European Commission

Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels

Annex 4 Report on Task 4

Research and Innovation

Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels

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Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels

Annex 4 Report on Task 4

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1. Introduction

This report presents the results of Task 4 **"synthesis of industrial outlook"** of the *"development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels"*. The objective of Task 4 is twofold. Firstly, it shall provide evidence and analysis of industries' outlooks and secondly, it will define strategic research and innovation directions along with a roadmap for the industrial developments.

As depicted in Figure 1-1, Task 4 consists of four subtasks, which are interrelated with each other and with other Tasks, in particular Task 1, 2 and 3:

- Task 4.1: Determination of additional needed advanced biofuels capacity in 2030 and 2050
- Task 4.2: Gap analysis to identify actions and investments the advanced biofuels industry should take in order to be able to meet the targeted demand
- Task 4.3: Evidence for renewable fuels capacity foreseen in 2030 and 2050
- Task 4.4: Roadmap and recommendations for strategic research directions.

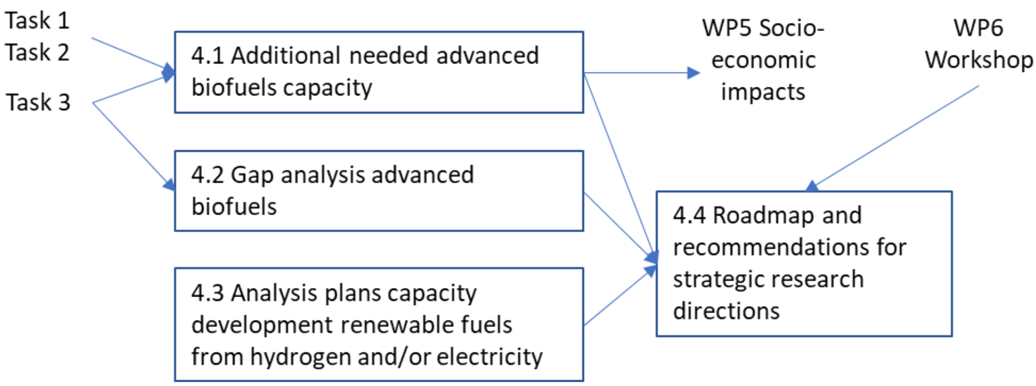

Figure 1-1 Linkages between the different subtasks of Task 4

This report shows the results of tasks 4.1 to 4.3 which each chapter containing the methodology and results of one sub-task.

2. TASK 4.1 Additional needed advanced biofuels capacities

2.1. Introduction

In this task we determine whether there is a gap between the demand for advanced biofuels in 2030 and 2050 as determined by modelling in Task 1 on the one hand, and the already implemented and expected (advanced) biofuels production capacity as determined in Task 3 on the other hand. This gap has been quantified for a low, central and high biofuels demand scenario in section 2.3 . A possible way to fill this gap with additional advanced biofuels capacity is investigated in section 2.4 . Finally, in section 2.5 we have checked whether sufficient biomass is available in the EU27 to meet the targeted demand (with the gap filled), using the low, medium and high biomass feedstock mobilisation scenarios as determined in Task 2, taking additionally into account (1) the ability of the advanced biofuels technologies to process different feedstocks in 2030 and 2050, and (2) the current use of the feedstocks for heat and power production.

2.2. Methodology

The work performed consists of three parts:

- Determination of the gap between demand and expected advanced biofuels capacity in 2030 and 2050;
- Determination of a possible way to fill the gap;
- Check whether sufficient feedstock is available to meet the demand (including filled gap).

Determination of gap between demand and advanced biofuels capacity

We can distinguish three groups of advanced biofuels production capacity (See Figure 2-1):

- Capacity already implemented and available to respond to the targeted demand (as determined in Task 3)
- Capacity foreseen by the industry for 2030 and 2050, based on their outlook of new industrial installations (as determined in Task 3).
- Additional capacity needed to meet the targeted demand for advanced biofuels in 2030 and 2050, but not yet foreseen by the industry (as determined in section 2.3 of this report).

