Energy Transition
Radarweg 60
1043 NT Amsterdam
The Netherlands

www.tno.nl

T +31 88 866 50 10

TNO report

TNO 2022 P10989

Renewable Fuels of Non-Biological Origin (RFNBO) for transport - Exploration of options to fulfil the obligation in the Netherlands

Date	2 June 2022
Author(s)	Ayla Uslu, Marcel Weeda, Ruud Verbeek, Remko Detz, Hein de Wilde
Number of pages	29 (incl. appendices)
Number of appendices	
Sponsor	
Project name	Feasibility of RFNBO obligation for 2030
Project number	

Contents

1 Introduction ... 3

2 RFNBO within Fit-for-55 proposals ... 4

2.1 REDIII Directive proposal ... 4
2.2 ReFuelEU Aviation Regulation proposal ... 5
2.3 FuelEU Maritime Regulation proposal ... 5

3 Exploring RFNBO demand and supply in 2030 ... 6

3.1 Demand in 2030 ... 6
3.2 RFNBO in aviation and related hydrogen demand ... 7
3.3 RFNBO obligation and the fleet requirements ... 8
3.4 Fuels that contribute to the transport targets and the transition pathways of the different sectors ... 12
3.5 E-fuels as RFNBO and related renewable electricity and CO_2 demand ... 19

4 Summary and synthesis of results ... 21

4.1 Summary ... 21
4.2 Synthesis of results ... 22

5 Concluding remarks ... 27

References ... 28

1 Introduction

The European Commission has proposed a revision of the Renewable Energy Directive (COM(2021) 557 final), hereinafter referred to as REDIII, as part of the “Fit for 55” package. This proposal revised many provisions of the Renewable Energy Directive (REDII), which was adopted in 2018. One of the key changes relates to Article 25 Mainstreaming renewable energy in transport sector. This article was amended to set a new 13% greenhouse gas (GHG) intensity reduction target; increase the sub-target for advanced biofuels; and introduce a new sub-target for renewable fuels from non-biological origin (RFNBO). By 2030, 2.6% of the energy supplied to the transport sector, covering all transport activities, should be met by RFNBO. In addition, the Commission has also proposed to boost the uptake of sustainable aviation fuels (SAF) in air transport through the draft ReFuelEU Aviation Regulation (COM(2021) 561 final). A sub-target of 0.7% in 2030 was introduced for synthetic fuels (e-jet fuel) for the aviation sector. The FuelEU Maritime proposal regulation (COM(2021) 562 final) introduced increasing limits on the carbon-intensity of the energy used by vessels from 2025.

The Ministry of Infrastructure and Water Management has asked TNO to map out the options to comply with the RFNBO obligation for the transport sector in the Netherlands. In this report, we explore and quantify the range of options to meet the 2.6% sub-target. More specifically, below questions were addressed.

- What will be the size of RFNBO obligation in 2030, including the sub-obligation in aviation?
- What are the options to meet this obligation?
  - If the demand is to be fully met by direct use of renewable hydrogen in one of the transport sector modalities, what fleet development will be needed?
  - If the demand is to be met via use of hydrogen to produce conventional fuels and biofuels, or via synthetic fuels:
    - What can be the contribution of RFNBO use as an intermediate product in the production of conventional fuels?
    - What can be the contribution of RFNBO use as intermediate product in the production of biofuels?
    - What can be the order of magnitude of renewable hydrogen and CO_2 demand to supply RFNBO in the form of synthetic fuels such as e-methanol?

This document consists of five chapters. The next chapter presents the main elements of the relevant legislative packages for the RFNBO. Chapter 3 introduces the order of magnitude RFNBO demand driven by REDIII and details the viable options to meet this demand. Chapter 4 summarises and synthesises the viable options. Finally, Chapter 5 contains the concluding remarks.

2 RFNBO within Fit-for-55 proposals

2.1 REDIII Directive proposal

The European Commission published a proposal to review the Renewable Energy Directive in June 2021, referred to as REDIII hereinafter. This was part of the package 'Delivering on the European Green Deal' and aims to accelerate the uptake of renewable energy in the EU and contribute to the net GHG emissions reduction of at least 55% by 2030. Article 25 was amended to set a new 13% GHG intensity reduction target, compared to the new emissions-based benchmark covering all transport modes. This GHG emission intensity target will replace the overall renewable energy target for the transport sector. The sub-target for advanced biofuels was kept, but it was increased. In addition, a new sub-target was introduced for RFNBO. These are liquid and gaseous fuels the energy content of which is derived from renewable sources other than biomass. According to Article 25 (b), the share of RFNBO should be at least 2.6% by 2030. For the calculation of the share of RFNBO, Member states can also include RFNBO when they are used as intermediate products to produce conventional fuels. So, the obligation can be met using the following options:

- Direct use of RFNBO in the vehicle fleet, vessels and aircrafts, and
- Use of RFNBO as intermediate product to produce conventional fuels, such as in refineries.

The sub-target must be met by fuel suppliers, and it covers all fuels and electricity supplied to the transport sector. The RFNBO supplied in the aviation and maritime modes shall be considered to be 1.2 times their energy content (Article 27(1a) c[1]).

In the framework of REDII, the Commission was requested to develop a Union methodology to ensure that the electricity used to produce RFNBO is of renewable origin. On May 2022, the Commission published the draft delegated act that sets out detailed rules by which economic operators are to comply with the requirements laid down in the fifth and sixth subparagraphs of Article 25 (3) of the REDIII.

Article 29 (a) indicates that RFNBO can be counted towards the 2.6% sub-target only if the GHG emission savings from the use of those fuels are at least 70%. The commission published, on May 2022, a draft delegated act that specifies the methodology to assess the GHG emissions savings from RFNBO. The consultation period for this and above act was ended on 17 June 2022, and it is hoped that both acts can be adopted by the Commission shortly.

Next to the RFNBO sub-target for the transport sector REDIII also introduced an obligation for the industry. According to Article 22a, Member States shall ensure that the contribution of RFNBO used for final energy and non-energy purpose shall be 50% of the hydrogen used for final energy and non-energy purposes in industry by 2030. This obligation excludes hydrogen used as intermediate products for the production of conventional transport fuels to avoid any double counting.

[1] The exact text in REDIII is: "(c) the shares of advanced biofuels and biogas produced from the feedstock listed in Part A of Annex IX and of renewable fuels of non-biological origin supplied in the aviation and maritime modes shall be considered to be 1.2 times their energy content.

2.2 ReFuelEU Aviation Regulation proposal

As part of the 'Fit for 55" climate package, the European Commission released the ReFuelEU Aviation proposal COM(2021) 561 final). This proposal aims to reduce the GHG emissions in the aviation sector by introducing a sustainable aviation fuel (SAF) mandate on fuel suppliers to the aviation sector. The obligation will start in 2025 and gradually increase to 2050. This proposal also included a sub-obligation of 0.7% by volume for RFNBO in the form of synthetic aviation fuel for 2030, increasing to 28% in 2050. RFNBO for aviation is, hereafter referred to as e-jet fuel. The obligation is set on all aviation fuel suppliers on the EU internal market[2].

2.3 FuelEU Maritime Regulation proposal

In July 2021, the European Commission presented the FuelEU Maritime proposal (COM(2021) 562 final) within its "Fit for 55" package. This proposed regulation introduces increasing limits on the greenhouse gas (GHG) intensity of the energy used on board by vessels[3] from 2025. Annual average GHG intensity will be required to decrease by 2% overall by 2025 and 6% overall by 2030. Subsequent reductions will be required over 5-year periods until 2050, when carbon intensity should be 75% less when compared to the 2020 base year. The GHG intensity relates to well-to-wake (WTW) CO_2-equivalent emissions to account for all the life cycle GHG emissions (CO_2, CH_4, N_2O) of the different fuels and relevant engine technologies. Shipping companies will be responsible for meeting the obligation. The obligation covers all energy used on board when the ship is at an EU port, all energy used by the ship on voyages between EU ports and 50% of the energy used on voyages departing from, or arriving at an EU port, where the last or the next port of call is a third country.

The FuelEU Maritime proposal does not contain any specific measure to promote the use of RFNBO, but this is being considered in the negotiation process. As the discussions are yet to be concluded, this possibility is not further assessed in this report.

[2] All aviation fuel made available to aircraft operators at each European Union airport should contain a minimum share of sustainable aviation fuel.

[3] Focus on ships with a gross tonnage above 5 000.

