Renewable Energy Directive

RFNBOs (including hydrogen) and carbon dioxide are primarily regulated in the Renewable Energy Directive (RED). The Directive was first adopted in 2009, with a goal of achieving a 20 % share of renewable energy sources (RES) in the final energy consumption of the EU by 2020.[88] The Directive was revised in 2018 (Directive (EU) 2018/2001 of the European Parliament and of the Council, RED II), setting a binding target for the Union's gross consumption of energy to consist of 32% of renewable energy sources before 2030. The RED II states that the European Commission is to give Delegated Acts to specify certain Articles. The Delegated Acts define when RFNBOs can be considered renewable, and the methodology for calculating the GHG emissions savings from RFNBOs and RCFs. These Delegated Acts were delayed from their initial deadline but were finally published in 2023. Their contents immediately caused controversy among PtX producers: firstly, even though the acts do specify some matters, a lot of questions remain open, and secondly, the requirements set for the producers are viewed as being too strict to allow economically feasible production of these fuels.

The RED was revised again in 2023. The new Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October (RED III) introduces more ambitious targets and means to achieve them. The Commission aims to both increase the share of renewables in the energy mix, as well as to decrease the total energy consumption in the Union. To contribute to reaching the 2030 GHG emissions reduction target, the target share of 32 % of renewables in the EU energy mix was increased to 42,5 %.[89] Increasing the share of renewables in the energy mix of the Union is important to accelerate the phase-out of the Union's dependence on Russia by increasing the availability of affordable, secure and sustainable energy in the Union.[90] A substantial change brought by the RED III was that to broaden the scope of the definition of transport sector to cover the aviation and maritime sectors as well.[91] As explained earlier, PtX

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[87] COM(2022) 230 final, p. 7.
[88] European Parliament press release, 5/2024.
[89] RED 2023/2413 recital (5), p. 2.
[90] RED 2023 recital (5), p. 2.
[91] Euractiv, 7.4.2023, Kerres, Klessmann, Schimmel. Accessed 13.6.2024.

fuels are expected to be largely used in those sectors, so this extension brings a significant change from RED II. Other solutions to decarbonize industry and transport are incentivized in the EU ETS.[92]

Article 25 (1) of RED III, sets *measures to increase renewable energy and reduce greenhouse gas intensity in the transport sector, by entailing* that EU Member States must set an obligation for fuel suppliers to ensure that: (a) the amount of renewable electricity supplied to the transport sector leads to: (i) a share of renewable energy within the final consumption of energy in the transport sector of at least 29 %; *or* (ii) a GHG intensity reduction of at least 14,5 % by 2030, compared to the baseline set out in Article 27(1), point (b),[93] in accordance with an indicative trajectory set by the Member State. Article 25(1) (b) sets a target for the combined share of advanced biofuels and biogas produced from the feedstock listed in Part A of Annex IX and of the RFNBOs, to constitute at least 1 % of the energy supplied to the transport sector in 2025, and 5,5 % in 2030. This target includes a sub-target for RFNBOs: there must be no less than 1 %-point of RFNBOs of the 5,5 % target in 2030. This target was originally higher: 2,6 % in the initial EC proposal, but it was reduced during negotiations.[94] In order to reach the sub-target, Member States are encouraged to set differentiated targets for advanced biofuels and biogas and RFNBOs, to ensure development and promotion of both fuels.

In accordance with Article 25(2), concerning the calculation of the targets set in paragraph 1, the Member States (a) shall take into account RFNBOs also when they are used in intermediate products for the production of (i) conventional transport fuels. When designing the obligation on fuel suppliers, Member States may: (a) exempt fuel suppliers supplying electricity or RFNBOs from the requirement to comply with the minimum share of advanced biofuels and biogas produced from the feedstock listed in Part A of Annex IX[95] with respect to those fuels; (b) set the obligation by means of measures targeting volumes, energy content or greenhouse

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[92] Euractiv, 7.4.2023, Kerres, Klessmann, Schimmel. Accessed 13.6.2024.
[93] The baseline shall be calculated until 31 December 2030 by multiplying the amount of energy supplied to the transport sector by the fossil fuel comparator EF (t) set out in Annex V; from 1 January 2031, the baseline referred to in Article 25(1), first subparagraph, point (a)(ii), shall be the sum of: (i) the amount of fuels supplied to all transport modes multiplied by the fossil fuel comparator EF (t) set out in Annex V; (ii) the amount of electricity supplied to all transport modes multiplied by the fossil fuel comparator ECF (e) set out in Annex V.
[94] Euractiv, 7.4.2023, Kerres, Klessmann, Schimmel. Accessed 13.6.2024.
[95] Feedstocks for the production of biogas for transport and advanced biofuels listed in Part A of Annex IX include, but are not limited to: biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under point (a) of Article 11(2) of Directive 2008/98/EC; animal manure and sewage sludge; nut shells; biomass fraction of wastes and residues from forestry and forest-based industries, namely, bark, branches, pre-commercial thinnings, leaves, needles, tree tops, saw dust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin and tall oil; and other non-food cellulosic material.

gas emissions; (c) distinguish between different energy carriers; (d) distinguish between the maritime transport sector and other sectors.

RED III sets mandatory targets for the share of hydrogen in the industrial sector. According to Article 22a of RED III, RFNBOs must account for at least 42 % of hydrogen used in the industrial sector by 2030, and 60 % by 2035. Although these targets contribute to the production of hydrogen for use in the industrial sector and not transport, these targets aid in the uptake of hydrogen production which is an important step in the upstream production of many different fuels. The RED III does not set regulatory measures to meet industry targets, so Member States now have to define the regulatory framework to reach these targets nationally. Concerning the targets set for the transport sector, however, the RED III mandates that the sub-targets need to be included in national quota obligations. This means that national fuel suppliers have the responsibility for achieving the target.[96]

Accounting methods are revised in the RED III as well. Contrary to RED II, the renewable electricity that is used to produce RFNBOs is no longer counted towards the overall energy targets; the energy content of the RFNBOs produced will instead be counted in the sector and country where they are consumed. According to RED III, when calculating the share of renewable energy in a Member State, RFNBOs should be counted in their end-use sector: electricity, heating and cooling, or transport. The electricity that is used to produce the RFNBOs shall not be counted towards the renewable energy targets in order to avoid double counting. This system will harmonize the accounting rules for fuels throughout the ETS, regardless of whether they are counted for the overall renewable energy target or for any sub-target. The accounting rules for the fuels throughout Directive (EU) 2018/2001 would thus be harmonized, regardless of whether they are counted for the overall renewable energy targets or sub-targets. This would also take into account energy losses of the process, allowing the real energy consumed to be counted, and take into account the RFNBOs imported and consumed in the Union.[97] Article 25 (4) entails that the Member States shall establish a mechanism to allow fuel suppliers in their territory to exchange credits for supplying renewable energy to the transport sector. Economic operators supplying renewable electricity to electric vehicles through public recharging points shall receive credits, with no regard to whether the economic operators are subject to the obligation set by the Member State on fuel suppliers and may sell those credits to

96 Euractiv, 7.4.2023, Kerres, Klessmann, Schimmel. Accessed 13.6.2024.
97 RED III, recital (12), p. 4.

fuel suppliers which shall be allowed to use the credits to fulfil the obligation set out in paragraph 1, first subparagraph. The Member States should be allowed to agree with a specific cooperation agreement, to count the RFNBOs consumed in a Member State towards the share of gross final consumption of energy from renewable sources in the Member State of production as follows: up to 70 % of their volume in the country were they are consumed and 30 % of their volume in the country of production. The specific cooperation agreements may be made in the Union's renewable development platform.[98] Therefore, if Finland would produce and then export a share of RFNBOs, it could still count 30 % of their volume towards the share of gross final consumption of energy.

3.1.1 Delegated Act 2023/1184

Commission Delegated Regulation (EU) 2023/1184 (hereinafter the Delegated Act 2023/1184 or DA 2023/1184) was introduced to supplement RED II by establishing a Union methodology setting out detailed rules for the production of RFNBOs. Rules for considering the electricity used to produce RFNBOs as renewable are set out in Articles 3 and 4 of the DA. Articles 5, 6 and 7 of the DA 2023/1184 specify further conditions set out in Article 4(4) concerning the conditions for when fuel producers may consider electricity as fully renewable. Since the Delegated Act 2023/1184 was published, it has caused controversy among PtX fuel producers, as the requirements that must be fulfilled are viewed to be too strict to allow for financially manageable business.

Article 3 of the DA 2023/1184 contains the rules for counting electricity obtained via a *direct connection* to an installation generating renewable electricity as fully renewable. The installations generating renewable electricity shall be connected to the installation producing the RFNBO either via a direct connection or the production should take place in the same installation. In Finland, this option is not currently possible in accordance with Article 13 of the Electricity Market Act, as direct connection can only concern small-scale electricity supply (under 2 MW), unless the electricity production facility is located on the same property or property group. However, the Finnish electricity Market Act is going to be amended and the option of direct connection is going to be allowed to scale hydrogen production.[99] The installation generating the renewable electricity must also comply with the additionality requirement, meaning that the installation must have come into operation not earlier than 36

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[98] RED III, recital (12), p. 4.
[99]The ministry of Employment and Economic Affairs, VN/13979/2023-TEM-19, p. 2.

months before the installation producing RFNBO. If the installation has added its renewable electricity production capacity, the additional capacity is considered as a part of the existing installation, provided that the capacity is added at the same site and that the addition takes place no later than 36 months after the initial installation has come into operation. The installation producing electricity may be connected to the grid, but in such cases a smart metering system must be in place to measure all electricity flows to ensure that no electricity is taken from the grid to produce RFNBOs.

Article 4 of the DA 2023/1184 sets the general rules for counting *electricity taken from the grid* as fully renewable. In accordance with paragraph 1 of Article 4, fuel producers may count electricity taken from the grid as fully renewable if the RFNBO production installation is in a bidding zone where the average proportion of renewable electricity exceeded 90 % in the previous calendar year, and the production of RFNBOs does not exceed a maximum number of hours set in relation to the proportion of renewable electricity in the bidding zone. The paragraph also sets a method for calculating the mentioned maximum number of hours.[100]

In accordance with paragraph 2 of Article 4, if the conditions of paragraph 1 are not met, the electricity taken from the grid may also be counted as fully renewable if the RFNBO installation is located in a bidding zone where the emission intensity of electricity is lower than 18 gCO_2eq/MJ, provided that (a) the fuel producers have either directly or via intermediaries concluded, one or more PPAs with economic operators producing renewable electricity for an amount that is equivalent to at least the amount of electricity that is claimed as fully renewable, and that (b) the conditions of temporal and geographical correlation set out in articles 6 and 7 must be met as well; the emission intensity of electricity shall be determined based on latest available data, from which the average carbon intensity of grid electricity is calculated using the methodology for determining the GHG emissions savings from the RNFBO and from RCF set out in the DA 2023/1185. If the emission intensity of electricity is lower than 18 gCO_2eq/MJ during a calendar year, the average emission intensity shall be considered under 18 gCO_2eq/MJ for the subsequent five years.

In accordance with paragraph 3 of Article 4, the *electricity taken from the grid may be considered as fully renewable if the electricity is consumed to produce RFNBO during an*

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[100] This maximum number of hours shall be calculated by multiplying the total number of hours in each calendar year by the share of renewable electricity reported for the bidding zone where the renewable liquid and gaseous transport fuel of non-biological origin is produced.

imbalance settlement period,[101] and the fuel producer is able to demonstrate that the power-generating installations were redispatched[102] downwards in accordance with Article 13 of Regulation (EU) 2019/943;[103] and that the electricity consumed reduced the need for redispatching by a corresponding amount.