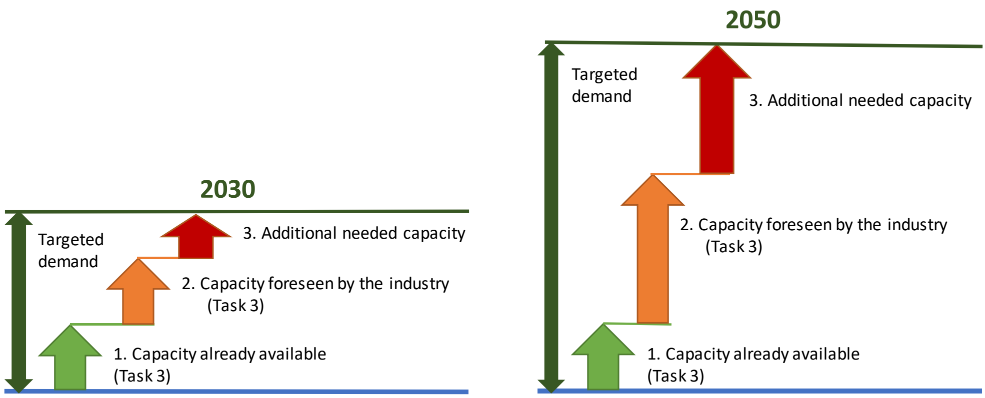

Figure 2-1 Available, projected and required additional advanced biofuels production capacity in 2030 and 2050

The capacity potential to produce advanced biofuels has been determined in Task 3. This data, consists of the following:

- The current biofuels production – in 2023 – per technology pathway, and the expected biofuels production capacity in 2030 and 2050 per technology pathway (see also Task 3),

- Allocation of the 2023, 2030 and 2050 production capacities to the various transport sectors (aviation, maritime, road) and other sectors (see also Task 3).

This information from Task 3 was drafted by project partner BEST, in cooperation with different groups of external experts, and also displayed in Table 2-5. With this information from Task 3 it is possible to determine the biofuels capacity already available, and the capacity foreseen by the industry.

The targeted minimum and maximum demand per subsector, i.e., road, marine and aviation, as well as the demand as described in the provisional agreement scenario (FF55 RED) was provided in Task 1. After discussion with the consortium and the EC the "provisional agreement scenario" was selected as the central scenario. Besides that, out of the scenarios defined in Task 1, the minimum and maximum demand scenarios have been selected both for 2030 and for 2050.

The targeted minimum and maximum demand per subsector were compared to the capacity potential to determine the gaps between installed and foreseen capacity and the targeted demand as further elaborated in section 2.3.2 and 2.3.3.

Determination of a possible way to fill the gap

Based on this quantitative information on the gaps between demand and capacity, the value chains most suitable for the supply of additional needed advanced biofuels capacity were determined, together with the experts. The methodology is further explained in section 2.4 . The capacities per pathway have been quantified and were included in the main scenario for the analysis of socio-economic impact, GHG emissions and costs in Task 5.

Determination of feedstock availability to meet the demand (including filled gap)

Feedstock availability was considered in the estimation of advanced biofuels production capacities in Task 3. Moreover, in Task 2 the low, medium and high feedstock mobilisation scenarios were compared to the demand scenarios in Task 3. In this task we have made another comparison of targeted demand with feedstock availability, taking into account (1) the contribution of the different technologies to fill the gap, (2) the ability of the technologies to uptake certain feedstocks (see the feedstock matrices in Annex 1) and (3) the current use of biomass for heat and power (for our estimation see Annex 2). These three elements made it worthwhile to perform this additional assessment of feedstock availability versus demand. The approach is further explained in section 2.5 .

2.3. Determination of gaps between demand and foreseen capacity in 2030 and 2050

2.3.1. Targeted minimum and maximum demand per subsector

An overview of the EU-27 biofuels demand as generated in Task 1 is shown in Table 2-1 (for 2030), and Table 2-2 (for 2050).

			2030		
Name	Road	Aviation	Rail/Inland	Maritime	Total
FF55	19.6	1.9	0.6	1.7	23.9
FF55_LTD	27.0	2.2	0.8	1.9	31.9
FF55_ESR	34.6	2.2	1.0	1.9	39.7
FF55_RED	33.0	2.2	0.9	1.9	38.1
FF55_LTD_RITA	29.5	2.2	0.8	1.9	34.4
FF55_ESR_RITA	37.6	2.2	1.0	1.9	42.8
RePower	19.1	1.9	0.6	1.7	23.4
RePower_LTD	31.5	2.2	0.9	1.8	36.4
RePower_ESR	35.1	2.2	1.1	1.8	40.1
RePower_LTD_RITA	34.4	2.2	0.9	1.8	39.4
RePower_ESR_RITA	38.2	2.2	1.1	1.8	43.3