3 Exploring RFNBO demand and supply in 2030

3.1 Demand in 2030

Article 25 (b) of the REDIII set the share of RFNBO to be at least 2.6% of the energy demand in the transport sector by 2030. The obligation applies to all fuels and electricity supplied to the transport sector. Thus, the total energy demand of the transport sector in 2030 will determine the actual RFNBO required to meet the sub-target. PBL's Climate and Energy Outlook (KEV) provides energy projections for the Netherlands based on both adopted and proposed policies. The definition of the transport sector in Eurostat covers five main types of transport modes, namely air, inland waterways, rail, road and maritime (sea). Off-road use in agriculture and forestry is excluded from transport, and is instead counted towards the final energy consumption of the agriculture and forestry sector. Fuel used in ships for fishing is also excluded from transport, and included in the final energy consumption of the fishing sector[4]. Therefore, the total energy demand for non-road machinery and fisheries are excluded from the KEV projection. In the Netherlands, the renewable fuel obligation was set to fuel suppliers supplying fossil gasoline and diesel as part of the REDII implementation. In this study, we follow the REDIII and base our calculations on the total fuel supply, including all forms of energy. Table 3.1 presents the energy projections for the transport sector for 2030. This table also includes the CBS data on transport energy consumption in 2019. Based on these data, the demand for RFNBO is estimated to be in the range of 28-29 PJ to meet the 2.6% sub-target by 2030.

REDIII includes an exception for the sub-target on advanced biofuels. Member States can decide to exclude electricity or RFNBO from the denominator for the calculation of the advanced biofuel sub-target. While such an exception is not mentioned for the RFNBO, a similar approach may also be followed for this sub-target. If the electricity consumption and consumption of advanced biofuels could also be excluded from the denominator for RFNBO, this would reduce the absolute amount of RFNBO to meet the 2.6% target[5]. Further reduction is possible if the share of electrification increases and/or more advanced biofuels need to be applied to achieve the GHG emissions reduction target.

As introduced in chapter 2, REDIII included also a separate RFNBO obligation for industry. By 2030, 50% of the energy content of hydrogen for final energy and non-energy purposes should be met by RFNBO. Hydrogen used for the production of conventional transport fuels was excluded from this industry obligation. Instead, the hydrogen use for the production of conventional fuels was included in the RFNBO sub-target of 2.6% for the transport sector. According to CE Delft & TNO study (2022), the 50% obligation for industry corresponds to about 50 PJ RFNBO based on the current use of hydrogen in industry. The amount of RFNBO may increase if hydrogen

4 See https://ec.europa.eu/eurostat/databrowser/view/ten00126/default/table?lang=en

5 Excluding only advanced biofuels from annex IX, list A from the denominator can reduce the RFNBO sub-target by 2%. When both electricity and advanced biofuels are excluded, RFNBO sub-target can be reduced by up to 5%. In this calculation total electrification of transport is considered to be 26 PJ (based on KEV, 2021 established and proposed policy projections).

use in industry increases towards 2030, for example if the steel industry switches to a hydrogen based process for the reduction of iron ore.

Table 3.1 Total energy consumption in the transport sector in 2019 (CBS) and demand in 2030 in the Netherlands (according to KEV (2021)).

	CBS	KEV	
		Established policy (vastgesteld beleid)	Established and planned policies (vastgesteld en voorgenomen beleid)
	2019[2]	**2030**	**2030**
	PJ	**PJ**	**PJ**
Inland transport demand[1]	455	418	411
of which electricity	*8*	*23*	*26*
of which hydrogen	*0*	*0.21*	*0.42*
Bunker fuels aviation	166	201	
Bunker fuels shipping	475	475	
Total transport demand	1,097	1,094	1,087
2.6% RFNBO for transport	29	28	28

1) Excluding non-road machinery, fisheries, bunker fuels for aviation and shipping

2) NEa, 2020 indicates the total energy use as 466.8 PJ, of which 0.5 PJ is from electricity

3.2 RFNBO in aviation and related hydrogen demand

The RefuelEU Aviation regulation proposal introduces the 0.7 vol.% sub-obligation for RFNBO in aviation. This target requires supply of 1.2 PJ e-jet fuel when it is based on the CBS data from 2019, and 1.4 PJ, when based on KEV projections for 2030. It should be noted that the RFNBO sub-obligation increases to 5% in 2035. This means that by 2035, e-jet fuel volume will need to reach seven times the 2030 volume when the total energy consumption in aviation is kept constant. So, a very rapid upscaling of production and supply of e-jet fuel is required after 2030.

E-jet fuel can be produced via various production pathways. The Fischer-Tropsch (FT) synthesis pathway appears to be one of the promising routes to produce e-jet fuel. The product of this route consists of a mixture of different hydrocarbons, and the composition of these hydrocarbons is influenced by the operating parameters, the catalysts used and the composition of the synthetic gas (syngas) input. Literature indicates 25-60% of the product mix to be suitable for jet fuel (AdvanceFuel, 2019; ICCT, 2019; Schmidt, et al., 2016). Higher single-pass jet fuel selectivity of up to 70% are at research stage (Li et al., 2018).

E-kerosene can also be produced via methanol synthesis. This route consists of either the commercial methanol production process, where syngas as input is needed, or direct methanol production using CO_2 and hydrogen, which is at a lower technology readiness level (TRL 6-7). The methanol is subsequently converted into jet fuel via the methanol to olefins, and Mobil olefins to gasoline and distillate (MTO-MOGD) process, which was developed by Mobil in the 1980s.

The share of jet fuel in the final product depends on the specific process design. The product consists of a mix of naphtha, jet fuel, base oil and waxes and fuel gases. Depending on the market conditions, the product slate (the mix) can be optimised in favour of the one of the products. The current market conditions have been favouring diesel production above jet fuel production. In this study, three options are defined for 2030:

- The market will continue to favour renewable diesel and e-jet fuel will stay as one of the by-products (BAU). Thus, the product slate suitable for jet fuel will be about 25% of the total FT process.
- The market will favour e-jet fuel production. Nevertheless, other products will continue to be produced. In this case e-jet fuel will constitute 60% of the total product slate.
- The process will be fully optimised and designed to form high shares of hydrocarbon chains. This will result in approximately 85% of the product slate to be e-jet fuel.

Table 3.2 shows the need for renewable hydrogen and the renewable electricity to produce hydrogen if the e-jet fuels would be produced and consumed in the Netherlands. This, however, is not necessary as e-fuels will be tradable commodities, similar to biofuels and conventional fuels, and the obligation can be met by import.

Table 3.2 Production of e-jet fuel and other e-fuels and the renewable electricity demand to meet the 0.7% sub-obligation

		BAU	Optimisation	Max. optimisation
		25% of the product slate e-jet fuel	60% of the product slate e-jet fuel	85% of the product slate e-jet fuel
Products/Output				
e-jet fuel	PJ	1.2-1.4	1.2-1.4	1.2-1.4
e-diesel	PJ	2.8-3.4	0.5-0.6	0
e-naphtha/gasoline	PJ	0.7-0.8	0.3-0.4	0.2
Total e-fuels	PJ	4.7-5.6	1.9-2.3	1.4-1.6
Input				
Renewable hydrogen	PJ	6.3-7.6	2.6-3.2	1.8-2.2
Renewable electricity to produce hydrogen[1]	*PJ*	*10.9-13.1*	*4.5-5.5*	*3.2-3.9*

1) The energy consumption to produce 1 kg of H_2 is set to 57.8 kWh. This value is consistent with SDE++ and the CE Delft/TNO report (2022). Literature however provides a range of values, i.e., IRENA (2020) refers to 50-83 kWh/kg.

3.3 RFNBO obligation and the fleet requirements

This section explores the number of vehicles required to meet the 2.6% RFNBO-obligation for the transport modalities for which direct use of hydrogen as fuel is considered as an option. This includes cars, vans, buses, trucks, trains and inland ships. As introduced in chapter 3, the 2.6% target is translated into 29 PJ of RFNBO demand.

Table 3.3 presents the calculation results. Due to lack of adequate data no numbers are included for vans and trains. Buses and trucks are taken together because they have similar characteristics in terms of consumption and annual mileage. A reference vehicle for each transport modality is selected and presented in the table below. Based on the reference vehicles, the number of vehicles is calculated that consume 1 PJ and 29 PJ of fuel energy on an annual basis. This table also presents the overview of Dutch policy plans and market development. The market development of vehicles[6] suitable for specific sustainable fuels is monitored on behalf of the Dutch Ministry of Infrastructure and Water management and periodically updated. The last reports include the RWS Routeradar and the monitoring report of the AFID guideline (AFID, 2021 and Routeradar, 2021).

Results show that if the RFNBO is to be fully met by passenger cars, more than 878 thousand fuel-cell electric cars (FCE-cars) will need to be on the road by 2030. The number of hydrogen cars in fleet by the end of March 2022 was around 505, which is still much lower than the 2020 target, which was approximately 2200 hydrogen cars. If the RFNBO is to be fully used in long-haul trucks the number of hydrogen FCE-trucks will need to be around 39,000. Hydrogen can also be supplied for inland shipping. In this case, the number of ships will need to be around 1,700. However according to the plans, the first 100% hydrogen-FCE cargo vessel will not be operational until around 2025. This relates to the construction of the new inland vessel Antonie van Lenten Scheepvaart BV that will transport salt from the salt factory of Nouryon in Delfzijl to the Botlek in Rotterdam.