Finally, in accordance with paragraph 4 of Article 4, where the conditions in paragraphs 1,2 and 3 are not met, *fuel producers may count electricity as fully renewable if it complies with the conditions of additionality, temporal correlation and geographical correlation in accordance with Articles 5 6, and 7.*

The condition of additionality is defined in Article 5 of the DA 2023/1184. According to Article 5, the condition of additionality shall be considered complied with if the fuel producers produce an amount of renewable electricity in their own installations that is at least equivalent to the amount of electricity claimed as fully renewable, or have concluded directly or via intermediaries, one or more PPAs with economic operators producing renewable electricity for an amount of renewable electricity that is at least equivalent to the amount of electricity that is claimed as fully renewable. The installation generating renewable energy must also meet the following criteria: (a) it has not come into operation earlier than 36 months before the installation producing RFNBOs, and (b) it has not received operating aid or investment aid.[104] Article 11 concerning the transitional phase states that Article 5 points (a) and (b) shall apply from 1 January 2038 to RFNBO installations that come into operation before 1 January 2028. To put it in simpler terms, RFNBO producers must either produce the renewable energy themselves or acquire it from a renewable electricity installation that has come into operation

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[101] According to Regulation (EU) 2019/943 Article 2 (15), imbalance settlement period means the time unit for which the imbalance of the balance responsible parties is calculated.

[102] According to Regulation (EU) 2019/943 Article 2 (26), 'redispatching' means a measure, including curtailment, that is activated by one or more transmission system operators or distribution system operators by altering the generation, load pattern, or both, in order to change physical flows in the electricity system and relieve a physical congestion or otherwise ensure system security.

[103] Article 13 of Regulation (EU) 2019/943 regulates on the redispatching of generation. Article 13 (6) lists the principles that must be applied in the non-market based redispaching, and states that
(a) power-generating facilities using renewable energy sources shall only be subject to downward redispatching if no other alternative exists or if other solutions would result in significantly disproportionate costs or severe risks to network security; (b) electricity generated in a high-efficiency cogeneration process shall only be subject to downward redispatching if, other than downward redispatching of power-generating facilities using renewable energy sources, no other alternative exists or if other solutions would result in disproportionate costs or severe risks to network security; (c) self-generated electricity from generating installations using renewable energy sources or high-efficiency cogeneration which is not fed into the transmission or distribution network shall not be subject to downward redispatching unless no other solution would resolve network security issues; (d) downward redispatching under points (a), (b) and (c)shall be duly and transparently justified.

[104] This excludes support received before the repowering of an installation, financial support for land or for grid connections, and support that does not constitute net support.

within three years of the RFNBO installation coming into operation. The condition of additionality has a huge impact on when and where renewable hydrogen production facilities can be set up. Although it may cause a hindrance for RFNBO production, it makes sense that the existing renewable energy production is directed to the electricity grid instead of directed to PtX materials with a certain degree of efficiency loss. This comes back to the fact that the decarbonisation efforts are primarily achieved with electrifying sectors, instead of using sustainable fuels. Production facilities in Finland would probably have a competitive advantage in comparison to some other European projects, as Finland is planning to substantially increase renewables production with new wind farms and solar power projects.

Article 6 of the DA 2023/1184 concerns the condition of temporal correlation, which until 31 December 2029, shall be considered complied with if the RFNBO is produced during the same calendar month as the renewable electricity produced under the renewables power-purchase agreements (PPAs) or from renewable electricity from a new storage asset that has been charged during the same calendar month in which the electricity has been produced. From 1 January 2030, the time frame for complying with the condition of temporal correlation is reduced to one hour, meaning that the RFNBO must be produced during the same one-hour period as the renewable electricity under the renewables power-purchase agreement is produced, or from renewable electricity from a new storage asset that has been charged during the same one-hour period in which the renewable electricity has been produced. The Member States may apply the one-hour requirement from 1 July 2027 for the production of RFNBO in their territory. Additionally. the condition of temporal correlation shall always be considered complied with if the RFNBO is produced during a one-hour period where the clearing price of electricity resulting from single day-ahead market coupling in the bidding zone[105] is lower or equal to € 20 per MWh or lower than 0,36 times the price of an allowance to emit 1 tonne of carbon dioxide equivalent during the relevant period for the purpose of meeting the requirements of Directive 2003/87/EC. Especially after 1 January 2030, compliance with the requirement is difficult to attain due to the intermittent nature of renewable energy production. If the production stream uses renewable energy from e.g. wind or solar power sources only, would the facility have to shut down production during periods with no wind/sunshine? Of course, the producers can arrange to continue production utilizing grid electricity, but if the grid electricity does not meet EU standards, the hydrogen cannot be considered renewable in EU terms if the

[105] Article 39(2), point (a) of Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management.

production stream uses renewable energy from e.g. wind or solar power sources only with no possibility to store electricity into storage assets.

Article 7 concerns the requirement of geographical correlation. The condition shall be considered complied with if at least one of the following criteria (a)-(c) relating to the location of the electrolyser is fulfilled. According to the first paragraph, (a) the installation generating renewable electricity under the renewables PPA is located, or was at the time it came into operation, in the same bidding zone as the electrolyser; (b) the installation generating renewable electricity located in an interconnected bidding zone, including in another Member State, and electricity prices in the relevant time period on the day-ahead market in the interconnected bidding zone is equal or higher than in the bidding zone where the RFNBO is produced; or (c) the installation generating renewable electricity under the renewables PPA is located in an offshore bidding zone that is interconnected with the bidding zone where the electrolyser is located. Production facilities in Finland should not have too many issues as with the conditions of geographical correlation and additionality, as Finland makes one bidding zone, and it is going to increase renewables production. Complying with the requirement of geographical correlation may, however, become an issue in those Member States which consist of multiple bidding zones.

Compliance with these rules is ensured in accordance with Article 9 (certification of compliance), according to which, fuel producers may make use of national schemes or international voluntary schemes that have been formally recognized by the Commission pursuant to Article 30(4) of Directive (EU) 2018/2001. The Commission has formally recognized only 15 certification agencies. These schemes check that the electricity used to produce renewable hydrogen is of renewable origin, and that the production of renewable fuels leads to sufficient GHG emissions savings.[106]

3.1.2 Delegated Act 2023/1185

Article 25 of RED concerns increasing the use of renewable energy and reducing GHG intensity in the transport sector. The Commission Delegated Regulation (EU) 2023/1185 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a minimum threshold for GHG emissions savings of recycled carbon fuels and by specifying a

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[106] European Commission, Voluntary schemes, Accessed 1 July 2024.

methodology for assessing GHG emissions savings from RFNBOs and from RCFs (hereinafter the DA 2023/1185) supplements the RED II and was adopted only shortly before RED III came into force. The GHG accounting methodology considers the life-cycle emissions of production based on objective and non-discriminatory criteria. Credits are not granted for capturing CO_2 which has already been taken into account under other provisions of Union law. Due to this, that kind of captured CO_2 should not be considered as being avoided when determining the emissions from the inputs' existing use or fate.[107] Sources of carbon that can be captured should become increasingly scarce in the medium- to long-term. Captured emissions from the combustion of non-sustainable fuels for the production of electricity should be considered avoided emissions up to 2035, and emissions from other users of non-sustainable fuels should be considered avoided emissions up to 2040, as these emissions shall remain longer.[108]

According to Article 3 of the DA 2023/1185 the GHG emissions savings from RFNBOs and RFCs shall be calculated in accordance with a methodology set in the Annex. The emissions intensity shall be expressed in terms of grams of CO_2 equivalent per MJ of fuel (gCO_2eq/MJ fuel). Where E represents the total emissions of the RFNBO or RCF, and EF represents the total emissions from the fossil fuel comparator, the GHG emissions savings shall be calculated with the formula (EF-E)/EF. To calculate the total emissions, the full value chain of RFNBOs is accounted for, excluding only the emissions from manufacturing the machinery and equipment.[109] For all RFNBOs (and RCFs), the total emissions from the fossil fuel comparator

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[107] DA 2023/1185, recital (3) and (4), p. 1.

[108] DA 2023/1185, recital (5), p. 1. The dates mentioned are subject to review.

[109] The emission sources are divided into the following categories: ei= ei elastic (emissions from elastic inputs) + ei rigid (emissions from rigid inputs) + ei ex-use (emissions from inputs' existing use or fate): emissions from supply of inputs (gCO2eq/MJ fuel); ep = emissions from processing; etd = emissions from transport and distribution; eu = emissions from combusting the fuel in its end-use; and eccs = emissions savings from carbon capture and geological storage. The total emissions from the use of the fuel shall therefore be calculated as follows: E= ei + ep + etd + eu - eccs. Emissions from inputs (Ei) are categorized further into elastic, rigid and ex-use inputs. According to the Delegated Act, elastic inputs are those whose supply can be increased to meet extra demand, such as petroleum products, hydrogen and electricity. When calculating emissions from elastic inputs, the data must include emissions from the extraction of primary energy required to make the input, emissions from the processing and the transportation of the inputs, excluding the emissions from combustion of inputs, as those are counted under ep or eu. Rigid inputs are those whose supply cannot be expanded to meet extra demand, e.g. all inputs qualifying as a carbon source for the production of recycled carbon fuels are rigid. The calculation of the emissions intensity of rigid inputs must include: all emissions from the diversion of feedstock from previous use, emissions from additional treatment and transport, and emissions from lost production. Emissions from inputs existing use or fate are emissions "that are avoided when carbon is used as input for fuel production," if the CO2 was captured via direct air capture, from biofuels/-liquids/-mass, RFNBO or RCF, geological sources or CO2 from activities subject to the EU ETS. Emissions from processing include direct emissions to the atmosphere from the processing, waste treatment and leakages, whereas emissions from combustion mean the total combustion emissions of the fuel when it is used. When calculating the emissions from transportation and distribution, emissions from the storage and distribution of the finished fuels shall be included. See also international PtXHub, 2023, p. 18–19.

shall be 94 g CO_2eq/MJ. This means that the maximum greenhouse gas emissions intensity of RFNBOs is 28.2 g CO_2eq/MJ. A fuel may exceed this threshold, but if so, they will not count for the renewable energy targets of the Renewable Energy Directive,[110] and will not be considered an RFNBO.

In accordance with paragraph A (10) of the Annex, the CO_2 used for the production of RFNBOs can be captured from: (a) activities subject to the EU ETS until 2036 when the CO_2 has been taken into account upstream in an effective carbon pricing system and is incorporated in the chemical composition of the fuel and until 2041 when the CO_2 has been captured from electricity production; (b) the atmosphere; (c) the production of biofuels, bioliquids or biomass fuels that have not been considered compliant with the GHG savings criteria of the DA 2023/1185; (d) combustion of RFNBOs or RFCs; and (e) from a geological CO_2 source.

The Annex of DA 2023/1185 also sets the rules for accounting when RFNBOs are co-processed and co-produced with conventional fuels and biomass. In such instances, the calculation shall distinguish them proportionally. Finally, the DA 2023/1185 defines the default GHG emissions intensities for common inputs. Electricity that qualifies as fully renewable in accordance with Article 27(3) of Directive (EU) 2018/2001 shall be attributed zero GHG emissions. GHG emissions of electricity that is taken from the grid and does not qualify as fully renewable is calculated by applying one of the following three methods: (a) the GHG emissions values shall be attributed according to part C of the Annex; (b) depending on the number of full load hours the installation is operating; or (c) using the value of the marginal unit generating electricity at the time of the production of the RFNBO.