Table 2-1 Biofuels demand in 2030 per transport modality (Mtoe)

			2050		
Name	Road	Aviation	Rail/Inland	Maritime	Total
FF55	5.7	15.9	1.5	22.3	45.4
FF55_LTD	6.8	15.9	1.5	22.3	46.4
FF55_ESR	6.0	15.9	1.5	22.3	45.6
FF55_RED	7.1	15.9	1.5	22.3	46.7
FF55_LTD_RITA	7.1	16.4	1.5	22.3	47.3
FF55_ESR_RITA	6.3	16.4	1.5	22.3	46.4
RePower	5.7	15.9	1.5	22.2	45.3
RePower_LTD	6.6	15.8	1.5	22.2	46.2
RePower_ESR	6.0	15.9	1.5	22.2	45.7
RePower_LTD_RITA	7.3	16.3	1.5	22.2	47.4
RePower_ESR_RITA	6.3	16.4	1.5	22.2	46.5

Table 2-2 Biofuels demand in 2050 per transport modality (Mtoe)

These tables show the scenario names on the left side, with one row per scenario. The demand as determined via the PRIMES model – see Task 1 – is listed for each of the scenarios.

There are four types of transport modalities mentioned (road, aviation, rail/inland and maritime). For the remainder of this report, the rail/inland transport modality is combined with the maritime transport sector.

In Table 2-3 and Table 2-4 for each scenario the demand for conventional biofuels or 1G biofuels, and two types of advanced biofuels are distinguished, namely those that conform to Annex IX A of the RED, and those that conform to Annex IX B.

		2030		
Name	Conventional	Annex IX A	Annex IX B	Total
FF55	11.2	6.2	6.5	23.9
FF55_LTD	8.0	15.0	8.9	31.9
FF55_ESR	11.1	19.0	9.5	39.7
FF55_RED	10.6	18.4	9.0	38.1
FF55_LTD_RITA	8.7	16.2	9.5	34.4
FF55_ESR_RITA	12.1	20.6	10.1	42.8
RePower	10.8	6.2	6.4	23.4
RePower_LTD	8.9	18.4	9.1	36.4
RePower_ESR	11.9	18.9	9.3	40.1
RePower_LTD_RITA	9.7	20.3	9.3	39.4
RePower_ESR_RITA	12.9	20.8	9.5	43.3

Table 2-3 Type of biofuels demand 2030 per scenario (in Mtoe)

		2050		
Name	Conventional	Annex IX A	Annex IX B	Total
FF55	0.2	33.5	11.6	45.4
FF55_LTD	0.3	39.6	6.5	46.4
FF55_ESR	0.2	38.9	6.5	45.6
FF55_RED	0.3	39.9	6.5	46.7
FF55_LTD_RITA	0.3	40.4	6.6	47.3
FF55_ESR_RITA	0.3	39.6	6.5	46.4
RePower	0.2	33.5	11.6	45.3
RePower_LTD	0.3	39.4	6.5	46.2
RePower_ESR	0.2	38.9	6.5	45.7
RePower_LTD_RITA	0.3	40.5	6.6	47.4
RePower_ESR_RITA	0.3	39.7	6.5	46.5

Table 2-4 Type of biofuels demand 2050 per scenario (in Mtoe)

The following observations are made:

- There is a large difference between the highest and the lowest biofuels demand scenario in 20230. The lowest demand – overall and specifically for advanced biofuels Annex IX A and B – is generated in case of the RePower scenario, while the highest advanced biofuels demand – although not the highest overall demand – is generated in the FF55_ESR_RITA scenario.

- For 2050, the various scenarios converge and there is limited variation between them.

- While conventional biofuels will still play a significant role in 2030, they will be nearly phased out in 2050.

Based on these tables, three scenarios will be selected for the gap analysis, namely the scenario with the highest advanced biofuels (Annex IX A+B) demand and the scenario with the lowest advanced biofuels demand. Apart from those scenarios, the ‘central scenario’ will also be selected. Specifically, this concerns the following scenarios:

- Highest advanced biofuels demand in 2030: scenario representing the peak advanced biofuels demand by 2030 within the context of the Fit for 55 package. This scenario assumes a substantial Effort Sharing Regulation (ESR) contribution from transport, increased transport activity (High scenario: FF55_ESR_RITA)

- Lowest advanced biofuels demand in 2030: scenario derived from the RePower EU context (Low scenario: RePower)

- Central scenario: aligning with the Fit for 55 principles and incorporating the provisional agreement on RED III (Central scenario: FF55_RED)

Since the differences between the scenarios for 2050 are minimal, the same three scenarios will be selected for 2050.