KEV projections related to hydrogen use in transport are very low, especially when compared with the RFNBO demand in REDIII. KEV projections from 2021 indicates the total supply of hydrogen to passenger cars and buses to be around 0.2 PJ and 0.3 PJ, respectively, in 2030. KEV estimates were based on the assessment of current market trends in combination with the effect of established and intended policies with respect to hydrogen vehicles. This concerns all policies that were officially communicated on 1 May 2021.

The following can be summarised regarding the possible market development for the different transport modalities:

- <u>Road transport</u>: the total number of hydrogen cars was 505 by the end of March 2022. This number is far below the target of 2020 (Routeradar, 2021). The key reasons for the low uptake are the limited number of brands and vehicle types on the market and the limited number of hydrogen fuelling stations (AFID, 2021). This applies to both cars and heavy-duty vehicles. At present, car manufacturers are primarily focusing on bringing new battery electric cars into the market. Fuel cell and hydrogen (FCH) heavy-duty trucks represent a promising zero-emission alternative, in particular in the long-haul segment. This is because battery electric trucks pose more restrictions in terms of range and flexibility. Also fuel cell electric vans driving longer ranges could present an interesting market segment[7]. Furthermore, recharging infrastructure also presents challenges in view of the (current) limitation in the capacity of the electricity grid and the possibilities in extension thereof.

---

6 The word 'vehicles' is broadly defined and include ships and airplanes as well.

7 https://www.miele.de/en/m/miele-relies-on-hydrogen-powered-service-vans-from-opel-5938.htm

- Rail transport: Nearly half of the railway lines in Europe are not electrified. The diesel-powered trains that run on these tracks produce emissions. Reduction of emission through electrification by installing overhead lines for all those railway lines is costly. Switching to fuel cell-based hydrogen commuter trains is being considered a viable alternative. Train manufacturer Alstom has already received the first orders for supply of hydrogen fuel cell trains, and also Siemens Mobility is equipping commuter trains with hydrogen fuel cells. In the Netherlands, most railways are equipped with overhead lines, but there are several regional lines in the north, east and south of the country where diesel trains run. Total diesel consumption of rail transport in the Netherlands amounts 0.9 PJ, including the consumption of shunting locomotives around ports and the large industrial clusters. Hydrogen for trains can contribute to fulfilling the RFNBO obligation, but the potential is limited, also because the trains are probably more efficient than comparable diesel trains.
- Inland shipping: There is genuine interest in the use of pure hydrogen from end-use perspective and also from the fuel cell system industry and engine manufacturers. Market development is still slow. It will still take 2-3 years before the first vessel 100% hydrogen-FCE driven, will be operational.
- Maritime shipping: Ship owners recognise the importance of GHG emissions reduction, but direct use of (renewable) hydrogen is not yet being considered that much. Apart from biofuels that can be blended in marine fuels, they are mostly interested in methanol as an alternative fuel[8], followed by liquefied bio-methane (bio-LNG) and ammonia. Methanol is popular because it is a practical fuel which can be produced at relatively competitive costs from biomass or as e-fuel. New ships are regularly ordered as dual-fuel diesel-methanol (or diesel-LNG), which makes the vessel fuel flexible (it can run on diesel only or it can run on methanol with diesel-pilot). LNG engines are readily available, and several engine manufacturers are offering methanol and hydrogen dual-fuel engines. In addition to methanol, interest in the use of ammonia as a carbon-free fuel for maritime shipping has also increased in recent years. Next to the need to reduce shipping emissions, the increase in interest stems from the many initiatives worldwide to develop renewable hydrogen-based ammonia projects, because it is relatively easy to store and transport renewable hydrogen in the form of ammonia of which there is also a large demand in itself in industry. This is expected to significantly increase the volume of international trade in ammonia which also offers opportunities to use it as fuel. There are many advantages of using ammonia as a marine fuel. There are also many challenges, and they need to be controlled by technical and regulatory measures to become a feasible solution for carbon-free shipping. Due to the large amount of marine bunker fuels in the Netherlands, it can, if possible, make an important contribution to an RFNBO target. However, due to the current status of development, no contribution is expected before 2030.
- Aviation: airplanes are not very flexible towards alternative fuels, other than jet fuel from renewable origin, because of the high energy density requirements, safety regulations and long airplane lifetime. For that reason, ReFuelEU Aviation Regulation proposal focuses on mandatory market shares of SAF, mostly to be supplied as a blend with fossil jet fuel. SAF can be bio- or RFNBO fuel. Nevertheless, aircraft manufacturers consider hydrogen as an option in the long(er) run. Airbus, for example, considers hydrogen critical in its aim of

[8] e.g.https://www.maersk.com/news/articles/2022/03/10/maersk-engages-in-strategic-partnerships-to-scale-green-methanol-production

developing the world's first zero-emission commercial aircraft by 2035[9]. This will, however, require an innovative approach to fuel storage. Real commercialisation will most likely not take place before 2040, if at all.

Table 3.3 Energy consumption per vehicle and projected number of vehicles for 1 and for 29 PJ. Sources for fuel energy consumption (TNO, 2020a, JRC, 2020, Transport & Environment, 2020, TNO, 2020b, Marin-TNO, 2020[10])

Vehicle		Cars	Trucks	Inland ships
		Average 22,000 km[11] annually	Tractor semi-trailer 86,000 km annually	M8 – 110m 14 hrs/day
Fuel type		Hydrogen FCE	Hydrogen FCE	Hydrogen FCE
Fuel energy per vehicle	MJ/km	1.5	8.7	307
	GJ/y	33.0	748	17,530
Number of vehicles needed	#/PJ	30,300	1,340	57
	#/ 29 PJ	878,790	38,760	1,654
Plans based on other studies and policy documents	# of vehicle in 2030	30,000(DEM, 2018[12]) – 300,000 (AFIR, 2021)	4,800 (AFIR,2021)	50 (DEM, 2018)
Market development		Slow market development (AFID, 2021)[13]		First 100% hydrogen-FCE vessel operational < 2025[14]

9 https://www.airbus.com/en/innovation/zero-emission/hydrogen

10 Fuel consumption info from boing 737 for European route of 2000 km and 4 one-way trips per day.

11 The annual average km is based on the DEM(2018) study, which was used for the Climate Agreement. The number of vehicles scales inversely with the mileage. If the mileage is 2x higher or lower in practice, then the number of vehicles will be 2x lower or higher.

12 Fuel vision working group DEM – Sustainable energy carriers mobility. Used as input for the Climate Agreement 2019.

13 Monitoring report AFID guideline: quote: 'In addition to the battery electric car, hydrogen can also be used for zero emissions. With 393 cars in 2020, the number of hydrogen cars in the Netherlands is still far below the 2020 target of approximately 2200 hydrogen vehicles. This is partly due to the limited supply of hydrogen vehicles and the relatively low coverage of filling stations. In order to achieve the 2030 target, significant growth still needs to be made in both vehicles and charging infrastructure.

14 135 m vessel Antonie: Eerste binnenvaartschip op waterstof komt eraan | Topsector Energie.

3.4 Fuels that contribute to the transport targets and the transition pathways of the different sectors

According to Article 25(1), when RFNBO are used as intermediate products to produce conventional fuels, these fuels shall be counted towards the RFNBO obligation of 2.6% in the transport sector. The exact section of the article is highlighted below.

For the calculation of the reduction referred to in point (a) and the share referred to in point (b) (point b refers to the sub-targets), Member States shall take into account renewable fuels of non-biological origin also when they are used as intermediate products for the production of conventional fuels.

REDIII, Article 22a (Mainstreaming renewable energy in industry) introduced another binding target for RFNBO with the aim of mainstreaming renewable energy in industry. According to this article, 50% of the hydrogen used in industry for final energy and non-energy purposes will need to be from RFNBO by 2030. Hydrogen used as intermediate product for the production of conventional transport fuels is excluded from this target to avoid any double counting. This means that the hydrogen used in refineries will need to be allocated to production of conventional fuels and the production of other products.

There is no clarification yet on how, in practice, the RFNBO used as an intermediate product in the production of conventional fuels will be certified and counted towards the RFNBO obligation. The 2.6% sub-target is set on the fuel suppliers at member state level. Within the existing renewable fuel obligation system, renewable certificates (HBE) are created by claiming deliveries of renewable energy in the Energy for Transport Registry (REV: Register Energie voor Vervoer) in the Netherlands. Therefore, in further calculations, we linked the use of RFNBO as intermediate product in the production of fuels to the supply volumes in the Dutch transport sector.