3.2 Hydrogen and Gas Market Package

The Hydrogen and Gas Market Package consists of the Directive (EU) 2024/1788 of the European Parliament and of the Council of 13 June 2024 on common rules for the internal markets for renewable gas, natural gas and hydrogen (the Hydrogen and Gas Market Directive) and a Regulation (EU) 2024/1789 of the European Parliament and of the Council of 13 June 2024 on the internal markets for renewable gas, natural gas and hydrogen (the Hydrogen and Gas Market Regulation). The Directive as well as the Regulation are both part of the Fit for 55 package.[111] The European Council and Parliament reached an agreement on 27 November 2023

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[110] International PtX Hub, 2023, p. 16.
[111] Council of the EU, Press Release 8 December 2023, accessed 12 July 2024.

on the future hydrogen and gas market concerning the Directive, and on 8 December 2023 concerning the Regulation.[112] The Council adopted the Regulation and the Directive for the Hydrogen and Gas markets on 21 May 2024.[113] The purpose of the Package is to facilitate the penetration of renewable and low-carbon gases – especially hydrogen and biomethane – into the energy markets.[114] To achieve this, the Directive, for example sets a common definition for low-carbon hydrogen.

According to Article 2(11) of the Directive, low-carbon hydrogen means hydrogen, the energy content of which is derived from non-renewable sources, which meets the greenhouse gas emission reduction threshold of 70 % compared to the fossil fuel comparator for RFNBOs set out in the methodology for assessing GHG emissions savings from RFNBOs and from RFCs. However, neither the Hydrogen and Gas Market Directive or the Regulation define the specific methodology for calculating these GHG emissions savings. This methodology is crucial for the production of low-carbon hydrogen, and will provide further incentives to producers and investors. Article 9(5) of the Directive 2024/1788 concerning the certification of renewable gas and low-carbon fuels states that by 5 August 2025, the Commission shall adopt delegated acts in accordance with Article 90[115] to supplement the Directive by specifying the methodology for GHG emissions savings from low-carbon fuels.

Despite these rules not yet being in force, some guidelines to their contents already exist. According to the Directive, the methodology shall ensure that credit for avoided emissions is not given for CO_2 from fossil sources the capture of which has already received an emission credit under other provisions of law and shall cover the life cycle of GHG emissions and consider indirect emissions from the diversion of rigid inputs. Furthermore, this methodology shall be consistent with the equivalent methodology for RFNBOs, including the treatment of emissions due to the leakage of hydrogen, and taking into account methane upstream emissions and the actual rates of carbon capture. However, since the Commission was delayed with the delegated acts of RED II, there is reason to doubt that the delegated acts on the Hydrogen and

[112] Council of the EU, Press Release 21 May 2024, accessed 12 July 2024.
[113] Council of the EU, Press Release 21 May 2024, accessed 12 July 2024.
[114] Council of the EU, Press Release 8 December 2023, accessed 12 July 2024.
[115] Article 90 concerns the exercise of delegation, and confers the power to adopt delegated acts to the Commission.

Gas Market Directive are ready and finalized by the deadline. This kind of delay would further disadvantage low-carbon hydrogen.[116]

3.3 The EU Emissions Trading System

The EU Emissions Trading System (ETS), established by Directive 2003(87/EC) aims to reduce GHG emissions by gradually making it more and more expensive for economic actors to emit, as they must purchase emissions allowances for the amount of carbon dioxide equivalent emissions they let out into the atmosphere. Free emissions allowances are allocated to some sectors that are deemed to be in need of support. The inevitable *energy efficiency loss of carbon capture can only be economically justified if the cost of emitting CO_2 in accordance with the EU ETS is higher than the cost to capture and utilise the CO_2.* This is a major obstacle for the broad implementation of CCU technologies.[117]

The ETS Directive was recast in 2023 (Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023) to better align the ETS with the Fit for 55. The revision concerns the ETS's current phase (phase 4 from 2021 to 2030), and its main elements are as follows: 1) a reduced cap and a more ambitious linear reduction factor for GHG emissions, 2) revision of rules on free allocation and the Market Stability Reserve, 3) extension of ETS to maritime transport, 4) establishing a new separate ETS for buildings and road transport; and 5) increasing of the Innovation and Modernisation Funds and new rules on use of ETS revenue.[118]

One of the principal mechanisms of the Fit for 55 is to be strengthening the EU ETS by expanding it to new sectors where emission reductions have been lacking so far. The ETS is gradually extended to cover the maritime sector over the period of 2023–2025. In accordance with Article 3gb of the Directive (EU) 2023/959 (phase-in of requirements for maritime transport) shipping companies have to surrender a gradually increasing portion of allowances that would be subject to surrender requirements in accordance with Article 12, in accordance with the following schedule: (a) 40 % of verified emissions reported for 2024; (b) 70 % of the verified emissions reported for 2025; and (c) 100 % of the verified emissions. The free emissions allowances in the aviation sector are phased out. The expansion of the ETS is

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[116] Talus – Pinto – Gallegos, 2024, p. 9–10.
[117] EU report 2022, p. 20.
[118] European Parliament, Legislative Train 5/2024, The Revision of the EU Emission Trading System (ETS), p. 1.

supposed to aid in bringing cleaner transport and heating fuels to the market.[119] The recast ETS Directive sets a target of reducing GHG emissions by 63 % by 2030 in the sectors covered. Free allowances in the sectors covered by the Carbon Border Adjustment Mechanism (CBAM)[120] are gradually phased out between 2027–2032.[121]

The ETS supports the uptake of RFNBOs in the aviation sector by providing 20 million emissions allowances from 2024 to 2030 to aircraft operators for free, to cover the remaining cost-difference for the deployment of RFNBOs and Sustainable Aviation Fuels (hereinafter SAFs). The use of CCU-based fuels is recognized in the EU ETS in order to avoid the embodied carbon emissions of such fuels. The industrial carbon management strategy also recognises the need for additional measures to recognize the potential climate benefits of using captured CO_2 instead of fossil carbon for other applications, such as manufacturing polymers, plastics, solvents and paints in the chemical industry.[122] The recital of the recast ETS (EU) 2023/959 addresses the main goals of the revision. According to paragraph 10 of the recital, the EU ETS should incentivise production from installations that either partly reduce or fully eliminate GHG emissions. Definitions for some categories of activities as well as products which are covered under the EU ETS are modified to ensure equal treatment of installations under the ETS. The free allocation should take into account the circular use-potential of materials.[123] Point 14 of the recital of the revised Directive also recognizes that new innovative technologies often allow the reduction of both GHG emissions and pollutants, and that it is important to ensure synergies between these measures.

Renewable hydrogen producers are subject to the free allocation of emission rights, which they can sell for more profit. The scope of the EU ETS regarding hydrogen was expanded to cover the production of hydrogen and synthesis gas up to a production capacity of 5 tonnes per day. Previously, the required production capacity to be included in the scope was 25 tonnes per day,[124] but it was lowered to 5 tonnes in the revision. Article 10a concerning the free allocation of emissions allowances was also amended in the revision. In accordance with paragraph 8 of

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[119] COM(2021) 550 final, p. 5–7.
[120] The Carbon Border Adjustment Mechanism, established under Regulation (EU) 2023/956 of the European Parliament and of the Council is a mechanism that is set to introduce carbon pricing for imports and domestic products under risk of carbon leakage, that are currently managed by free allocation under the EU ETS. The CBAM is going to be gradually phased in.
[121] European Parliament, Legislative Train 5/2024, The Revision of the EU Emission Trading System (ETS), p. 2–4.
[122] COM(2024) 62 final, p. 16–17.
[123] Official Journal of the European Union, 16.5.2023, L 130/134, p. 3.
[124] Hydrogen Europe Position Paper, 2022, p. 5.

Article 10a, 345 million allowances from the quantity of allowances which could otherwise be allocated for free, and 80 million allowances from the quantity which could be auctioned pursuant to Article 10, shall be made available to the Innovation Fund to support innovation in low-carbon technologies, processes and technologies that significantly contribute to decarbonisation of the sectors covered in the Directive. This includes also CCU that contributes significantly to mitigating climate change, especially for unavoidable process emissions, as well as products substituting carbon intensive ones produced in sectors covered by the ETS, and to help stimulate the construction and operation of CCS projects to further achieve decarbonisation goals.

A separate and independent emissions trading system for fuel distribution for the purposes of road transport and buildings shall be established from 2025. The so-called “ETS2” is completely separate from the existing ETS, although it is also regulated in Directive 2003/87/EC, with a new chapter IVa, “Emissions Trading System for Buildings, Road Transport and Additional Sectors.” Even though the ETS2 functions largely in the same manner as the existing ETS (meaning that there will be a linear decrease in the amount of emissions allowances through the years), the new system targets suppliers, rather than the end users.[125] Therefore, fuel distributors will have to report the amount of fuels placed in the markets from 2024, and from 2026 onwards, they will have to surrender to a corresponding amount of allowances. The goal is to reduce the emissions by 43 % by 2030 compared to 2005 levels. Another difference to the existing ETS is that all emissions allowances will be auctioned, meaning that there will be no free allocation in the new ETS.[126] These measures increase the administrative burden of fuel suppliers, but are necessary in achieving the decarbonisation targets of the transport sector.

The EU ETS is going to be reviewed in 2026, with the aim to assess several points, including whether or not the accounting system truly ensures that all emissions are accounted for and avoids double counting when captured CO_2 is used in products that are not considered permanent in the ETS context. The review shall assess whether or not the CO_2 potentially released from non-permanent CCU products and fuels should be accounted at the point of emission to the atmosphere (downstream accounting), or when the CO_2 is initially captured

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[125] European Commission, ETS2: buildings, road transport and additional sectors, Accessed 16 July 2024.
[126] European Parliament, Legislative Train 5/2024, The Revision of the EU Emission Trading System (ETS), p. 2.

(upstream accounting).[127] The revision of the recast ETS is a good way to assess the possible shortcomings. However, changing the legislation may affect the willingness of market players and investors to start new projects, as the legislation significantly affects how production should be organized.

[127] COM(2024) 62 final, p. 17.

4 EU support policies for the production of PtX fuels

Due to their high prices in comparison to fossil fuels, the production of RFNBOs (and other PtX fuels) is not economically feasible (at least in the early market phase) without additional policy measures and support schemes to artificially increase demand to aid projects in their early phases. This chapter aims to provide an answer to the research question on what EU policy measures are in place to support the production of Power-to-X fuels. In the beginning, this chapter continues the thematic of the previous chapter and introduces EU policies to increase the demand of these fuels in the aviation and the maritime sectors, as well as the mandatory requirements for the fuelling infrastructure for road transport, and finally the EU's goals for carbon management. This chapter then goes over the projected investment needs required to achieve the goals established for the production of hydrogen, and finally, introduces existing support mechanisms to direct funds to projects related to PtX production.

4.1 Policies to create a market for RFNBOs

Although PtX fuels are currently more expensive than their fossil comparators, demand for them is created through a set of EU standards. Gradually increasing minimum shares for PtX fuels are set e.g. in the Regulation (EU) 2023/2405 of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation), which sets an increasing minimum share for sustainable aviation fuels in EU airports, as well as the Regulation (EU) 2023/1805 of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport (FuelMaritimeEU), concerning the maritime sector. The deployment of sustainable fuels in the maritime and aviation sectors is promoted through these Regulations, which both aim to gradually make polluting fuels more expensive for suppliers.[128] Objectives for a functional fuelling infrastructure for road vehicles is set in the regulation (EU) 2023/1804 of the European Parliament and of the Council on the deployment of alternative fuels infrastructure and repealing Directive 2014/94/EU (Alternative Fuel Infrastructure Regulation, AFIR), which sets mandatory targets for infrastructure for the deployment of a functioning and user-friendly infrastructure for refuelling and recharging cleaner vehicles. It e.g. sets a maximum distance between fuelling stations to ensure alternative fuel availability also in the more remote areas of the Union.

[128] COM(2021) 550 final, p. 7–9.