2.3.2. Determination of gaps

In Figure 2-2 an impression is given of the current production of biofuels (EU-27, 2023), and the total biofuels demand, as given in the selected demand scenarios. In this figure, demand data are from the PRIMES model, while capacity data are from the Task 3 results.

This figure shows that current production is still very much focused on road transport, with only minimal contributions from biofuels for aviation and maritime applications. In all biofuels demand scenarios this remains the case: limited – but higher – contribution of biofuels for aviation and maritime applications.

The largest difference is made by biofuels for road transport. The graph shows a significant gap between current biofuels production and demand in all of the three scenarios.

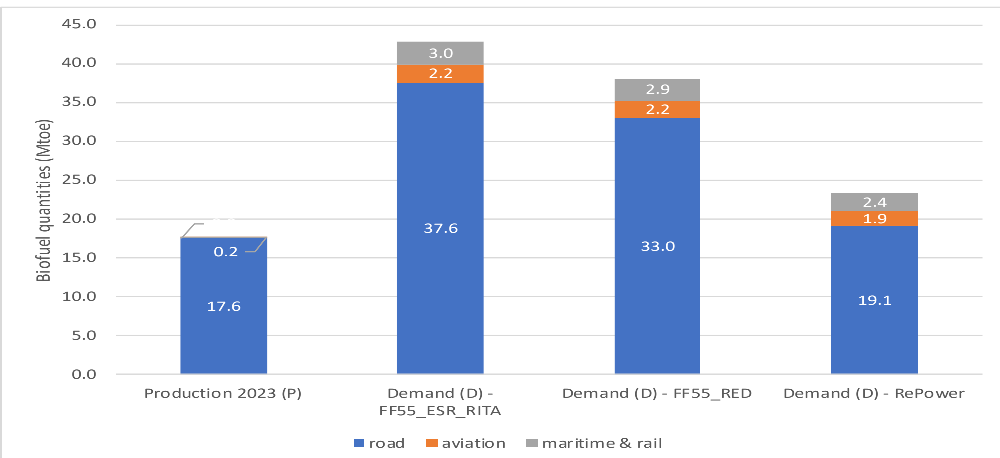

Figure 2-2 Biofuels production 2023 versus 2030 demand scenarios

This gap is shown more clearly in Figure 2-3. This figure shows the current capacity, the additionally foreseen capacity, and the maximum gap for the highest 2030 biofuels demand scenario.

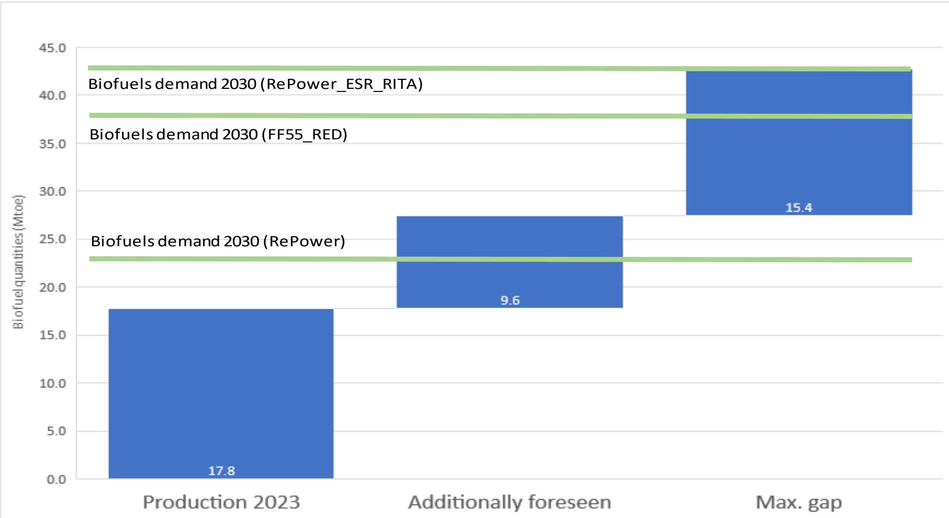

Figure 2-3 Available, projected and required biofuel capacity in EU in 2030

For 2050, all scenarios essentially converge on a total quantity of 45 to 47 Mtoe, which is graphically depicted in Figure 2-4. Obviously, the ‘Capacity available’ and the ‘additionally foreseen capacity’ is the same as for the 2030 projections.