3.4.1 Use of RFNBO as intermediate in refineries

In refineries, hydrogen is used in several processes, such as hydrotreating and hydrocracking. Hydrotreatment is one of the key stages of the diesel refining process and relates to several processes such as hydrogenation, hydrodesulphurisation, hydrodenitrification and hydrodemetalisation. Hydrocracking involves the transformation of long and unsaturated products into products with a lower molecular weight than the feed.

A major part of the hydrogen demand in Dutch refineries is met by on-site production through steam methane reforming (SMR) and from gasification of heavy oils. These are categorised as captive production. Another large part of the demand is met by recovering hydrogen from the residual gas of the catalytical reforming/platforming processes within the refineries (PBL & TNO, 2020a). In addition, hydrogen is also purchased from other companies, such as Air Liquide or Air Products, which is referred to as merchant supply and these are relatively small when compared with the captive production (Weeda and Segers, 2020). Figure 3.1 illustrates the hydrogen energy content broken down into different categories based on MIDDEN report (PBL & TNO, 2020a) and personal communications.

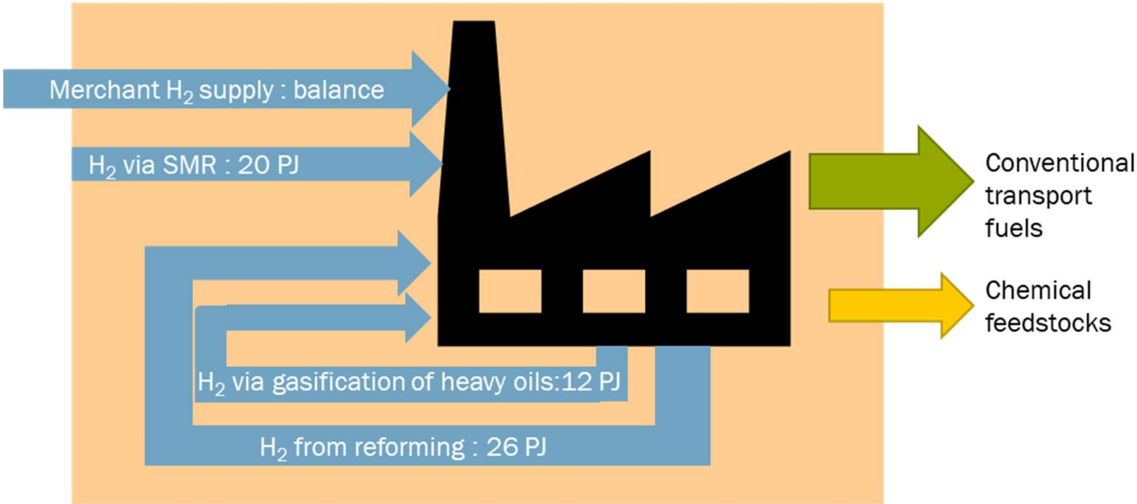

Figure 3.1 Schematic presentation of hydrogen flows to the fossil refineries (captive values are derived from MIDDEN report (PBL & TNO, 2020a)

The contribution potential of RFNBO as an intermediate product in the production of conventional fuels that are supplied in the Netherlands is calculated to be in the range of 8-18 PJ. The low value is based on the assumption that only on-site (captive) production of hydrogen via SMR using natural gas can be replaced by RFNBO, i.e., renewable hydrogen. The high value includes also the substitution of externally supplied merchant hydrogen from SMR by RFNBO. Internal (captive) hydrogen released as residual product from the naphtha catalytic reforming and produced from gasification of refinery heavy residues are excluded in both low and high range calculations. These calculations are based on the below assumptions.

- Hydrogen is used to produce both non-fuel products (referred to as chemical feedstocks in the figure above) and conventional transport fuels. The amount of hydrogen that can be allocated to the non-fuel output is calculated to be in the range of 10-14% (Concawe, 2021). In this study, 12% of the total hydrogen use is assumed to be for non-fuel production and 88% for conventional fuel production.
- The total hydrogen use that can potentially be substituted with RFNBO as the intermediate product in the production of conventional fuels is calculated to be in the range of 15.9-34.1 PJ. Since the 2.6% RFNBO blending[15] obligation is given to fuel suppliers, the RFNBO use as an intermediate product is linked to the total supply of transport fuels in the Netherlands.

[15] The specific hydrogen consumption is calculated by dividing the hydrogen use with the conventional fuel production volume. In the low value, hydrogen use covers only the on-site SMR production. For the high value, this is on-site SMR production plus external supply.

- The Dutch refinery production of conventional fuels[16] in 2019 as reported in the MIDDEN report (PBL&TNO,2020a) and verified by CBS data are used to define the specific SMR hydrogen consumption for low and high values (amount of SMR hydrogen per unit of fuels). These specific consumption figures are then multiplied by the total fuel volume supplied in the Netherlands in 2019 to estimate the potential contribution of this route to the RFNBO obligation. The numbers then reduce to the bandwidth 8-18 PJ[17]. Table 3.4 presents the total fossil fuel production of the Dutch refineries and the fuel supply in the Netherlands in 2019. Overall, 51% of the production volume corresponds to the fuel supply in the country. While gasoline and fuel oil consumption appear to be larger than the Dutch refinery production volumes, diesel, kerosene and LPG production volumes were much larger that the fuel use in the Netherlands.

Table 3.4 The conventional fuel production of the Dutch refineries and the fuel supply to the transport sector in 2019

	Production	Supply	Share of fossil fuel use compared to fossil fuel produced
	PJ	PJ	%
Gasoline	174.6	183.2	105%
Diesel	896.5	255.5	28%
Kerosene	394.3	166.7	42%
Fuel oil	365.3	385.5	106%
LPG	71.0	5.8	8%
Total	1,902	968	51%

3.4.2 Use of RFNBO as intermediate in biorefineries

While the REDIII proposal did not include the use of RFNBO in the production of biofuels it is highly likely that the final proposal will also include biofuels. The use of hydrogen as intermediate product in the production of biofuels is similar to the use of hydrogen as intermediate product in the production of conventional fuels, which is excluded from the RFNBO-obligation for industry (Article 22(a)). As a result, it is indicated that hydrogen for the production of biofuels can be excluded for the industry target[18]. If not counted in industry, it should be counted in transport where the use of hydrogen for biofuels also shows similarities with the use of hydrogen for the production of synfuels.

---

[16] Gasoline, diesel, kerosene, fuel oil and LPG.

[17] This indicates that the amount of fuels supplied in the Netherlands is approximately 50% of the amount of fuels produced in the Dutch refineries. This, however, does not mean that 50% of the fuels produced in Dutch refineries is actually supplied to the transport sector in the Netherlands as the mix of fuels produced is not the same as the mix of fuels needed (see Table 3.4). Import and export play a role.

[18] Personal communications with the Commission.

The Ministry has requested TNO to also explores this option and to assess the order of magnitude of possible renewable hydrogen use that may contribute to meeting the RFNBO obligation for the transport sector.

Biorefineries that produce advanced biofuels via hydro-processing vegetable oils and fats use a significant amount of hydrogen. Hydrogen is used during the hydrodeoxygenation of fatty acids, followed by cracking the hydrocarbons to yield HVO, commonly referred to as renewable diesel. This diesel can be used up to high fractions in road transport. When hydro-processed ester and fatty acids (HEFA) are produced, hydrocarbons are cracked further than HVO, which means that more hydrogen is needed. HEFA fuel has been approved by the American Society for Testing and Materials (ASTIM) and can be blended with conventional jet fuel. Thus, the amount of hydrogen needed relates to whether the process is run to produce only renewable diesel (HVO mode) or to produce mainly jet fuel (HEFA mode). In addition, the composition of the pre-treated bio-oil (i.e., the amount of oxygen) plays an important role in the amount of hydrogen needed. The table below introduces the hydrogen demand collected from different literature sources.

Table 3.5 Total hydrogen demand of the HVO/HEFA processes

		MIDDEN Report (PBL &TNO, 2020b)	Hamelinck et al., 2021	
			HVO mode	HEFA mode
Input				
Pre-treated oil	kg	1,191	1,000	1,000
Hydrogen	kg	42	41	44
Steam	MJ		813	4,445
Electricity	kWh		85.9	46.5
Output				
Renewable diesel	kg	1,000	778	135.7
Bio-naphtha	kg	25	62.9	93.9
Propane	kg	72	36	84
HEFA	kg			610
Hydrogen demand per tonne input	**kg/t**	**35**	**41**	**44**
Hydrogen demand per tonne output	**kg/t**	**38**	**47**	**48**

3.4.2.1 *Existing production capacity in the Netherlands, expansion plans and the total hydrogen use*

Neste operates a biorefinery in Rotterdam. The annual production capacity of this plant is around 1 Mt (PBL&TNO, 2020b**)**. In addition to drop-in biofuels, the Neste plant produces renewable naphtha, propane, and alkanes. Neste has announced that it intends to modify its existing renewable production capacity to enable production of sustainable aviation fuel (SAF). The modifications will enable Neste to optionally produce up to 500 kt SAF per annum as part of the existing capacity.