4.1.1 ReFuelEU Aviation

In the aviation sector, the uptake of RFNBOs as well as other sustainable fuels is incentivized by obliging suppliers to blend an increasing amount of SAFs in their jet fuel mix. In accordance with Article 3, point (7) of the Regulation (EU) 2023/2405, the term sustainable aviation fuels refers to aviation fuels that are either (a) synthetic aviation fuels; (b) aviation biofuels; or (c) recycled carbon aviation fuels. Synthetic aviation fuels, in turn, are defined in Article 3(12) of regulation (EU) 2023/2405 as aviation fuels that are RFNBOs as defined in Article 2(36) of Directive (EU) 2018/2001, therefore including RFNBOs into the SAF definition. The ReFuelEU Aviation regulation lays down harmonised rules on the uptake and supply of sustainable aviation fuels (SAF).

The Regulation sets an obligation for an increasing minimum share of sustainable aviation fuels in the fuel mix of aircrafts. According to Article 4 of the Regulation, titled *Shares of SAF available at Union airports*, aviation fuel suppliers shall ensure that the aviation fuel made available to aircraft operators contains the minimum share of SAF in accordance with the dates and values set in Annex I of the Regulation. For each year, the Annex mandates a minimum share of SAF

- 2 % of from 1 January 2025,
- 6 % from 2030, 20% from 2035,
- 34 % from 2040,
- 42 % from 2045 and
- 70 % from 2050.

A sub-target for synthetic aviation fuels is included into these targets; from 1 January 2030 until 31 December 2031, an average share of 1,2 % of synthetic fuels, of which each year a minimum share of 0,7 % of synthetic aviation fuels. From 1 January 2032 until 31 December 2034, an average share of 2 % of synthetic fuels, of which each year a minimum share of 1,2 % from 1 January 2032 until 31 December 2033, and of which a minimum share of 2 % from 1 January 2034 until 31 December 2034 of synthetic aviation fuels. The target shares of SAF should from 1 January 2035 contain a minimum share of 5% of synthetic aviation fuels, and accordingly, 10% from 2040, 15% from 2045 and 35 % from 2050.

Due to the global and cross-border nature of the aviation sector, the chosen legislative instrument for the ReFuelAviation EU is a regulation. A level playing field is secured by directly and uniformly regulating the actions of the economic actors.[129] The regulation hinders fuel tankering practices of aircraft operators, as Article 5, paragraph 1 contains an obligation for aircraft operators not to uplift aviation fuel over 90 % of the yearly quantity that is necessary. Fuel tankering means when aircraft operators tanker more fuel than necessary at the departing airport in order to avoid refuelling completely or partially at the destination, where fuel is more expensive. This practice increases emissions and is harmful for healthy competition in the aviation industry.[130] This is a good example of efficiently regulating economic actors in order to create a functioning and equal regulatory framework, even though it reduces the Member State's ability to create their own regulatory approaches.

4.1.2 FuelEU Maritime

Sustainable maritime fuels are promoted by creating new requirements by imposing a limit for the GHG content of the energy used for ships arriving to or departing from EU ports. The regulation applies to both cargo and passenger ships of above 5000 gross tonnages, which make up to about 55% of all ships calling at ports and about 90% of all CO_2 emissions from the maritime sector. The FuelEU Maritime initiative aims to ensure fair competition while creating favourable conditions for renewable and low-carbon fuels to penetrate the market. In Article 1, the regulation lays down uniform rules for (a) the limit on the GHG intensity of energy used on board by a ship arriving at, staying or departing from Member State ports; and (b) an obligation to use on-shore power supply or zero-emission technology in ports under the jurisdiction of a Member State.

Accounting rules for calculating the GHG intensity in the maritime sector are favourable to RFNBOs. The GHG intensity limit on energy used on board by a ship is laid out in Article 4(1) and shall be calculated by *reducing* the reference value of 91,16 grams of CO_2 equivalent per MJ by 2 % from 2025, 6 % from 2030, 14,5 % from 2035, 31 % from 2040, 62 % from 2045 and 80 % from 2050. For the GHG intensity calculation of RFNBOs, a multiplier of 2 may be used in accordance with Article 5 of the Regulation, favouring the use of RFNBOs in the maritime sector.

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129 COM(2021) 561 final, p. 7.
130 COM(2021) 561 final, p. 1.

In addition to the FuelEUMaritime Regulation, Article 25 of RED reinforces the uptake of RFNBOs in the maritime sector as well. According to Article 25, Member States with maritime ports shall endeavour to ensure that as of 2030, the share of RFNBOs in the total energy supply of the maritime transport sector is at least 1,2 %. These measures obligating ships over 5000 gross tonnages to gradually start using more sustainable options in their fuel-mix contribute to reaching the EU's decarbonisation targets as well as facilitating the market penetration of renewable and low-carbon fuels.

4.1.3 Alternative Fuels Infrastructure Regulation

Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on deployment of alternative fuels infrastructure concerning road vehicles, trains, vessels and stationary aircraft does, in accordance with paragraph (9) of the recital, *lay down mandatory minimum targets for the deployment of publicly accessible recharging and refuelling infrastructures for road vehicles.* Although road transport can be largely decarbonized with electric vehicles, there is still a place for alternative fuels in future road transport. Taking into account the value-chain nature of RFNBO development, the targets set for hydrogen refuelling stations in the AFIR incentivize the uptake and production of other PtX fuels as well.

According to Article 6 of the Regulation, titled *[t]argets for hydrogen refuelling infrastructure of road vehicles*, Member States shall ensure the deployment of a minimum number of publicly accessible hydrogen refuelling stations by 31 December 2030. By 31 December 2030, publicly accessible hydrogen refuelling stations[131] are deployed with a maximum distance of 200 km between them, and that at least one is deployed in each urban node. The Regulation also includes obligations to ensure user friendliness, e.g. that prices charged by the operators of hydrogen refuelling points shall be reasonable, easily and clearly comparable, transparent and non-discriminatory. These rules aid in decarbonizing road transport, which causes 76 % of emissions from the transport sector.[132]

4.1.4 Carbon Management Strategy and CCU

Carbon Capture and Utilisation is incentivised not only in the EU ETS, but also in other policy measures, such as the Industrial Carbon Management Strategy (COM(2024) 62 final),

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[131] Stations must be designed for a minimum cumulative capacity of 1 tonne per day and equipped with at least a 700 bar dispenser.
[132] EEA, 24 October 2023, accessed 26 June 2024.

established on 6 February 2024. Before the Strategy, the Commission has adopted a communication (COM(2021) 800 final) in 2021 to establish sustainable and climate-resilient carbon cycles by listing key actions to support CCUS.[133] In accordance with the new strategy, the EU's goals for the uptake of renewable hydrogen in industry and transport by 2030 will further incentivise the use of CO_2 for the production of methanol and e-fuels.[134]

To reach the EU's climate targets for 2040, modelling shows that approximately 280 million tonnes would have to be captured by 2040, and approximately 450 million tonnes by 2050.[135] By 2040, carbon value chains should become economically viable, and up to a third of captured CO_2 could be utilized. However, the planned future value chains require a significant addition in transport and storage infrastructure, that would enable cross-border transportation in the EU's single market.[136] The goal of the EU industrial carbon management strategy is to establish a non-discriminatory, open-access and transparent CO_2 value chain. One issue with ensuring equal opportunities is that carbon capture installations which are located far from industrial hubs and storage sites, as well as smaller emitters with not enough emissions to interest transport operators might risk exclusion from the market.[137] By early 2026, the Commission plans to establish an EU CO_2 aggregation platform to support companies capturing CO_2 and producing CO_2 value chain services.[138]

According to the industrial carbon management strategy, setting specific objectives for carbon removals could be considered in line with the overall EU net GHG emissions reduction objective for 2040 and climate neutrality by 2050. This could be achieved by integrating industrial carbon removals in the EU ETS or with a new separate compliance mechanism for such removals, linked either directly or indirectly to the EU ETS.[139] The strategy further states that to enable CCU technologies, access to hydrogen is required. This means that synergies between CCU and hydrogen networks play a key role in decarbonisation.[140] Setting binding targets for carbon removals would greatly incentivize the industrial sector to use carbon capture

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[133] COM(2024) 62 final, p. 11.
[134] COM(2024) 62 final, p. 6.
[135] COM(2024) 62 final, p. 2.
[136] COM(2024) 62 final, p. 7.
[137] COM(2024) 62 final, p. 9.
[138] COM(2024) 62 final, p. 11.
[139] COM(2024) 62 final, p. 14.
[140] COM(2024) 62 final, p. 16.

technologies. This would benefit not only the climate, but also the uptake of captured carbon as raw material in the production of multiple products, including RFNBOs.

4.2 Investment needs for PtX fuel value chains

As the PtX fuel market is not yet fully developed in the EU, market players might not have sufficient interest in investing in the market, because the ratio of costs for investment and expected outcome is still too low. Furthermore, there is uncertainty on the expectations of other market players, which may play negatively into the willingness of investors to invest. According to Baumgart and Lavrjissen, this market failure could be addressed with EU subsidies, e.g. for building a hydrogen infrastructure which could help stimulate investments into sustainable hydrogen.[141]

According to a report published by the European Investment Bank (EIB), in order to achieve the goals set by the EU, the cumulative investment needed in hydrogen production capacity in the EU could amount up to €470 billion by 2050.[142] According to the report on the potential of RFNBOs, the scaling-up of production capacities of RFNBOs requires substantial investments in production facilities, especially to renewable energy production plants and electrolysers, but also to synthesis plants for the conversion of hydrogen and CO_2 into carbon-based fuels. The need for investments is largely based on the future demand of RFNBOs, which can be modelled into different scenarios ranging from conservative to ambitious. According to the report, depending on the scenario, investment needs for RFNBO plants until 2050 range from € 155 billion $_{2019}$ (of which € 18 billion to non-domestic production capacities).[143] to € 390 billion$_{2019}$ (of which € 250 billion to non-domestic production capacities). Regardless of the scenario, the majority (about 80 %) of these investments would go to installing electrolysers, and the rest to gaseous and liquid synthesis routes.[144] When it comes to infrastructure, according to the RePowerEU Plan, the total investment needs for hydrogen infrastructure are estimated to be € 28 – 38 billion for EU-internal pipelines and € 6-11 billion for storage.[145]

The EU report on RFNBO potential in the transport sector examines the expected economic development of RFNBOs and RFCs in comparison to fossil fuels. Due to unevenly distributed

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[141] Baumgart – Lavrijssen, 2024, p. 146–147.
[142] European Investment Bank, 2022, p. 11
[143] EU Final report. Task 1, 2022, p 95.
[144] EU Final report. Task 1, 2022, p 95–96.
[145] COM(2022) 230 final, p. 7.

gas and oil resources, the global fossil fuel markets suffer from a lack of competition, which leads to a situation where fossil fuel suppliers get margins far beyond actual production costs. This will likely not be the case for RFNBOs, as renewable electricity production capacity as well as water are widely available. Of course, production in some countries (like Finland) is going to have a competitive advantage if the country has better conditions to produce these fuels. However, more competition can be expected between RFNBO suppliers than what fossil fuel suppliers currently face.[146]

As PtX fuels do not really have any user advantages than their green label when compared to fossil fuels, the main barrier of their market uptake is their price. The EU report on the potential of RFNBOs in the transport sector (Task 1) examines the price developments of comparative fossil fuels[147] and indicates policy measures to close the price gap. In all scenarios, the price gap between RFNBOs and their fossil comparators is substantial. The price gap is bigger for methane and liquid RFNBOs when compared to hydrogen; hydrogen may close the price gap in the long term, but this may not happen for methane and liquid RFNBOs. The report concludes that *regardless of the type, RFNBOs will not be cost-competitive with fossil fuels without additional measures*. The distribution and sales costs will be mainly the same for both renewable and fossil alternatives. The policy changes suggested in the report are e.g. pricing carbon emissions and increasing taxes and levies.[148] The ETS2 for the transport sector should gradually increase the prices of fossil fuels for transport, closing the price gap. However, the required carbon price level for the ETS to be effective varies significantly depending on the types of RFNBOs in 2030.