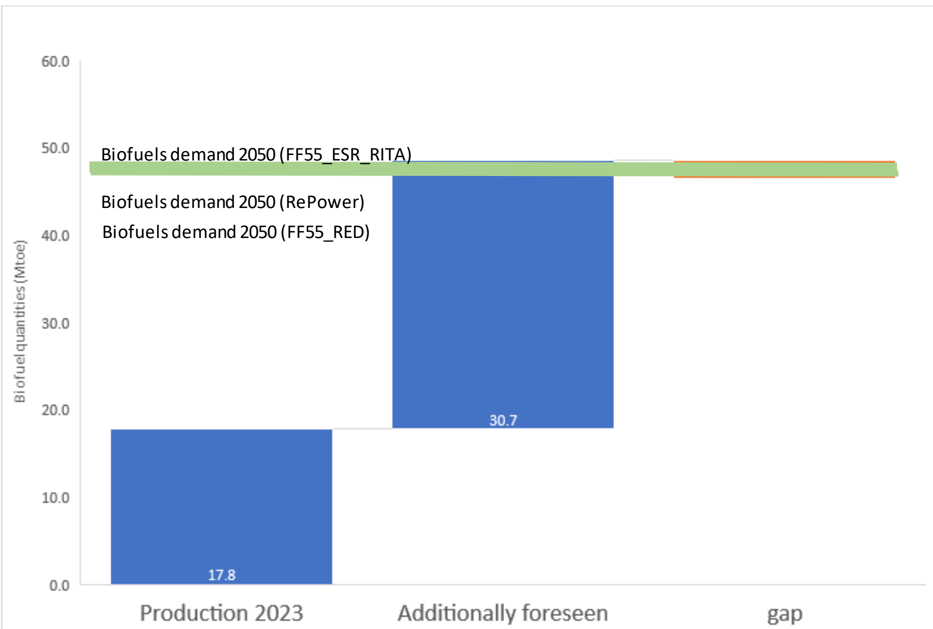

Figure 2-4 Available, projected and required biofuel capacity in EU-27 in 2050

2.3.3. Detailed gap analysis

As shown in Figure 2-3 and Figure 2-4 there is for 2030 in practice no gap for the minimum scenario (RePower), a large gap of ca 10.6 Mtoe compared to the central scenario (FF55_RED) and a very large gap of ca 15.4 Mtoe compared to the maximum scenario (FF55_ESR_RITA). The gap is between the max demand and the current production plus additionally foreseen capacity. When compared to the foreseen capacity, as shown in Table 2-5, there is in fact no gap.

Technology	2023			2030			2050		
	Road	Aviation	Shipping	Road	Aviation	Shipping	Road	Aviation	Shipping
Transesterification of f/f crops	4.50	-	0.09	4.87	-	0.26	0.26	-	4.87
Hydrotreatment of food/feed crops	5.25	-	-	5.25	-	-	5.25	-	-
Ethanol fermentation of f/f crops	3.16	-	-	3.74	-	-	-	-	-
Anaerobic digestion	0.32	-	-	0.45	-	1.05	-	-	4.51
Transesterification of e.g. br. grease	1.04	-	0.02	1.43	-	0.08	0.08	-	1.43
Transesterification cover crops m. l.	-	-	-	2.69	-	0.14	0.14	-	2.69
Hydrotreatment of tall oil	0.13	0.00	-	0.13	0.06	0.02	0.02	0.13	0.27
Hydrotreatment cover crops m.l.	-	-	-	1.45	0.73	0.24	0.27	1.61	3.48
Lignin boost of fatty acids	-	-	-	0.05	-	0.09	0.23	-	0.47
Advanced ethanol	0.13	-	-	0.29	0.03	-	-	-	-
ATJ	-	-	-	-	0.10	-	-	7.70	-
Gasification + Methanol	-	-	0.00	-	-	0.21	-	-	2.87
Gasification + SNG	0.00	-	-	0.01	-	0.02	-	-	0.75
Gasification + FT	-	-	-	-	0.05	-	-	4.47	0.79
Pyrolysis	0.01	0.01	0.01	0.05	0.06	0.06	-	0.41	0.41
HTL	0.00	-	0.00	0.02	-	0.01	1.00	0.17	0.50
Transesterification of UCO and AF	3.03	-	0.06	2.10	-	0.11	0.11	-	2.10
Hydrotreatment of UCO and AF	-	-	-	0.95	0.47	0.16	0.08	0.47	1.02
Total	**17.6**	**0.0**	**0.2**	**23.5**	**1.5**	**2.5**	**7.4**	**14.9**	**26.2**

Table 2-5 Estimated evolution of biofuel production capacities (see also Task 3)

In the following tables (Table 2-6, Table 2-7, and Table 2-8), these gaps are further quantified.