In 2019 and 2020, roughly 85% of the feedstock used by Neste to produce renewable diesel consisted of waste fats and oils. The waste and residues consist of used cooking oil (UCO), wastewater from palm oil mills, bleaching earth oil, technical corn oil, and animal fats. On November 3, 2020, Neste announced that it would acquire Bunge's Loders Croklaan's palm oil refinery plant in Rotterdam. Neste's goal is to reach a 100% waste and residues share by 2025 (USDA, 2021).

In addition, there are other plans to build biofuel refineries in the port of Rotterdam.

- The Finnish forestry company UPM has announced their plans to build a new-generation biofuel refinery in Rotterdam. The estimated annual capacity is 500 kt of high-quality renewable fuels, including aviation fuel[19].
- Neste announced in 2021 that they chose Rotterdam as the intended location for expansion of their sustainable fuels production capacity. The planned expansion will be located partly on the existing site and partly on a new site on Maasvlakte 2. If this expansion occurs, the total production capacity is projected to double[20].
- Shell has announced a final investment decision to build a biofuel pant with an annual production capacity of 820,000 tonne at the Shell Energy and Chemicals Park Rotterdam, formerly known as the Pernis refinery[21]. This facility will produce SAF (HEFA) and renewable diesel from waste in the form of used cooking oil, waste animal fat and other industrial and agricultural residual products, using advanced technology developed by Shell. The Rotterdam biofuels facility is expected to start production in 2024[22].
- In 2019, SkyNRG, together with KLM, SHV Energy and Schiphol announced plans to build a sustainable kerosene production facility in Delfzijl. The plant will produce 100 kt SAF and 15 kt bioLPG[23].

---

[19] https://nord.news/2022/01/27/upm-favors-rotterdam-over-a-billion-euro-biofuel-refinery-instead-of-kotka/

[20] https://www.portofrotterdam.com/en/news-and-press-releases/neste-chooses-rotterdam-intended-location-expansion-sustainable-fuels

[21] https://www.shell.com/media/news-and-media-releases/2021/shell-to-build-one-of-europes-biggest-biofuels-facilities.html

[22] Advanced production methods uses bio-naphtha and light hydrocarbon gasses created during the formation process to create hydrogen. Hydrogen and high-pressure steam are then used in the production process to convert oils into fuels (hydro-processing), helping to reduce the fuel's carbon intensity.

[23] SkyNRG, KLM and SHV Energy announce project first European plant for sustainable aviation fuel | SkyNRG

Table 3.6 presents the total hydrogen demand of the existing and planned biofuel facilities in the Netherlands. As stated previously, expansion plans of the Neste facility and the UPM biorefinery are only announcements. There are no final decisions about these plans. Therefore, the hydrogen demand from these companies should be considered with caution. Shell has announced the final investment decision for the biorefinery, but it is unclear to what extent the company will meet its hydrogen demand from bio-naphtha to ascertain the possibility of using e-hydrogen in this facility. Thus, while the total RFNBO use as intermediate may reach to 15.7-19.8 PJ, this number contains high uncertainties. A demand based on the existing Neste biorefinery, which requires 4.6-5.8 PJ hydrogen, appears more plausible to consider for the use of RFNBO as intermediates in biofuel refineries for 2030.

Important for the analysis in this report is to note that not all the products are supplied to the Dutch market. These companies produce tradable goods, and the market conditions will define what share of the production will be supplied to the Dutch transport sector.

REDIII includes a cap on biofuels produced from feedstocks that are included in list B, Annex IX of REDIII. According to Article 26, the share of biofuels and biogas produced from these feedstocks should not be more than 1.7% of the energy content of fuels and electricity supplied to the transport sector. List B includes used cooking oil and animal fats. This means that biofuel supply from UCO and animal fats should not be more than 18.5 PJ. These feedstocks are used to produce not only HVO or HEFA but also UCO methyl ester (UCOME), for which hydrogen is not needed in the production process. In 2019, UCOME supply to the Dutch market was around 3.5 times the HVO supply[24]. The total HVO supply was around 4.8 PJ in 2019, which corresponds to less than 11% of the current renewable diesel production of Neste. If, and when, the maximum limit for these feedstocks would be fully met via HVO, this would correspond to 42% of the current Neste production volume. In that case 1.9-2.4 PJ renewable hydrogen could be linked to the total supply of HVO in the Netherlands and contribute to meeting the RFNBO-obligation. It is necessary to highlight that there are a number of uncertainties. First, it is not very likely that the 1.7% cap will be fully met by HVO. UCOME, a relatively cheaper biodiesel production pathway, is likely to stay in the market. This will mean that less HVO/HEFA supply and related to that less RFNBO as intermediate product can be allocated to the biofuel supply. Second, HVO (and HEFA) are also produced from other feedstocks than list B. In fact, in 2019, 6.9% of HVO was from palm oil mill effluents and 7.3% was from tall oil (NEa, 2020). This means that HVO (and HEFA) that do not fall under the 1.7% cap can be supplied to the Dutch market in 2030. This means that there can also be more HVO/HEFA supply and related to that more RFNBO can be allocated as an intermediate to the biofuel supply.

Hydrogen can also be used in the production of advanced biofuels (through thermochemical production) to improve the (drop-in) biofuel yield. These options are not explored in this study as there are currently no advanced biofuel facilities in the Netherlands.

[24] According to NEa (2020), the total amount of double counting FAME was around 33140 TJ and the double counting HVO was 9538 TJ (4769 TJ single counting). 91.9% of the FAME was from UCO and animal fats.

Table 3.6 Hydrogen demand of existing and planned biofuel production facilities in the Netherlands

Plant name	Production capacity (Mt)	Hydrogen demand (PJ)
Neste (current production and modifications)	1.0	4.6 - 5.8
Neste (expansion plans)	1.0	4.6 - 5.8
Shell	0.8	3.7 - 4.7
UPM	0.5	2.3 - 2.9
SkyNRG	0.1	0.5 - 0.7
Total hydrogen demand range		15.7 - 19.8
RFNBO as intermediate product that can be allocated to HVO/HEFA supply to the Dutch market		1.9 - 2.4

LHV hydrogen = 119.96 MJ/kg

3.4.3 E-methanol

Methanol can be blended with gasoline at a maximum of 3 vol% according to the EU regulations. This can be conventional “grey” methanol produced from natural gas, bio-methanol produced from biomass, and e-methanol based on renewable hydrogen from electrolysis and carbon dioxide (CO_2). If the use of e-methanol leads to a reduction of carbon dioxide emissions of at least 70% compared to the conventional fossil fuel, the e-methanol can be counted as RFNBO.

According to CBS 183 PJ of gasoline was supplied to the transport sector in 2019. The KEV2021 projects gasoline demand as 188 PJ for 2030. The 3 vol%[25] limit results in an amount of 2.7-2.8 PJ of e-methanol that could be blended into gasoline and counted towards the RFNBO-obligation. In the Netherlands, the production capacity of the methanol plants of BioMCN is about 900 kt. Without major modification, it is estimated that some 10% of conventional natural gas-based methanol production can be replaced by e-methanol within existing plants. Considering a capacity factor of 90% this could result in the production of about 1.6 PJ of e-methanol. This requires the production of 2.0 PJ, or about 17 kt of hydrogen. To produce this amount of hydrogen, an electrolysis unit of about 200 MW is required, which runs at full load on average 50% of the time.

Possibilities for e-methanol production within the BioMCN facility seem to be lower than the possibilities for blending methanol to gasoline that is supplied in the Netherlands. To be able to use the full potential of e-methanol via admixture for the RFNBO-obligation would require an expansion of the e-methanol production capabilities, or the import of certified e-methanol that can be counted as RFNBO in the context of the obligation.

[25] The density of methanol and gasoline are 792 kg/m^3 and 755 kg/m^3, respectively, and the energy content of methanol and gasoline are 20 and 43 MJ/kg, respectively.