Significant investments are necessary in CO_2 management systems across the value chain. One Commission study estimates that a CO_2 transport network (for both CCU and CCS) which would include pipelines and shipping routes could span up to 7300 km by 2030 and its deployment could cost up to € 12.2 billion, and rising to 19 000 km and € 16 billion in total by 2040.[149] In order to optimise the investments to carbon management, interactions with the electricity sector, gas sector and hydrogen sector should be looked at. It may also be possible

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146 European Commission, Final report Task 1, 2022, p. 89–90. The report notes that the situation is different for blue hydrogen- based fuels, as natural-gas-based hydrogen production relies on the natural-gas supply.
147 Crude oil for Power-to-Liquid fuels, natural gas for synthetic methane, fossil hydrogen from steam reformation of natural gas for green hydrogen.
148 European Commission, Final report Task 1, 2022, p. 89–93.
149 COM(2024) 62 final, p. 8.

to repurpose existing CO_2 infrastructure for the new purposes.[150] According to the EU industrial carbon management strategy, the Commission foresees to develop policy options as well as support mechanisms, as well as to review if and how carbon removals should be accounted in the EU ETS. The Commission further aims to boost innovation and research under Horizon Europe and the Innovation fund. [151]

4.3 Support mechanisms to boost investments

4.3.1 Investor perspectives for the hydrogen economy

The production ramp-up of RFNBOs is encouraged in many innovation and investment support schemes that target projects related to the green transition. These market support schemes are vital especially in the transitional phase and must therefore not be overlooked. Each scheme sets its own rules for eligibility, which the applying projects need to fulfil. These terms may concern things such as other possible funding, the location, size and the nature of the project. The EU has policies in place directing financial support to projects that help reach the decarbonization targets in different sectors.

The European Investment Bank has published an interview-based report in 2022 on the investor perspectives on risks, challenges and the role of the public sector in stimulating investments on the hydrogen economy. The key findings of the report state that even though investors do acknowledge the potential and importance of hydrogen projects as an investment opportunity, they are held back by the high economic risks related to these projects. In the report, these risks are divided into the following categories: market and regulatory conditions, access-to-finance conditions, and value chain integration and ecosystem development.[152] The report continues to provide suggestions on how these issues could be addressed to better facilitate investments and to create a mature financing ecosystem. Although many regulations have been recast, and new ones such as the Net-Zero Industry Act have been adopted since the report has been published, it can still be used to understand what the investors view important for the development of hydrogen projects.

The report further identifies the challenging economic conditions into two different issues: the economic disadvantage of low-carbon hydrogen and its applications compared to other

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[150] COM(2024) 62 final, p. 9.
[151] COM(2024) 62 final, p. 15.
[152] European Investment Bank, 2022, p. 11.

alternatives, which limits the demand of low-carbon hydrogen; and the lack of regulatory clarity regarding key hydrogen development aspects, which creates risks for investors.[153] To tackle the economic disadvantage of low-carbon hydrogen, the investors view that to close the cost gap of renewable hydrogen, a sufficiently robust support ecosystem is crucial especially for the early stages of growth, as the existing public support mechanisms for hydrogen projects are somewhat fragmented. In addition, they call for acceleration of the scaling-up of hydrogen projects in order to decrease costs over time, as well as a full market uptake of hydrogen projects across the value chain.[154] What comes to the lack of regulatory clarity, the report is somewhat outdated, as uncertainties regarding the EU taxonomy and the additionality requirements have been clarified since its publishing. However, some uncertainties still remain, for example with regards to support mechanisms and policies in the EU, which should be sufficiently harmonized to avoid creating uneven economic conditions for investors in different locations. Not surprisingly, many investors also pointed out the yet open questions regarding renewable versus low-carbon hydrogen and the eligibility of low-carbon hydrogen to apply for financial support.[155] However, as mentioned, these rules are going to be clarified in the delegated acts of the Hydrogen and Gas Market Directive.

When it comes to the access-to-finance conditions, the report identifies two types of projects which have constrained access to finance: early-stage innovation projects as well as large-scale hydrogen infrastructure projects.[156] To further accelerate research and development of even more advanced technologies, early-stage investment aid is necessary, as a significant opportunity exists here. Financing conditions of hydrogen infrastructure projects are not always ideal, and the projects are associated with many risks, such as the fluctuating offtake price,[157] long duration and volume risk of projects, uncertainty of the technology maturity and scale-up of certain technologies, as well as operational risks.[158] In addition, the financing ecosystem is not yet mature and integrated enough,, and project promoters may not even be aware of all possible funding options from which they could assemble a functioning financing structure for their projects.[159]

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[153] European Investment Bank, 2022, p. 11.
[154] European Investment Bank, 2022, p. 12–13.
[155] European Investment Bank, 2022, p. 14–15.
[156] European Investment Bank, 2022, p. 11.
[157] Offtake price means the price that offtakers are willing to pay the producer for the product, i.e. how much the hydrogen producer can expect to sell.
[158] European Investment Bank, 2022, p. 15–17.
[159] European Investment Bank, 2022, p. 20.

Finally, the report identifies the importance of a value-chain approach for policies to create a functioning hydrogen economy. A value-chain approach is crucial as hydrogen projects are interdependent and linked across their value chains, which means that the projects should be planned coherently and in a coordinated manner, to be located around optimal locations.[160] As has been emphasized earlier, producing renewable hydrogen is an upstream production phase of multiple different products, so it is important to scale hydrogen production as efficiently as possible to promote its use further in the value chain. According to the report, with regards to the s-called ecosystem development, project promoters lack knowledge of possible funding options.[161] However, there are already new policy measures on the financing of hydrogen projects, such as the European Hydrogen Bank, established in 2023.[162]

4.3.2 Existing support schemes for PtX projects

The Fit for 55 package sets a policy framework for pushing innovations and investments for a commercially competitive and climate neutral economy. The Union's long-term budget as well as its recovery package – NextGenerationEU – are planned to support the green transition, and 35 % of research and innovation funding under Horizon Europe is targeted for green investments. Furthermore, the Horizon Europe provides support for companies to develop and scale up "game-changing" innovations.[163] Although electrolyser technologies already are scalable, further research and development should be sufficiently funded. In addition, the Fit for 55 package envisaged the revision of the Energy Taxation Directive to incentivize the uptake of renewable fuels in both transportation as well as heating.[164] In connection with the revision of the Energy Taxation Directive, International Civil Aviation Organization's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) will be implemented to make clean fuels more attractive and to close loopholes for polluting fuels.[165]

The NZIA aims to increase the production capacity of these technologies as well as their components, and it includes provisions regarding hydrogen production as well as carbon capture and storage technologies. The key actions included in the NZIA are: setting enabling

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[160] European Investment Bank, 2022, p. 19–20.
[161] European Investment Bank, 2022, p. 20.
[162] COM(2023) 156 final, p. 1.
[163] COM(2021) 550 final, p. 11.
[164] European Commission, Revision of the Energy Taxation Directive, Accessed 26 August 2024. The Commission adopted a proposal for a revision of the Energy Taxation Directive on 14 July 2021. According to the revised directive, fuels will be taxed according to their energy content and environmental performance instead of their volume. Thus, their environmental impact is going to be reflected better in their prices.
[165] COM(2021) 550 final, p. 7–9.

conditions, ramping-up carbon capture, improving the market access, ensuring skilfulness of workforce, fostering innovation and setting up a platform for coordinating action and exchanging information (the Net-Zero Europe Platform). Although the regulation does not directly address PtX fuels for the transport sector, it is an important policy instrument for the scaling of electrolyser production to produce hydrogen. The Net-Zero Industry Act includes a definition for so-called strategic net-zero projects, which in accordance with Article 3(18) means a net-zero technology manufacturing project, a CO_2 capture project, a CO_2 storage project or a CO_2 transport infrastructure project located in the Union that a Member State has recognised as a net-zero strategic project pursuant to Articles 13 and 14. Net-zero projects can benefit from a streamlined permitting process,[166] and those projects that are granted the net-zero strategic project status will be considered of high national significance and treated with urgency in accordance with Article 15.

At the EU level, the production of low and zero-carbon technologies as well as transport fuels is incentivized by extending the scope of the Innovation Fund referred to in Article 10a (8) of Directive 2003/87/EC to cover them. According to paragraph 54 of the recital of (EU) 2023/959, the Innovation Fund should especially serve to support investments to decarbonize the maritime sector, including investments in sustainable alternative fuels such as hydrogen and ammonia that are produced with renewable energy. Article 10d of the Directive 2003/87/EC concerns the Modernisation Fund. Paragraph 2 of the Article allocates revenue that is gained from the allowances to the support the investments of e.g. the generation and use of electricity from renewable sources, including renewable hydrogen. In accordance with Article 10(1) subparagraph four, 2,5% of the total quantity of emissions allowances between 2024 and 2030 are auctioned to the Modernisation Fund, where the funds will be distributed to beneficiary Member States in accordance with Annex IIb, Part B.[167]

Furthermore, the Commission published the European Hydrogen Bank on 16 March 2023 to support the uptake of renewable hydrogen, both in the EU internal market as well as through imports. The purpose of the Hydrogen Bank is to unlock private investments in hydrogen value chains by efficiently connecting supply of renewables with demand and addressing the initial

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[166] Net-Zero Industry Act, recital point (21), p. 6.

[167] Beneficiary Member States shall be those with a GDB per capita at market prices below 75% of the Union average during the period from 2016 to 2018: 4,9% to Bulgaria; 12,6% to Czechia; 2,1% to Estonia; 10,1% to Greece; 2,3% to Croatia; 1,0% to Latvia; 1,9% to Lithuania; 5,8% to Hungary; 34,2% to Poland; 8,6% to Portugal; 9,7% to Romania; 4,8% to Slovakia; and 2,0% to Slovenia.

investment challenges. The European Hydrogen Bank is envisioned to help in reaching the EU's hydrogen goals by creating new jobs and growth opportunities, creating an emerging European hydrogen market.[168] The Hydrogen Bank aims to i) cover and lower the cost gap between renewable hydrogen and fossil fuels for early projects; ii) play a coordination role and facilitate blending with the existing financial instruments at EU and national level; iii) de-risk hydrogen projects, maximise leverage of private capital and increase confidence of investors, financiers and the industry; iv) increase transparency, gather information, and provide price information as well as develop price benchmarks; v) support infrastructure planning and provide visibility on hydrogen infrastructure needs; vi) support the coordination of cooperation and trade with third countries; and vii) enhance transparency and coordination of renewable hydrogen transactions and negotiations within the EU as well as with third countries.[169] These actions can further encourage private investors to fund PtX projects, as they provide further security and transparency in the emerging hydrogen production network.

The first EU-wide auction for the production of RFNBO hydrogen was launched under the European Hydrogen Bank. In total, 132 bids were submitted to the auction, of which seven renewable hydrogen projects were selected and will receive nearly € 720 million in project support from the Innovation Fund. One of these projects is located in Finland. Together, these projects plan to produce 1.58 million tonnes of hydrogen over a period of ten years. The European Commission plans to launch a second European Hydrogen Bank auction by the end of 2024.[170] The European Hydrogen Bank is a policy measure that directs funds exclusively to projects contributing to the hydrogen economy. It concerns hydrogen projects across the value chain, and is therefore an important scheme to promote PtX projects in an abundance of decarbonisation projects across sectors.

The EU Emissions Trading Scheme also contains provisions that direct finances to projects that contribute to the decarbonisation targets. Article 10 of Directive 2003/87/EC sets the rules for the auctioning of emissions allowances in Member States. According to paragraph 1 of the Article, 2% of the total quantity of allowances between 2021 and 2030 shall be auctioned to establish a fund to improve energy efficiency and modernise the energy systems of certain

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[168] COM(2023) 156 final, p. 2.
[169] COM(2023) 156, p. 5–7.
[170] European Commission Press Release 30 April 2024, accessed 13 August 2024.

beneficiary Member States.[171] Paragraph 3 of Article 10 of the revised Directive lists purposes for which the Member States must determine the use of revenues generated from the auctioning of allowances, with the exception of revenue used for the compensation of indirect carbon cost.[172] The revenue can be used for e.g. (e) the environmentally safe capture and geological storage of CO2, (f) to invest and accelerate the shift to decarbonized transport, including development of sustainable alternative fuels, such as hydrogen, or (g) to finance research and development in energy efficiency and clean technologies in the sectors covered by the Directive.