In Table 2-6, the third column shows the demand in Mtoe according to the FF55_RED scenario (D). The existing production (P) is shown in the column next to that. The next columns show the "growth foreseen by experts" (F). This is the additional production (that is: additional to the current (2023) production) as foreseen by the experts in the framework of Task 3. Data from this column is the same as given in Table 2-5. The gap is defined as the gap between demand and the existing production + growth foreseen growth by experts.

What is clear from Table 2-6 is that the 2030 gap for biofuels for road transport is significant, while the gap for aviation and maritime is far less, or even negative. For 2050 we see a lot of biofuels capacity for road transport disappearing, while aviation and maritime + rail are the largest biofuels consumers.

		Demand (D)	Production (P)	Growth foreseen by experts (F)	Gap (D-P-F)
2030	**totals**	**38.1**	**17.8**	**9.6**	**10.6**
	road	**33.0**	**17.6**	**5.9**	**9.6**
	aviation	**2.2**	**0.0**	**1.5**	**0.7**
	maritime+rail	**2.9**	**0.2**	**2.3**	**0.4**
2050	**totals**	**46.7**	**17.8**	**30.7**	**-1.8**
	road	**7.1**	**17.6**	**-10.1**	**-0.4**
	aviation	**15.9**	**0.0**	**14.9**	**0.9**
	maritime+rail	**23.7**	**0.2**	**26.0**	**-2.4**

Table 2-6 Gap between demand and current production & growth foreseen by experts in 2030 - FF55_RED scenario (Mtoe)

		Demand (D)	Production (P)	Growth foreseen by experts (F)	Gap (D-P-F)
2030	**totals**	**23.4**	**17.8**	**9.6**	**-4.0**
	road	19.1	17.6	5.9	-4.3
	aviation	1.9	0.0	1.5	0.4
	maritime+rail	2.4	0.2	2.3	-0.1
2050	**totals**	**45.3**	**17.8**	**30.7**	**-3.2**
	road	5.7	17.6	-10.1	-1.8
	aviation	15.9	0.0	14.9	1.0
	maritime+rail	23.7	0.2	26.0	-2.4

Table 2-7 Gap between demand and current production & growth foreseen by experts in 2030 - RePower scenario (Mtoe)

In Table 2-7 the gaps with between demand and foreseen production for the Repower scenario are shown. While results for 2050 are similar to the FF55_RED scenario, the gap for 2030 is negative. This means that the demand is lower than the current production + additionally foreseen capacity, which means that part of that capacity will be underutilized, or not be built.

The maximum scenario – FF55_ESR_RITA – (see Table 2-8) shows a very large gap in 2030, especially with respect to biofuels for road transport.

		Demand (D)	Production (P)	Growth foreseen by experts foreseen (F)	Gap (D-P-F)
2030	**totals**	**42.8**	**17.8**	**9.6**	**15.4**
	road	37.6	17.6	5.9	14.1
	aviation	2.2	0.0	1.5	0.7
	maritime+rail	3.0	0.2	2.3	0.5
2050	**totals**	**46.4**	**17.8**	**30.7**	**-2.1**
	road	6.3	17.6	-10.1	-1.1
	aviation	16.4	0.0	14.9	1.4
	maritime+rail	23.8	0.2	26.0	-2.4

Table 2-8 Gap between demand and current production & growth foreseen by experts in 2030 – FF55_ESR_RITA scenario (Mtoe)

2.4. A possible way to fill the gap

In order to obtain an impression how this remaining gap between demand and (current and foreseen) biofuels production could be bridged (D-P-F in the tables above) it was evaluated which technologies could give an additional contribution, on top of the growth foreseen by the experts (F in the tables above). The following technologies are not expected to be able to provide an additional contribution to fill the gap:

- Conventional biofuels production technologies, as these are capped in the RED and not eligible to meet the targets of ReFuel EU Aviation and FuelEU maritime.
- Technologies using Annex IX A or B fat-based feedstock (e.g. transesterification of e.g. brown grease, cover crops from marginal land, and hydrotreatment of tall oil and cover crops from marginal lands), as the growth foreseen by experts already substantial amounts of transesterification of Annex IX-A feedstocks, transesterification and hydrotreatment of intermediate crops and hydrotreatment of tall oil. Additional feedstock availability within the EU27 is limited (see section 2.5 for a more in-depth analysis of feedstock availability).
- ATJ/MTJ, as in the relevant demand scenarios the gap between demand for aviation and additionally foreseen capacity is minor. To assume additional growth - beyond the growth foreseen by the experts - would mean that more than the mandated amount of aviation

fuel will be produced. This is not to be expected, due to the high costs difference of SAF and regular aviation fuel.

We have assumed that all remaining technologies, i.e., anaerobic digestion, lignin boost of fatty acids, advanced ethanol, gasification + methanol, gasification + SNG, gasification + FT pyrolysis and HTL contribute to filling the gap relative to their additionally foreseen capacity in 2030 (F in the earlier tables). A single growth factor has been applied to the growth foreseen by experts in 2030 (i.e. to the initial capacity growth foreseen by the experts of Task 3 between 2023 and 2030), in such a way that the demand of the FF55_RED scenario and the FF55_ESR_RITA scenario is exactly met.

In Table 2-9 the result is shown in the case of the FF55_RED scenario in 2030. The growth factor that is needed to fill the gap is calculated to be 5.4. So, the growth foreseen by 2030 needs to grow further by another factor of 5.4 The additional biofuels production this brings per technology is shown in the 'ways to fill the gap' column. All this leads to a total biofuel capacity of 38.1 Mtoe in 2030, in accordance with the FF55_RED scenario.

An example of how these calculations have been carried out is as follows: for the technology pathway Advanced Ethanol, current production is 200,000 t/y, or 0.13 Mtoe/y (Conversion factor: 0.64 toe/t). Additional capacity foreseen is 300,000 t/y, bringing the total – current plus foreseen production – to 500,000 t/y, or 0.32 Mtoe/y. To fill the gap, an additional growth of a factor 5.39 x 300,000 t/y = 1,617,099 t/y is needed. This brings the total advanced ethanol production to 2,117,099 t/y, or 1.35 Mtoe/y.

In Table 2-10 the same data as in Table 2-9 is shown, but now in million tonnes of biofuels. In Table 2-11 and Table 2-12, the same exercise is repeated, but now for the FF55_ESR_RITA scenario. The growth factor that is needed to fill this gap is calculated to be 7.8. So, the additionally foreseen capacity needs to grow further by another factor of 7.8.

For 2050 all relevant scenarios show a total biofuels demand of ca 45-47 Mtoe, which is less than the total capacity that is forecasted with help of the experts (see Table 2-7), which was 48.5 Mtoe. This means no additional efforts - beyond what is already forecasted by the experts - are needed.

The use of one single growth factor for a selection of emerging technologies may mean that the growth for some technologies may be underestimated, and for some its over-estimated. The applied extrapolation of the additional capacity forecasted by the experts gives however an initial impression what the different technologies may contribute to fill the identified gap.

Technology	Production 2023 (Mtoe/y)	Growth foreseen till 2030 (Mtoe/y)	Total (2030) (Mtoe/y)	Production assumed to fill the gap (2030) (Mtoe/y)	Total incl. filled gap (2030) (Mtoe)
	P	F	P+F	D-P-F	D
transesterification of food/feed crops	4.60	0.53	5.13	-	5.13
hydrotreatment of food/feed crops	5.25	-	5.25	-	5.25
ethanol fermentation of food/feed crops	3.16	0.58	3.74	-	3.74
transesterification of UCO and AF	3.09	-0.88	2.21	-	2.21
hydrotreatment of UCO and AF	-	1.58	1.58	-	1.58
transesterification of intermediate crops	-	2.83	2.83	-	2.83