Renewable methanol is considered as one of the promising fuels for decarbonising the maritime sector. There are already commercial examples, where ships have been retrofitted with methanol engines, such as Stena Lines' Stena Germanica, which was retrofitted with a dual methanol/diesel engine (IRENA, 2021). Maersk, the world's largest container shipping company, has plans to have 12 green container vessels that will be powered by green methanol[26]. Furthermore, this company has announced to engage in strategic partnership across the globe to boost the global production capacity of green methanol. Among the six strategic partnerships, three of them appears to be on e-methanol production. If sufficient e-methanol could be supplied to meet the 2.6% RFNBO obligation fully this would be fuelled for about 240 ships[27].

3.5 E-fuels as RFNBO and related renewable electricity and CO_2 demand

The table below introduces the hydrogen and CO_2 demand of various e-fuel pathways to meet the RFNBO obligation. It presents the renewable electricity demand to produce hydrogen and also the total renewable electricity demand to produce these fuels, including hydrogen and CO_2 via direct air capture (DAC). In addition to that, the total electrolyser capacity and the number of plants to produce e-fuels are specified for different types of e-fuels. This is to show what is needed if the RFNBO obligation would be fully met by one or another e-fuel option.

Consuming e-hydrogen, e-LNG/CNG or e-methanol in such quantities will require a drastic shift in the vehicle fleet and/or major adaptations to the vessels if they are used in ships. E-FT liquids consists of drop-in fuels and will require no modifications to the fleet. The e-FT value chain will have the advantage in that it can also produce e-jet fuel and, thus, contribute to the obligation in aviation.

[26] See A.P. Moller - Maersk engages in strategic partnerships across the globe to scale green methanol production by 2025 | Press Release | News

[27] This number is calculated based on a reference general cargo ship of 112 m, that consumes 1181 MJ/km (MARIN-TNO, 2020).

Table 3.7 Hydrogen and CO_2 demand of various e-fuel pathways to meet the RFNBO obligation

	e-hydrogen	e-FT liquids	e-methanol	e-LNG/CNG
Total fuel (PJ)[1]	29	29	29	29
Hydrogen demand (PJ)	29	40	35	35
Renewable electricity demand to produce hydrogen[2]	50.3	69.4	60.7	60.7
CO_2 demand (Mton)[3]	-	2.4	2.1	1.6
Total renewable electricity (PJ)	50.3	82	69	67
Electrolyser capacity ($GW_{e,in}$)[4]	3.2	4.5	3.9	3.9
E-fuel plant capacity ($GW_{fuel,out}$)[5]	1.0	1.0	1.0	1.0

1) More information available in TNO technology factsheets (energy.nl)
2) Specific energy demand is assumed to be 57.8kWh/kg
3) Via low temperature direct air capture (with an assumed electricity usage of 3 MJ/kg)
4) Plant efficiency of 58% (LHV) and operating for 4300 hours per year
5) Operating for 8000 hours per year

Production of 29 PJ of e-fuels requires approximately 4 GW of electrolyser capacity, with an efficiency of 58% (LHV) and operating for 4300 hours per year, and around 1 GW of fuel production capacity, which for FT liquids equals roughly 10% of the scale of the 300 PJ FT liquids synthesis section of the Shell Pearl GTL plant in Qatar.

REDIII also introduces an RFNBO target for the industry. By 2030, 50% of the hydrogen used in industry for final energy and non-energy purposes will need to be from RFNBO. This means that the amount of renewable electricity and electrolysis capacity required for hydrogen production for the Dutch RFNBO market will be much higher than what is introduced in this table. The RFNBO does not need to be produced in the Netherlands but can be imported from elsewhere, where there are more abounded renewable energy resources.

4 Summary and synthesis of results

4.1 Summary

REDIII has introduced a sub-target for RFNBO. By 2030, the share of RFNBO in the energy supplied to the transport sector should be at least 2.6%. This obligation corresponds to around 28-29 PJ of RFNBO supply. Next to REDIII, the ReFuelEU Aviation Regulation proposal included a 0.7%vol sub-obligation for the aviation sector. This will require around 1.2-1.4 PJ of RFNBO, which is referred to as e-jet fuel.

This study explored different aspects of meeting this sub-target. First, the needed amount of vehicle in 2030 was explored if the obligation was to be met through direct supply of hydrogen to the transport sector. The results showed that this option would require a significant number of hydrogen-powered vehicles on the market. The numbers calculated for the different transport modes were much higher than the number of vehicles included in the existing policy documents, plans or other studies.

Second, this study calculated the total amount of hydrogen used in the Dutch refineries that can be allocated to the production of conventional fuels. REDIII recognises RFNBO use as intermediate product to produce conventional fuels and this intermediate use can be counted towards the 2.6% sub target. The captive production of hydrogen via SMR using natural gas and the merchant hydrogen supply were taken into account. The results showed that the total hydrogen use in the refineries are much higher than the amount of RFNBO needed to meet the sub-obligation. These refineries, however, export a large volume of the conventional fuels. When looking at the volumes supplied to the Dutch transport sector, the total amount of hydrogen that can be substituted by RFNBO is smaller, with a maximum contribution of 60% of the RFNBO sub-target.

RFNBO use as intermediate product in the production of biofuels was also assessed. This assessment was based on the existing and planned HVO/HEFA plants in the Netherlands. While the total demand for hydrogen use as intermediate product can be high (current hydrogen use corresponding to 16-20% of the RFNBO sub-obligation, future demand can reach up to 65%), a large amount of these biofuels was exported to other countries and the supply to the Dutch market was limited. Furthermore, a cap has been introduced in RED to the supply of biofuels that are produced from used cooking oil and animal fats, and these feedstocks have been the main feedstocks to produce HVO/HEFA. This supply limitation reduces the contribution of this option significantly.

A particular attention was paid to the e-methanol supply option. There are two reasons behind this. E-methanol can be blended with gasoline up to 3%vol and used in the existing internal combustion engines with no modifications. Next to that, there has been a growing interest from the maritime sector to this fuel to reduce the GHG emissions.

Finally, the order of magnitude renewable electricity and CO_2 demand were explored for various e-fuel supply options, namely, e-hydrogen, e-FT liquids, e-methanol, and e-LNG/CNG. The total renewable electricity demand to produce these fuels will be high, i.e., corresponds to 40-50% of the renewable electricity produced in 2021. The total demand for CO_2 will also be high, for instance comparable or even higher than the future external CO_2 demand projections for the Dutch greenhouses[28].

4.2 Synthesis of results

The first assessments, summarised in the previous section, highlight the difficulty of meeting the RFNBO obligation. The assessment results can be synthesised via two specific cases, where the main difference relates to the total amount of hydrogen that can be substituted by RFNBO as intermediate product in the production of conventional fuels. The main features of the cases are introduced below.

- RFNBO can be used as an intermediate product to produce conventional fuels, and their contribution to the sub-target relates to the total fossil fuel supply to the Dutch market. Case 1 refers to RFNBO that replaces captive hydrogen use only. This means only on-site hydrogen production via SMR using natural gas is replaced by RFNBO. Case 2 considers replacement of both captive production and merchant supply of SMR-hydrogen to refineries to produce conventional fuels. In both cases hydrogen production via gasification of refinery heavy residues and hydrogen derived from the refinery processes are excluded.
- RFNBO can be used as an intermediate product to produce biofuels (HVO and HEFA), and their contribution to the sub-target relates to the maximum limit introduced to biofuels from feedstocks in list B, Annex IX of the REDIII. This means that the supply of HVO/HEFA cannot exceed 1.7% of the energy and electricity consumption in the transport sector. Case 1 assumes that RFNBO use as intermediate product in the production of biofuels is not counted towards the obligation. In case 2, we assume that hydrogen use as an intermediate in the production of biofuels can be counted towards the sub-target[29].
- The 0.7% e-jet fuel obligation is assumed to be met in both scenarios. E-jet fuel can be counted 1.2 times the RFNBO sub-obligation (Article 27(1a)c). This means e-jet fuel obligation can administratively be in the range of 1.4-1.7 PJ. In the case assessment the average value of 1.5 PJ is used.
- E-methanol blending with gasoline is limited to converting 10% of the domestic methanol production in the Netherlands and this e-methanol is assumed to be supplied to the Dutch market in case 1. In case 2, e-methanol supply is maximised up to 3 vol.% blending limit in the existing vehicle fleet[30].
- The rest is assumed to be met by RFNBO supply to the Dutch market. This can be in the form of gaseous RFNBO or liquid RFNBO for aviation, shipping and/or road transport.

Figure 4.1 and Figure 4.2 illustrate the two cases constructed. In case 1, total supply of RFNBO that can be used as an intermediate product in the production of conventional fuels contribute to almost 30% of the total obligation. Assuming that RFNBO obligation for aviation has to be met via e-jet fuel, the remaining direct supply of RFNO will be around 19.4 PJ (e-methanol blending + RFNBO supply to transport

[28] When compared with the pessimistic scenario.

[29] RFNBO contribution was counted to be in the range of 1.9-2.4 PJ. In this case, 2.4 PJ is assumed.