As can be seen here, the EU directs funds towards decarbonisation efforts across different sectors. Studies show that significant investments are needed for the different steps of hydrogen and PtX value chains, ranging from production of renewable electricity and electrolysers to pipelines and storage facilities. Public and private funding schemes are vital for these projects to get started, as the operations are not as economically competitive as the production of fossil fuels. Other options introduced in the report include giving investment support, introducing quotas, creating demand and reducing or limiting taxes and levies which RFNBO production is subject to. In the report, demand for RFNBOs is created via high carbon pricing, and suggests adding the transport sector to the EU ETS.[173] Furthermore, after the report has been published, the EU ETS revision created a separate ETS for buildings and the transport sector.

According to the investors interviewed in the EU study, the investment ecosystem of hydrogen projects is yet immature. Different support schemes (public and private) are scattered, making it difficult for project promoters to easily create a functioning financing structure by combining different funding sources. The conditions under which a PtX project may be eligible to apply for public support can be somewhat strict, but this can be viewed as somewhat inevitable, as there are a multitude of projects applying for public funding. However, avoidable bureaucracies relating to applying support should be dropped to avoid unnecessary labour and inefficient use of time.

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[171] The Member States with GDP per capita at market prices below 60% of the Union average in 2013. The funds corresponding to that amount of allowances shall be distributed in accordance with Part A of Annex IIb as follows: 5,84 % to Bulgaria; 15,59 % to Czechia; 2,78 % to Estonia; 3,14 % to Croatia; 1,44 % to Latvia; 2,57 % to Lithuania; 7,12 % to Hungary; 43,41 to Poland; 11,98 to Romania and 6,13 % to Slovakia.

[172] Indirect carbon cost referred to in Article 10a (6) of the ETS Directive mean indirect costs that are actually incurred from greenhouse gas emission costs passed on in electricity prices.

[173] European Commission, Final report, Task 1, 2022, p. 106.

Investments to hydrogen projects are encouraged in Finland as well. The Governmental Programme of Finland envisions creating a good environment for investments into renewable and fossil-free energy production and storage. This includes new hydrogen solutions, in which Finland shall become a key player and an attractive location for investments into hydrogen refining projects. For the use of public funds, research, development and innovation funding, smoother permit processes as well as energy transfer infrastructure will be emphasized in accordance with the Programme.[174] Furthermore, preparations are to be made for "investments in the hydrogen transmission network with the aim of encouraging the processing of electricity and hydrogen in high value-added goods in Finland.".[175]

[174] Publications of the Finnish Government 2023:60, p. 149–150.
[175] Publications of the Finnish Government 2023:60, p. 158–159.

5 Evaluation of the legislative framework – implications and ideas

In this chapter, I assess whether the legislative framework facilitates the establishment of a functional and economically feasible PtX fuel production network. I will first introduce elements of good energy regulation. The chapter aims to answer the research question of the issues that can be identified with regards to Power-to-X fuel production within the current legislative framework. This is examined in relation to the requirements presented in the legislation, the economic challenges as well as technology neutrality. Then, I aim to provide answers to the research question on how the EU regulatory framework could be revised to better foster the ramp-up of PtX fuel production and give de lege ferenda -recommendations on how the regulations could be reviewed.

5.1 Contradictions within the legislative framework of PtX fuels

The regulatory framework for PtX fuels faces some contradictions regarding the different goals that it strives to achieve. The objectives that the regulatory framework should simultaneously seek to achieve include: facilitating innovation and development of new technologies with sufficient flexibility while creating a framework in which project developers and investor can rely on not to change to facilitate long-term investments; technology neutrality concerning different production pathways of PtX fuels while striving to achieve climate targets in the established schedule; and finally, participation possibilities for both market players and local governance bodies to create suitable legislation for the production and to increase acceptability and legitimacy of the legislation, all the while ensuring that the framework sufficiently steers towards mitigating climate change

In the article *Exploring regulatory strategies for accelerating the development of sustainable hydrogen markets in the European Union*, Baumgart and Lavrjissen argue that energy law is an economic law which aims to regulate the energy system with steering instruments to build the system in accordance with established goals, while simultaneously protecting consumers.[176]

The regulatory framework should facilitate a suitable platform for innovations and developing technologies. According to Baumgart and Lavrijssen, the PtX regime should be sufficiently flexible and responsive, since it should be possible to adapt the regulations in order for them to be consistent with their initial goals and for them to not fall behind market needs. Experimental

[176] Baumgart – Lavrijssen, 2024, p. 137.

regulation – the so-called sandbox regulatory strategy[177] – can also be considered to experiment innovative and alternative regulatory solutions. The contradiction related to the requirement of flexibility and responsiveness arises as the flexibility and responsiveness may lead to a situation where legislation is constantly changing, which in turn can drive away investors and stand in the way of project planning.[178] Predictability (which ties to transparency) of legislation, is also important for market players, so they can plan operations for long-term.[179] PtX projects require long-term investments on infrastructure, production facilities, adapting existing technologies to the new fuels etc., but it can be difficult to plan a business amidst an ever-changing regulatory framework.

Contradictory to pursuing flexibility and responsiveness in PtX regulation, a trend has been observed lately, where the EU aims to regulate the energy markets in a manner which does not allow for a lot of flexibility for Member States, in order to complete the Union internal market for energy and avoiding market distortion risks and possible harm for consumers. Effectiveness requires taking decisions on the most appropriate level, and efficient market organisation means that action is taken by the most appropriate actors and with the most appropriate instruments.[180] Although regulation at the EU level has its downsides, as it may not sufficiently consider the individual characteristics of the Member State's energy systems and economic advantages or obstacles, I –for the most part – still view the trend as necessary for developing a level playing field in the internal PtX economy of the EU.

Technology neutrality is a principle according to which laws and regulations should not favour one technology over another, and instead maintain a level playing field by letting each technology compete on its own merits.[181] It has been argued that the Union's regulatory framework is too focused on RFNBOs, the production of which is under such strict standards that it is questionable if it is possible to scale production to achieve targets and decarbonisation goals in accordance with the established schedule with the existing regulatory framework.[182] . A balance must be found between flexibility of the rules and the legal certainty that they offer.

[177] A regulatory sandbox, according to Baumgart and Lavrijssen, 2024, p. 153, is a space or a forum to try out different regulatory strategies. However, these experiments cannot deviate from EU law due to the legal hierarchy in the EU.
[178] Baumgart – Lavrijssen, 2024, p. 147.
[179] Baumgart – Lavrijssen, 2024, p. 147-148.
[180] Baumgart – Lavrijssen, 2024, p. 147–149.
[181] Talus – Pinto – Gallegos, 2024, p. 17.
[182] See: Talus – Pinto – Gallegos, 2024, p 10, 17.

Legislation that is too vague can lose its ability to steer economic actors.[183] Therefore, the regulatory framework should be revised in some regards to allow the development and market uptake of other options.

Regulatory strategies range from command-and-control approaches to principle-based regulation. When it comes to innovative technologies and a fast-changing environment, command-and-control strategy may not address the problems at stake sufficiently, as they are not especially flexible and do not allow for a lot of room for amendments. This may be particularly true for the emerging PtX market, which is in a constant state of development. Principle-based regulation, in turn, includes principles that set out regulatory objectives and values, but allows for the addressees to develop their own approaches to address the outlined principles.[184] In the EU context, this could allow for more flexibility in each Member State, but it might simultaneously cause market imbalances in the EU internal market, if the regulation would be more favourable for producers in some countries. Principle-based regulation can be fitting for some situations, but in my view, more binding regulations could be better for creating a level playing field for PtX fuels in the EU internal market.

Although some of these contradictions remain, it is evident that in some cases the regulatory framework should be revised. Especially concerning widening the focus of the legislation from RFNBOs to facilitate the development and market uptake of other options, as well as facilitating the use of low-carbon options at least for the transitional phase to speed up the decarbonisation targets.

5.2 The hindrances caused by the legislative framework for establishing economically feasible PtX production

The key implications presented by the legislative framework of the EU on establishing an economically feasible production network for RFNBO production are examined in further detail in this chapter. The principal issues identified here are as follows; strict regulations which must be adhered to in order for the product to comply with EU standards; the high price of RFNBOs compared to their fossil fuel alternatives, as well as technical, societal and

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[183] Giljam, 2018, p. 237.

[184] Baumgart – Lavrijssen, 2024, p. 150.

structural hindrances. Although the legislative framework alone cannot be blamed for the slow production ramp-up of RFNBOs, legislative hindrances can still be identified.

A significant feature of the envisioned PtX economy is that the legislation should not only cover the production of hydrogen, but rather the whole value chain of its downstream products. The value chain of hydrogen, which begins from the production of renewable energy, from which renewable hydrogen can be produced via electrolysis, continues to different fuels for the use of multiple sectors, such as ammoniac and methanol for the purposes of the maritime sector, or fisher-tropfsch -liquids and e-kerosene for the aviation sector. Outside the transportation sector, the hydrogen value chain will continue to the production of chemicals which are used in chemical industrial processes, heating and cooling. One could argue that the downstream manufacturing and project planning stalls due to the heavy regulation of the upstream production. The value-chain nature of the PtX economy also means that efficiency loss occurs in each step of the process, while the price of the end-product increases accordingly.

5.2.1 Compliance with the requirements of the legislative framework

The legislative framework of the EU concerning RFNBO production is quite complex. There are multiple separate legislative elements – such as the RED III, the EU ETS, the CBAM and the Hydrogen and Gas Market package – which can be quite difficult for operators to navigate. In order to produce hydrogen that can be considered renewable, operators must comply with a complex set of rules. The Delegated Acts under Articles 27 and 28 of RED II were long waited for, as projects around the globe needed to know the finalized technical rules in the European Union.[185] Although the new rules clarify how operations must be organized, these additional obligations increase administrative burden.

To clarify how renewable hydrogen producers must organise their activities, I will elaborate what compliance with the Delegated Act 2023/1184 means in practice. In accordance with the Delegated Act, a production facility basically has five options where the RFNBOs produced can account for the RED targets in the transport sector: 1) direct connection to a renewables plant; 2) grid electricity with an average share of at least 90 % renewable electricity; 3) grid electricity with low CO_2 emissions; 4) using imbalance settlement periods; and 5) grid electricity and compliance with criteria of additionality, temporal correlation and geographical

[185] Allen & Overy LLP, 2023, p. 1.

correlation. Option 1 is quite simple, but producers must demonstrate with a metering system that electricity is used for RFNBO production, and the RED plant must not come into operation earlier than 36 months of before the RFNBO installation. Option 2 means that the average grid electricity in the biding zone of the RFNBO plant must have an average share of renewables of over 90 %, yet the use of electricity for RFNBO production is limited by the grid share of renewables, as the production of RFNBOs does not exceed the maximum number of hours in proportion to the share of renewables. Currently, this requirement is difficult to fulfil, but as renewables production is added, it will become easier to achieve. Option 3 means that the electricity in the bidding zone has an emissions intensity lower than 18 gCO_2eq/MJ, and the production plant has a PPA in place with a renewables plant at least for the amount of electricity that is used and claimed as fully renewable, and geographical correlation as well as temporal correlation are complied with. In option 4, the RFNBO producer may use grid electricity during imbalance settlement periods, but this option entails demonstrating that renewables production was redispatched downwards and that the electricity consumed reduced the need for redispatching. Option 5 requires compliance with the requirements of additionality, temporal correlation and geographical correlation,[186] of which especially the requirement of temporal correlation can cause administrative burden. Concerning option 5, there is a transitional phase, meaning that the requirement of additionality only applies to installations that come into operation before 2028 after 2038.

The regulatory framework is quite different concerning carbon dioxide, the other principal feedstock of PtX fuels. Carbon capture and utilization activities are not regulated as comprehensively as hydrogen production is. In order for a product to qualify as an RFNBO, the GHG emissions savings should be reduced by at least 70 %. Whether or not the CO_2 captured from fossil-derived sources is eligible for this criterion depends on the timeframe. The CO_2 captured from upstream fossil sources will be considered avoided in the downstream product; qualifying the downstream fuel as an RFNBO allows to obtain the 70 % reduction threshold. However, the CO_2 used in the product still is of fossil origin, and combustion of the fuel emits CO_2 back to the atmosphere. Therefore, to avoid the continuous use of fossil fuels upstream and their related end-use emissions, the regulation qualifying RFNBOs intends to only hold up to 2035 for electricity generation with capture and up to 2040 for other industry-related capturing processes. After this, RFNBOs are mainly going to be produced with atmospheric or biogenic

[186] International PtX Hub, 2023, p. 10.

CO_2 using direct air capture or bio-energy carbon capture technologies. Carbon loops will therefore be closed, as biogenic or atmospheric CO_2 keeps circulating. Renewable electricity will be used for capture and conversion processes, minimizing emissions of carbon capture.[187]

The EU ETS (1) entails that emissions allowances for the captured carbon must be surrendered at some point, unless the carbon dioxide is permanently bound somewhere. Hence, the EU ETS 1 provides a good incentive for CCS, as upstream firms do not need to surrender allowances when permanently storing carbon. EU ETS 2 covers fuel use in road transport as well as buildings. RFNBOs are not supposed to be covered under the EU ETS 2 to avoid double counting.[188] The issue with two emissions trading systems arises if the carbon pricing is different: nonetheless, EU institutions aim to keep the price of ETS 2 allowances below 45 €/tCO_2, which is about half of the ETS 1 carbon price. A low ETS 2 price in comparison to ETS 1 price would push the market towards the "conventional" process route, as this would require less allowances spending than using CCU, thus artificially making fossil fuels more competitive.[189] Hence, it can be considered positive that an ETS 2 for the transport sector has been created, but it may need adjustments to become as efficient as possible in incentivising alternative fuel production.

5.2.2 Does the legislative framework achieve technology neutrality of different production pathways?

Especially with the challenges of achieving target production for hydrogen with the current regulations, it can be argued that the current EU framework for hydrogen is not technology neutral enough. Technology neutrality has an exception concerning the energy transition, as EU energy law favours renewable energy technologies over the combustion of fossil fuels. According to Talus et al., this exception should not concern the production of hydrogen in the same manner, as focus should be towards the emissions intensity of different hydrogen production methods. The chosen approach uses legislative targets without letting the market choose the winning technologies. Instead, a sustainable hydrogen framework should be focused on technologies that enhance efficiency by reducing the energy consumption per tonnes of CO_2

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[187] Delarue – Meus – Moncada – Valkering – Verbist, 2024, p. 3.
[188] Double counting would occur when a RFNBO is produced from fossil CO_2, which is covered twice in the EU ETS: once by upstream surrending of EU ETS I credits for the transferred CO_2, and again in the EU ETS 2 for the same CO_2 which is contained in a product and emitted during its use-phase.
[189] Delarue – Meus – Moncada – Valkering – Verbist, 2024, p. 4–5.

saved (measured in MWh/t CO_2 saved). Producing hydrogen with e.g. pyrolysis could help achieve these types of targets.[190]

According to Giljam, the EU energy governance struggles with finding the balance between sufficient clarity and the vagueness that technology neutrality would require. Steering energy production to be more sustainable seems to require somewhat technology specific laws, but at the same time the legislation needs to be comprehensive as well as time-resilient (requiring technology neutral legislation). EU regulation aims to achieve other – sometimes conflicting - goals as well, such as affordability and energy security, which further complicates the creation of a balanced and functioning Union energy policy.[191] Another possible problem with the regulation of constantly advancing technology is that the existing energy systems (necessary infrastructure as well as energy-using equipment) are adapted to existing energy sources.[192] According to Giljam, ecological governance to mitigate climate change could be operationalized by reinterpreting the BAT concept and expanding its scope of application, so that the legislation concerning BAT would largely be technology neutral.[193]

According to Giljam (2018) both the Gas Directive and the Electricity Directive are fully technology neutral, as their provisions apply to all sources of electricity and gas without considerations to the technology used to extract the primary sources or their conversion into secondary energy.[194] However, the RED is considerably less technology neutral than the Gas and Electricity Directives, as it specifically aims to promote the market penetration of renewable energy, which is facilitated through positive discrimination.[195] To reach the climate targets, the regulation should support sustainable technologies. However, between these sustainable options, the regulation should be as technology neutral as possible to facilitate innovation. The renewable energy targets outlined in the beginning of the RED text are quite technology neutral, and out of the three main branches identified in the RED (electricity, heating and cooling, and transport), the policies set for the first two branches are more technology neutral. The transport sector, however, is regulated in more detail, resulting in the ruling out of certain production paths. In addition, the calculation methodologies for certain fuels allow them

[190] Talus – Pinto – Gallegos, 2024, p. 17.
[191] Giljam 2018, p. 237–238.
[192] Giljam, 2018, p. 238–239.
[193] Giljam, 2018, p. 237.
[194] Giljam, 2018, p. 240.
[195] Giljam, 2018, p. 242.

to be calculated towards the targets more than once.[196] According to (EC)2018/2001 Article 27 *Calculation rules in the transport sector and with regard to renewable fuels of non-biological origin regardless of their end use* paragraph (2) *for the calculation of the minimum shares referred to in Article 25(1), first subparagraph, point (a)(i) and point (b), the following rules shall apply:*

> (c) the share of biofuels and biogas produced from the feedstock listed in Annex IX and renewable fuels of non-biological origin shall be considered to be twice its energy content;
>
> (d) the share of renewable electricity shall be considered to be four times its energy content when supplied to road vehicles and may be considered to be 1,5 times its energy content when supplied to rail transport; and
>
> (e) the share of advanced biofuels and biogas produced from the feedstock listed in Part A of Annex IX supplied in the aviation and maritime transport modes shall be considered to be 1,2 times their energy content and the share of renewable fuels of non-biological origin supplied in the aviation and maritime transport modes shall be considered to be 1,5 times their energy content.

Innovations in the energy sector face difficulties especially in relation to the network structure of existing energy systems, the specific features of energy-related technologies as explained before and the uncertainty of the impact of new policy instruments and legislation on the rate and direction of innovation. Despite these difficulties, innovations are necessary in achieving a sustainable energy system.[197] Technology neutral legislation should therefore be favoured, especially between different renewable options.

5.3 Recommendations to amend the legislative framework

5.3.1 Switch of focus from RFNBOs to other options

The EU regulatory framework for hydrogen is currently focused on RFNBOs. However, there is a significant risk of falling short the RFNBO production targets, as there are many unresolved challenges to the production ramp-up. For example, producing the required amount of

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[196] Giljam, 2018, p. 242.
[197] Giljam, 2018, p. 245.

renewable hydrogen requires significant additional production capacity of renewable electricity. Therefore, some argue that it is clear that the EU's rather narrow approach towards hydrogen production should be reconsidered, and the market penetration of low-carbon fuels should be encouraged.[198] This kind of policy change could be more strict gradually. However, if these low-carbon fuels would only seek to provide a solution in the medium-term, it may not encourage market players, as investments are made to long-term production facilities.

The EU report on the potential of RFNBOs in the transport sector suggests blending synthetic fuels with fossil fuels or advanced fuels to lower the costs and incentivise the market uptake of RFNBOs in the early market phase. Even though the required carbon price level to close the price gap of RFNBOs and fossil fuels will always be the same as for the RFNBO,[199] a relatively low price-premium would likely match the willingness to pay for a less-carbon intensive fuel.[200] However, according to the report, blending of RFNBOs and fossil fuels does not make sense anymore after the year 2050, as the EUs GHG neutrality objective requires the complete phasing out of fossil fuels.[201]

Hydrogen produced with nuclear electricity (pink hydrogen under the EU colour scheme) is not considered renewable, as the EU Member States are in disagreement over whether or not nuclear power should be considered renewable. Some member states such as France support it, and some, like Germany, are against it.[202] On 19 December 2023, eleven EU countries[203] issued a joint statement, calling on the EU to review its climate and energy policy framework and to fully acknowledge the contribution of all fossil-free energy sources. They claim that "[n]uclear power is indisputably a sustainable and equally valid technology to achieve these objectives for member states that opted to resort to its use." The Nuclear Alliance is also calling for the Union to adopt a target for low-carbon energy, not just for renewables. They present that instead of reviewing the RED once again, a new low-carbon directive could instead be introduced.[204] Hence, the Union's stance on the status of nuclear energy might yet change in the future. However, even if nuclear-electricity produced hydrogen would be

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198 Talus – Pinto – Gallegos, 2024, p. 17.
199 The report considers a case where RFNBO is blended with 10% fossil fuels. The wholesale price of this blend would at estimate be 58–60 $€_{2019}$/MWh for hydrogen, 36–39 $€_{2019}$/MWh for methane and 63–67 $€_{2019}$/MWh for liquid fuels.
200 European Commission, Final report Task 1, 2022, p. 92–93.
201 European Commission, Final report Task 1, 2022, p. 92.
202 Talus – Pinto – Gallegos, 2024, p. 7.
203 Bulgaria, Croatia, Czechia, Finland, Hungary, Poland, Romania, Slovakia, Slovenia, Sweden and France.
204 Messad, Eck, Euractive 2023.

considered renewable in the EU, it is still not the most efficient method of producing PtX fuels, as the necessary ramp-up of nuclear electricity production (i.e. new nuclear plants) is not fast enough, especially when compared to renewable energy sources from wind or solar power.

According to Talus et al., the Hydrogen and Gas Package admits that renewable hydrogen is not able to scale quick enough to meet the demand for hydrogen in the Union. However, low-carbon fuels are likely to play an important role especially in the short and medium term. Article 2 (11) of the recast Hydrogen and Gas Market Directive (EU) 2024/1788 defines low-carbon hydrogen as hydrogen, the energy content of which is derived from non-renewable sources, which meets the GHG emissions reduction threshold of 70% compared to the fossil fuel comparator for RFNBOs. Low-carbon fuels, in turn, are defined in Article 2(13) as RFCs as defined in Article 2 (35) of the RED, low-carbon hydrogen and synthetic gaseous and liquid fuels the energy content of which is derived from low-carbon hydrogen that meets the GHG emissions reduction target. Although the Hydrogen and the Gas Market Directive defines both low-carbon hydrogen[205] as well as low-carbon fuels,[206] the issue with these definitions is that the Directive does not address other categories of hydrogen, like hydrogen made from pyrolysis of methane using renewable electricity (turquoise hydrogen).[207] One such company utilizing pyrolysis to produce hydrogen is already in operation in Finland: Hycamite uses a methane pyrolysis technology to break down methane with a proprietary catalyst and heat.[208] The delegated acts that should come by August 2025 in accordance with Article 9 of the Hydrogen and Gas Market Directive is going to specify the methodology for GHG emissions savings from low-carbon fuels. The methodology is going to have a clarifying effect on the current situation with such fuels and can be expected to have an impact on investments and starting projects.