[30] This assumption is based on the fact that no adaptations to the vehicle fleet are needed. The possibility of e-methanol use in shipping can be considered as part of the rest of the RFNBO supply.

in the graph). There is a possibility to produce some e-methanol in the existing methanol production plants. This is highlighted in purple in the graph. This methanol can be blended to gasoline and used in road transport. It can also be used in shipping. The rest of the RFNBO can be in the form of hydrogen used in hydrogen fuelled vehicles and vessels (with fuel cells or internal combustion engines).

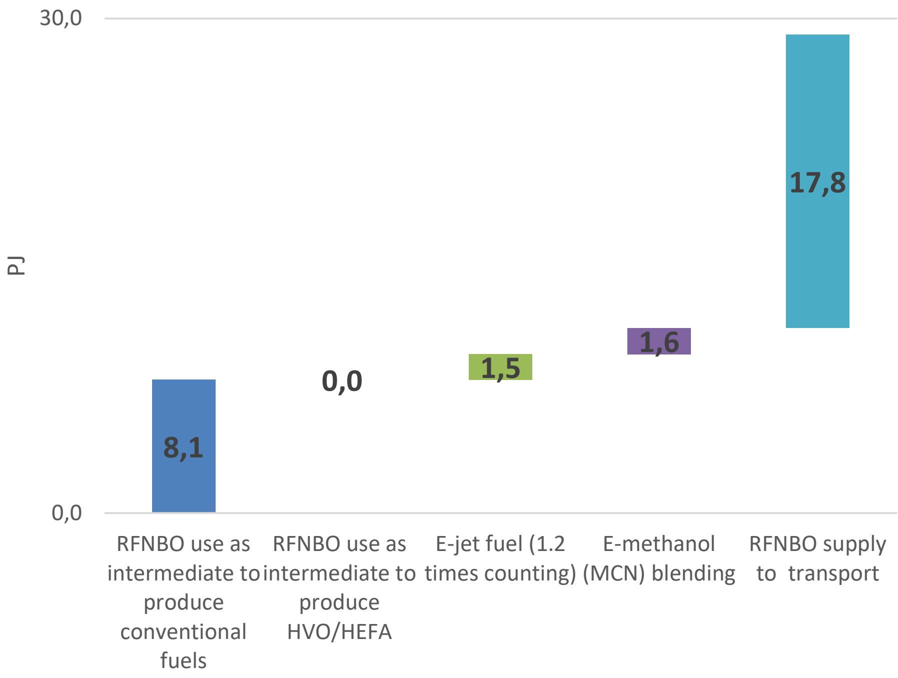

Figure 4.1 Illustration of case 1

In case 2, more than 65% of the sub-target can be met via the intermediate use of RFNBO to produce conventional fuels and biofuels. Next to e-jet fuel, 7.7 PJ of other RFNBO will have to be supplied to the Dutch market. As the figure illustrates, a part of this RFNBO can relate to direct use of e-methanol in existing internal combustion engines without any modifications.

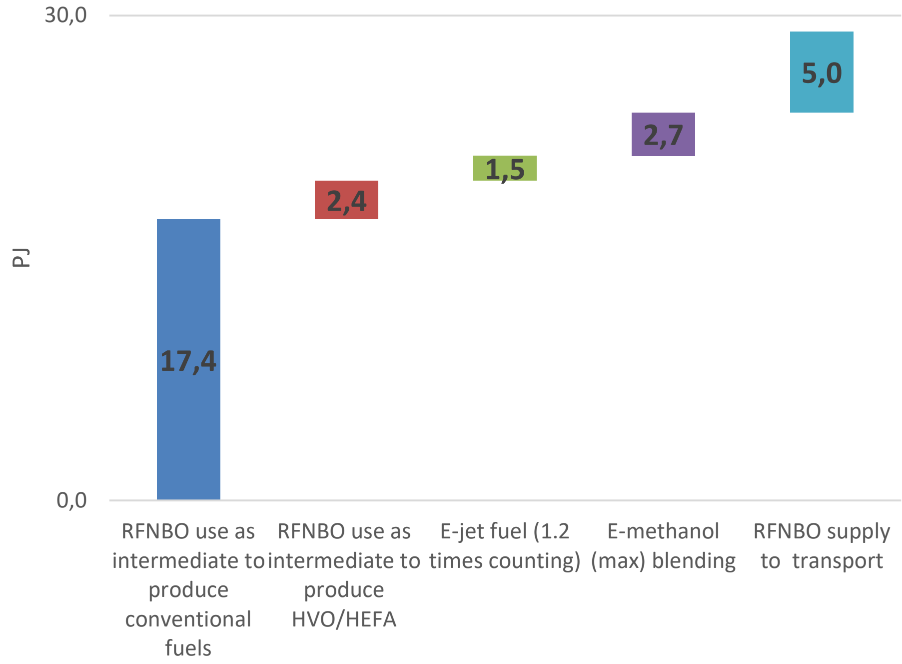

Figure 4.2 Illustration of case 2

Based on above analysis an amount of 5.0 to 17.8 PJ of RFNBO has to be supplied to the transport sector in another way. A part could result from using the e-fuels that are produced together with e-jet fuels (see Table 3.2) either in pure form or blended into conventional fuels. E-fuels from the FT process will not need any additional infrastructure or vehicle adaptations. In view of the desired development towards electrification and zero-emission vehicles by the European Commission and the Member States, the direct use of hydrogen in fuel cell electric vehicles appears as a promising option. The implication of this option in terms of needed number of vehicles is further explored. Results are shown in Table 4.1. The table presents the order of magnitude vehicles needed when RFNBO is supplied to either only one of the transport modes, or the combinations of different transport modes. These are illustrative combinations based as much as possible on policy documents and other studies as introduced in Table 3.3. The Climate Agreement (2019) refers to 15,000 hydrogen-powered passenger vehicles by 2025, and a potential growth of up to 300,000 vehicles by 2030. In this assessment the number of cars was kept to maximum 100,000. The total number of FCEVs were around 505 by the end of March 2022. Thus, the illustrative numbers included for the cars in both combinations can be considered as extreme cases. Nevertheless, they are much lower than the numbers introduced in the Agreement. For inland shipping, the fuel vision working group indicated 50 vessels by 2030 that can run on hydrogen (DEM, 2018). This number is used in “combination, 1”. For the second combination, a lower number is included. The remaining RFNBO is assumed to be supplied to the heavy-duty vehicles. This approach results in a considerable number of trucks and buses for Case 1. The number of trucks is much higher than the number of 4,800 reported in the AFIR (2021) study. The numbers presented for Case 2, on the other hand, are well in line with the estimate of the AFIR study for 2030.

Table 4.1 RFNBO supply to transport in case 1 and case 2 and the number of vehicles needed

H_2 FCE type	Supply to one transport mode	Combination 1	Combination 2
Case 1 (17.8 PJ)			
Cars	538, 800	Cars: 100,000	Cars: 30,000
Trucks/Buses	23,830	Trucks/Buses: 18,230	Trucks/Buses: 21,910
Inland shipping	1,000	Inland ships: 50	Inland ships: 25
Case 2 (5.0 PJ)			
Cars	151,870	Cars: 100,000	Cars: 30,000
Trucks/Buses	6,720	Trucks/Buses: 1,120	Trucks/Buses: 4,800
Inland shipping	290	Inland ships: 50	Inland ships: 25

All numbers are averaged.

Given the current number of hydrogen-powered vehicles and the rate at which they have grown over the recent years, the numbers indicated above appear to be very ambitious numbers. These numbers are only expected to be achievable if the roll-out of hydrogen-powered vehicles and ships is significantly accelerated through targeted financial support. Due to the large number of vehicles and vessels required, achieving the 2.6% RFNBO target according to case 2 seems a more realistic scenario than achieving the 2.6% RFNBO target according to case 1, in fact the number of hydrogen vehicles in case 2 is well in line with the numbers presented as ambitions in the Climate Agreement. Furthermore, it goes without saying that just focusing on the vehicle is not enough. In order to be able to realize the quantities, sufficient attention will also have to be paid to the roll-out of filling stations and bunker facilities.

4.2.1 RePowerEU Plans

The above synthesis is based on the 2.6% RFNBO sub-target that was introduced in the REDIII proposal. More recently, the Commission presented the REPowerEU Plan. One of the actions in this plan is to increase the share of renewables from 40% to 45% by 2030. Among other actions, the Commission calls upon the European Parliament and the council to align the sub-targets for RFNBO under the REDIII proposal. The recommendation is to increase it from 2.6% to 5% for transport. This increase corresponds to an additional RFNBO demand of 26 PJ. Thus, the total supply of RFNBO would need to be 55 PJ by 2030. Figure 4.3 shows the illustration of case 2 for the 5% sub-target. In this case hydrogen use as intermediate product in the production of conventional fuels contribute to around 35% of the total RFNBO demand. A significant amount of RFNBO remains to be supplied to the transport sector.