In accordance with the EU's definitions, turquoise hydrogen cannot be considered an RFNBO. As low-carbon hydrogen only includes hydrogen from non-renewable sources, turquoise hydrogen produced with biomethane (which is a renewable gas) cannot be considered low-carbon either. It is unclear whether turquoise hydrogen produced from biomethane can be

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[205] Article 2 (11) of the recast Hydrogen and Gas Market Directive (EU) 2024/1788 defines low-carbon hydrogen as hydrogen, the energy content of which is derived from non-renewable sources, which meets the GHG emissions reduction threshold of 70% compared to the fossil fuel comparator for RFNBOs.
[206] According to Article 2(139 of the Directive, low-carbon fuels are defined as RFCs as defined in Article 2 (35) of the RED, low-carbon hydrogen and synthetic gaseous and liquid fuels the energy content of which is derived from low-carbon hydrogen that meets the GHG emissions reduction target.
[207] Talus – Pinto – Gallegos, 2024, p. 10.
[208] Hycamite, – decarbonizing industry, https://hycamite.com/ (Accessed 15 July 2024).

considered as renewable hydrogen, even if it's not considered an RFNBO.[209] A clear definition would aid project developers as well as investors in taking action, as the uncertainty of the current rules discourages from investing and project planning.

5.3.2 Overcoming technical, structural and societal challenges

To overcome the technical and structural challenges of production, the EU report on the potential of RFNBOs recommends actions such as further support to research and development, incentivizing the build-up of renewable energy generation capacity and of hydrogen and CO_2 transport infrastructure.[210] Although the EU report concerns only RFNBOs, its recommendations can be interpreted widely to cover other PtX fuels. It is evident that technological development is vital for the green transition and decarbonisation across sectors, which means that research and development projects should be funded. Even though electrolyser technologies already exist, other options for producing renewable hydrogen should be explored, not to mention carbon capture technologies. The energy sector has certain characteristics, which must be considered in the Union energy governance and policy. As the EU energy policy is originally created for a somewhat centralized energy supply, the ramp-up of renewables production introduces some problems. Renewable energy sources produce energy more intermittently than fossil sources, which may threaten the safe and secure functioning of the existing energy systems. System operators face technical challenges, which are increasingly addressed to the legislators. The energy sector regulation is multi-level, as it is regulated at: the EU level, the national level and at the local level, in which all there are different entities with different competencies executing and enforcing the rules.[211]

When it comes to developing infrastructure, project investments are high cost and long-term, which means that the existing technological solutions are strongly embedded into the society.[212] According to the EU Hydrogen Strategy, the uptake of hydrogen solutions could lead to repurposing or re-using parts of the existing natural gas infrastructure.[213]As has been introduced earlier, market support mechanisms and policies are also targeted towards infrastructure projects to facilitate the transportation and storage as well as distribution of PtX fuels.[214]

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[209] Talus – Pinto – Gallegos, 2024, p. 16.
[210] European Commission, final report, Task 1, 2022, p. 106.
[211] Giljam, 2018, p. 238–239.
[212] Giljam, 2018, p. 239.
[213] EU Hydrogen Strategy, 2020, p. 1.
[214] E.g. the EIB Hydrogen Bank and the Alternative Fuels Infrastructure Regulation.

Societal barriers of PtX production can be related to the additional RES production capacity as well as infrastructure projects, which almost without exception face at least some local opposition. As was explained earlier, some carbon-based fuels may cause doubts among consumers. To tackle the societal barriers of RFNBO production, the EU report recommends raising end-customer awareness of RFNBOs as well as CCU(S)-technologies to facilitate the reception of these fuels. The report also recommends developing an information platform for project developers to access data on technical standards and funding guidelines, as well as creating a programme to allow communities to profit from added local infrastructure.[215] One such platform has been established in accordance with Article 32 of the NZIA to gather and exchange information between the Member States and the Commission. Although social acceptance of PtX fuels is different from their consumer demand, having a positive image of these fuels should help with their consumer uptake. Although environmentally conscious consumers might opt for a sustainable rather than fossil fuels even if they were more expensive, not all consumers are going to do so. Thus, providing information on the benefits of PtX fuels is a great way to increase consumer awareness.

To facilitate the imports of hydrogen to the EU in accordance with the RePowerEUPlan, the Commission will support the development of three major hydrogen corridors via the Mediterranean, the North Sea area and as soon as possible, Ukraine.[216] According to point 60 of the recital of recast RED III, a Union strategy for imported and domestic hydrogen is to be developed on the basis of data reported by Member States, in order to reduce the Union's dependence on fossil fuels and fossil fuel imports.[217]

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[215] EU report 2022, p. 106.
[216] COM(2022) 230 final, p. 7.
[217] RED III, recital (60), p. 15.

6 Conclusions

This thesis has examined the implications of the European Union's legislative framework on PtX fuel production by examining the existing legislative framework from a producer perspective. To help answer the principal research question I used four additional questions, which were as follows: 1) How must the production RFNBO raw materials be organized to adhere to current EU standards; (2) What EU policy measures are in place to support the production of Power-to-X fuels; (3) What issues can be identified with regards to Power-to-X fuel production within the current legislative framework; and (4) How could the EU regulatory framework be revised to better foster the ramp-up of PtX fuel production?

To answer the research question on how the production RFNBO raw materials must be organized to adhere to current EU standards, I give an introduction of the Renewable Energy Directive (recast in 2023), the Delegated Acts, the Hydrogen and Gas Market Package as well as the EU ETS. To achieve the target of reducing emissions by 55 % by 2030, the RED sets a target of 42,5 % for renewable energy of the EU energy mix by 2030. The RED sets sub-targets for PtX-fuels as well by entailing that Member States must set an obligation for fuel suppliers to ensure a certain level of renewable energy being supplied to the transport sector. Furthermore, the Delegated Acts of RED II, which came into force in 2023, specify the detailed rules for the methodology for the production of RFNBOS, and for a methodology for assessing GHG emissions savings from RFNBOs.

Compliance with the Commission Delegated Act 2023/1184, at least after the transitional rules no longer apply, signifies that production facilities must either: be directly connected to a RES production facility that complies with the condition of temporal correlation; use electricity taken from the grid in a bidding zone where the renewable content of the mix exceeds 90 % and where the production of RFNBOs does not exceed the maximum number of hours; use electricity taken from the grid where the emissions intensity of the electricity is less than 18 gCO2eq/MJ in the bidding zone, and where temporal correlation (per calendar month until end of 2029, after which hourly), and geographical correlation apply; produce RFNBOs during imbalance settlement periods or use electricity taken from the grid while complying with the requirements or additionality, temporal correlation as well as geographical correlation, while having in place PPAs for the amount that is claimed as fully renewable. The Delegated Act 2023/1185 sets out a Union methodology for calculating the GHG emissions savings, taking into account the entire value chain of RFNBOs. This means significant additional administrative burden for production facilities and could be argued that the rules set in the Delegated Acts are in fact too strict to allow for project developers to organize economically feasible production or experiment with new technologies. In addition, they hinder projects from getting funding, as it is very difficult to get returns for investments.

Although PtX fuels can offer great advantages in comparison to their fossil counterparts, they too face some obstacles. Firstly, PtX fuels are more expensive to produce than fossil fuels. Investors do not have sufficient interest in investing to PtX projects, as the scene is riddled with uncertainties concerning not only the price developments of PtX products, but also the ever-changing and unfinished legislative framework, infrastructure and technical challenges. Research shows that without additional measures, PtX fuels are not going to be commercially competitive with traditional fossil fuels. To answer the research question on the EU policy measures in place to support the production of Power-to-X fuels, I examine the different EU policies mandating the use of such fuels in different sectors, as well as existing support schemes. Although PtX fuels might not be commercially competitive when compared to fossil alternatives, the EU has set binding targets for their uptake, for example in the FuelEUMaritime[218] and the ReFuelEU Aviation.[219] Furthermore, I analyse the investment needs that the proposed hydrogen network of the future entails because PtX fuels are not going to be economically competitive with traditional fossil fuels without additional measures. Finally, I introduce support schemes and policies that direct funds to PtX projects, such as the Net-Zero Industry Act, the Horizon Europe, the European Hydrogen Bank and the Modernisation Fund.

What comes to the research question on the issues that can be identified with regards to Power-to-X fuel production within the current legislative framework, one of the primary conclusions of this thesis is that the requirements of the regulatory framework for production of RFNBOs are too strict to allow for economically feasible and large-scale ramp-up of production in time to reach the EU targets for the decarbonisation of the transport sector. According to some researchers,[220] the EU regulatory framework is too focused on RFNBOs and does not facilitate the research and development of other types of sustainable fuels, such as low-carbon fuels. This

[218] The FuelEUMaritime mandates that the GHG intensity limit of the energy used on board ships is going to reduce by 80 % in comparison to the reference value (average in 2020) by 2050.
[219] The ReFuelEU Aviation entails that aviation fuel suppliers shall ensure that of the aviation fuel made available for aircraft operators, the share of SAF grows gradually from 2 % in 2025 to 70 % in 2050.
[220] See: Talus – Pinto – Gallegos, 2024, p. 17.

ties with the last research question on how the EU regulatory framework could be revised to better foster the ramp-up of PtX fuel production. It is suggested in literature that at least for the transitional period, the legislation should be expanded to allow use of low-carbon hydrogen, which is defined in the new Hydrogen and Gas Market Directive as hydrogen, the energy content of which is derived from non-renewable sources, which meets the GHG emissions reduction threshold of 70 % (compared to the fossil fuel comparator for RFNBOs). Concerning the definition of low-carbon fuels, the delegated acts of the Hydrogen and Gas Market Directive are going to define the methodology for assessing the GHG emissions savings of low-carbon fuels should give clarity on the production requirements of such fuels, and aid in creating a market for them. What comes to analysing the legislative framework in the terms of regulatory theory, it is noted that a sufficient balance must be found between different goals of the legislation.

The need for further research on various topics, such as carbon capture and utilisation technologies as well as the definition of "low-carbon" is necessary. Regulation of carbon capture and utilization technologies should be critically assessed with a multidisciplinary approach, as CO_2 is an essential raw material not only in the transport sector, but also in other sectors, and the regulation concerning its uptake needs to take into account multiple different perspectives. Economic analysis could be commissioned on the efficiency of different support schemes on the economic feasibility of PtX fuels. As is recognized in this thesis, alternative policy instruments which are focused on other options and not only on RFNBOs should be assessed, and their possible impacts on achieving decarbonisation targets should be modelled. Furthermore, when the delegated acts of the Hydrogen and Gas Market Directive on the definition of low-carbon hydrogen come, it shall have a big impact on the PtX fuel production markets, which sparks the need for more research on their effects.

Finally, when it comes to the final concluding remarks of this thesis, it can be stated that although the EU has faced significant changes in the past years – the energy crisis, swift emergence of innovative technologies, uptake of new policy measures to fight climate change – the regulations that it has had to adapt relatively fast do provide a sufficient framework for PtX fuel production to be possible. However, within the current regulatory framework, these production facilities are not going to be able to scale their production fast enough to reach the EU targets or to operate in an economically feasible manner. Thus, notwithstanding the fact that ever-changing regulation drives away investments, the regulation should be further amended to facilitate the uptake of low-carbon options, and not only RFNBOs. This change is already underway as is evident in the new Hydrogen and Gas Market Package, but production is going to stall until the delegated acts come into force.

Increasing renewable electricity production capacity is essential for the ramping up of PtX fuel production too, as the fuels are produced using renewable electricity. Although electrification is going to be at the core of the energy transition, PtX fuels are going to function as an important pillar of the sustainability transition of the sectors that are hard to electrify. Furthermore, the first step of PtX fuel value chains is producing renewable electricity, which (especially because of the requirement od additionality) entails setting up new renewables production facilities. What comes to producing renewable hydrogen, it is a significant step in the beginning of various value chains, as it is further refined into different products. Currently this step can be a bottleneck for the production process of various PtX fuels, as the regulatory framework only facilitates the production of RFNBO-standard hydrogen. Therefore, the scope of the legislation should be widened to ramp-up hydrogen production, further aiding in the production of more refined fuels.