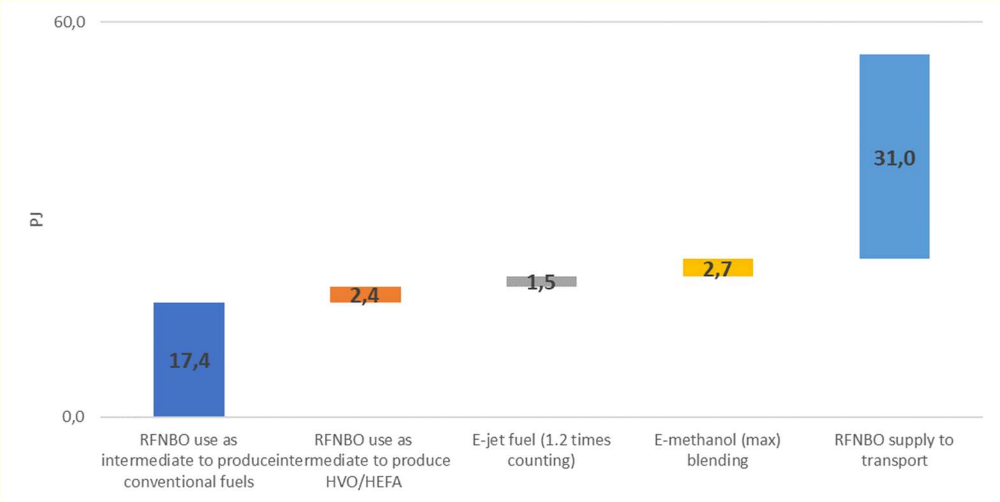

Figure 4.3 Illustration of case2 for 5% RFNBO sub-obligation.

Table 4.2 shows the order of magnitude hydrogen-powered vehicles needed when RFNBO is supplied to either only one of the transport modes, or the combinations of different transport modes. Results show that increasing the sub-target from 2.6% to 5% will make it even more challenging when this RFNBO is supplied in the form of hydrogen. It requires an unrealistic amount of hydrogen-powered vehicles in the fleet given the time for rollout to 2030 and will also require a very fast ramp-up of the rollout of new refuelling and bunkering infrastructure. To be able to meet this target significant additional contributions will be needed from other RFNBO-options such as synthetic diesel, gasoline and kerosene, and various types of biofuels which require hydrogen as intermediate product in the production process. This will limit the challenges in regard to vehicle fleet adaptations and infrastructure needs.

Table 4.2 RFNBO supply to transport in case 1 and case 2 and the number of vehicles needed

H_2 FCE type	Supply to one transport mode	Combination 1	Combination 2
Case (31 PJ)			
Cars	939,750	Cars: 100,000 Trucks/Buses: 35.960 Inland ships: 50	Cars: 30,000 Trucks/Buses: 39,640 Inland ships: 25
Trucks/Buses	41,560		
Inland shipping	1,770		

All numbers are averaged.

5 Concluding remarks

Results indicate that a significant contribution of RFNBO use as intermediate products in the production of conventional fuels is needed to be able to meet the 2.6% RFNBO obligation for the transport sector in 2030. RFNBO use as intermediate product will reduce the GHG emissions intensity of the conventional fuels and contribute to the overall energy system decarbonisation. However, this route will not contribute to reducing transport sector direct emissions at the tailpipe as will direct use of RFNBO. A strategic choice needs to be made for the level of contribution of RFNBO use as intermediate product in the production of conventional fuels towards the RFNBO sub-target.

RFNBO use in the production of biofuels appear to be neither recognised in the transport sector sub-target nor in the RFNBO obligation for industry. This may result in continuous use of fossil hydrogen in the production of biofuels, particularly HVO and HEFA. It appears more logical to also recognise RFNBO as intermediate product in in the production of biofuels as is the case with conventional fuels. The potential RFNBO contribution based on the HVO/HEFA supply is limited due to the cap introduced to feedstocks in Annex IX B, in REDIII. However, there are other value chains, where RFNBO use as intermediate product in the production of biofuels can be considered. The production and supply of gasification based bio-methanol and/or FT-fuels are two examples where the fuel yield can be optimised with the injection of renewable hydrogen.

REDIII does not specify how to count for the RFNBO as intermediate product in practice. It refers to RFNBO use in the production of conventional fuels whereas the RFNBO obligation is set to fuel suppliers. Thus, further clarifications about the allocation system are needed.

The ReFuelEU Aviation Regulation proposal indicates a significant increase of RFNBO use in the aviation sector. While the 2030 sub-target is set to 0.7%, in the subsequent five years this will need to increase to 5%. This shows the significant importance of increasing the supply of e-jet fuels. Next to that, RePowerEU Plan presented by the Commission on 18 May 2022 suggests to increase the RFNBO sub-obligation to 5%. This means that the target achievement may become even more challenging and synthetic fuels will become particularly important to supply not only e-jet fuel, but also other type of renewable drop-in fuels.

References

AdvanceFuel, 2019. D3.5 First data on efficient, low-risk ramp-up of liquid biomass conversion technologies - from short time to long term. Paraskevi Karka, Stavros Papadokonstantakis, Filip Johnsson.

AFID, 2021. Monitoring report AFID guideline

AFIR, 2021. Interpretation of the AFIR proposal on the required construction of fueling and charhing infrastructure in the Netherlands. TNO 2021 R12693

Brandstofvisie werkgroep DEM – Duurzame Energiedragers Mobiliteit. Gebruikt als input voor het klimaatakkoord 2019.

COM(2021) 557 final . Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652

COM (2021) 561. Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on ensuring a level playing field for sustainable air transport

COM (2021) 562 final. Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the use of renewable and low-carbon fuels in maritime transport and amending Directive 2009/16/EC

Concawe, 2021.Hyrogen Uses in Refineries -Hydrogen allocation into fuel products. Confidential!

Hamelinck, C., Defillet, M., Smeets, B., van den Heuvel, E. 2021. Conversion efficiencies of fuel pathways for Used Cooking Oil.

ICCT, 2019. *Long-term aviation fuel decarbonization: Progress, roadblocks, and policy opportunities,* s.l.: s.n. Schmidt, et al., 2016

IRENA, 2020. Green hydrogen cost reduction: Scaling up electrolysers to meet the 1.5ºC Climate Goal. Abu Dhabi, International Renewable Energy Agency (IRENA).

JRC, 2020. JEC Tank-To-Wheels report v5: Heavy duty vehicles.

$(S\&T)^2$, 2018, Description and data collection on biofuel technologies. Behrends, 2018,

KEV (2021). Klimaat-en Energieverkenning 2021. PBL. See Klimaat- en Energieverkenning 2021 (pbl.nl)

Li, J., Y., H. & al., L. T. e., 2018. Integrated tuneable synthesis of liquid fuels via Fischer–Tropsch technology. *Natural Catalysis,* pp. 787-793.

MIDDEN Report (PBL&TNO, 2020a). Decarbonisation options for the Dutch refinery sector. C. Oliveira and K.M. Schure.

MIDDEN Report (PBL & TNO, 2020b). Decarbonisation options for the Dutch biofuels industry. M. Khandelwal and A.W.N. van Dril

Nikander, S., 2008. Greenhouse gas and energy intensity of product chain: case transport biofuel. Master of Science In, 112.

NEa, 2020. Rapportage Energie voor Vervoer in Nederland 2019.

Routeradar, 2021. Routeradar Duurzame Energiedragers in Mobiliteit 2020 (Routeradar DEM). RWS. October 2021. Website version 15 December 2021.

Schmidt, P. et al., 2016. Power-to-Liquids – Potentials and Perspectives for the Future Supply of Renewable Aviation Fuel. *Umweltbundesamt*

TNO 2021 R12693. Duiding van het AFIR-voorstel op de benodigde opbouw van tank- en laadinfrastructuur in Nederland.

TNO, 2020a . Real-world fuel consumption of passenger cars and light commercial vehicles, TNO 2020 R11664

TNO,2020b. Smartport: Power-2-Fuel Cost Analysis

Marin-TNO, 2020c. Vervolgstappen validatie methodieken t.b.v. transitie naar emissieloze scheepvaart.

Transport & Environment, 2020. Comparison of hydrogen and battery electric trucks.

USDA, 2021. Biofuels Annual.
https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=
Biofuels%20Annual_The%20Hague_European%20Union_06-18-2021.pdf

WEEDA, M. & SEGERS, R. 2020. The Dutch hydrogen balance, and the current and future representation of hydrogen in the energy statistics. Amsterdam: TNO.