Technology	Production 2023 (Mtoe/y)	Growth foreseen till 2030 (Mtoe/y)	Total (2030) (Mtoe/y)	Production assumed to fill the gap (2030) (Mtoe/y)	Total incl. filled gap (2030) (Mtoe)
	P	F	P+F	D-P-F	D
hydrotreatment of intermediate crops	-	2.42	2.42	-	2.42
transesterification Annex IX A feedstock	1.06	0.44	1.50	-	1.50
hydrotreatment of tall oil	0.14	0.07	0.21	-	0.21
anaerobic digestion	0.32	1.18	1.50	6.35	7.85
lignin boost of fatty acids	-	0.14	0.14	0.75	0.89
advanced ethanol	0.13	0.19	0.32	1.04	1.37
ATJ	-	0.10	0.10	-	0.10
gasification + methanol	0.00	0.21	0.21	1.16	1.37
gasification + SNG	0.00	0.03	0.03	0.16	0.19
gasification + FT	-	0.05	0.05	0.28	0.34
pyrolysis	0.04	0.14	0.18	0.77	0.95
HTL	0.00	0.02	0.03	0.13	0.15
Total	**17.8**	**9.6**	**27.4**	**10.6**	**38.1**
Total food/feed crops	13.01	1.11	14.12	-	14.12
Total hydrotreatment, transesterification (Annex IX B)	3.09	5.94	9.03	-	9.03
Total hydrotreatment, transesterification (Annex IX A)	1.20	0.52	1.71	-	1.71
Total anaerobic digestion (Annex IX A and B)	0.32	1.18	1.50	6.35	7.85
Total lignocellulosic advanced biofuels (Annex IX A)	0.17	0.90	1.07	4.29	5.36
Total	**17.8**	**9.6**	**27.4**	**10.6**	**38.1**

Table 2-9 Ways to fill the gap between production forecast and demand (FF55_RED) scenario for 2030 (in Mtoe)

Technology	Production 2023 (Mtonnes/y)	Growth foreseen till 2030 (Mtonnes/y)	Total (2030) (Mtonnes/y)	Production assumed to fill the gap (2030) (Mtonnes/y)	Total incl filled gap (2030) (Mtonnes/y)
	P	F	P+F	D-P-F	D
transesterification of food/feed crops	5.20	0.60	5.80	-	5.80
hydrotreatment of food/feed crops	5.00	-	5.00	-	5.00
ethanol fermentation of food/feed crops	4.90	0.90	5.80	-	5.80
transesterification of UCO and AF	3.50	-1.00	2.50	-	2.50
hydrotreatment of UCO and AF	-	1.50	1.50	-	1.50
transesterification of intermediate crops	-	3.20	3.20	-	3.20
hydrotreatment of intermediate crops	-	2.30	2.30	-	2.30
transesterification of annex IX A feedstock	1.20	0.50	1.70	-	1.70
hydrotreatment of tall oil	0.13	0.07	0.20	-	0.20

Technology	Production 2023 (Mtonnes/y)	Growth foreseen till 2030 (Mtonnes/y)	Total (2030) (Mtonnes/y)	Production assumed to fill the gap (2030) (Mtonnes/y)	Total incl filled gap (2030) (Mtonnes/y)
	P	F	P+F	D-P-F	D
anaerobic digestion	0.27	0.99	1.26	5.34	6.60
lignin boost of fatty acids	-	0.14	0.14	0.75	0.89
advanced ethanol	0.20	0.30	0.50	1.62	2.12
ATJ	-	0.10	0.10	-	0.10
gasification + methanol	0.00	0.45	0.50	2.42	2.87
gasification + SNG	0.0001	0.02	0.03	0.13	0.16
gasification + FT	-	0.05	0.05	0.27	0.32
pyrolysis	0.10	0.35	0.45	1.89	2.34
HTL	0.00	0.03	0.03	0.15	0.18
Total	**20.50**	**10.50**	**31.01**	**12.58**	**43.58**
Total food/feed crops	15.10	1.50	16.60	-	16.60
Total hydrotreatment, transesterification (Annex IX B)	3.50	6.00	9.50	-	9.50
Total hydrotreatment, transesterification (Annex IX A)	1.33	0.57	1.90	-	1.90
Total anaerobic digestion (Annex IX A and B)	0.27	0.99	1.26	5.3	6.60
Total lignocellulosic advanced biofuels (Annex IX A)	0.30	1.44	1.75	7.2	8.98
Total	**20.50**	**10.50**	**31.01**	**12.6**	**43.58**

Table 2-10 Ways to fill the gap between production forecast and demand (FF55_RED) scenario for 2030 (in Million tonnes advanced biofuel)

Technology	Production 2023 (Mtoe/y)	Growth foreseen till 2030 (Mtoe/y)	Total (2030) (Mtoe/y)	Production assumed to fill the gap (2030) (Mtoe/y)	Total incl. filled gap (2030) (Mtoe)
	P	F	P+F	D-P-F	D
transesterification of food/feed crops	4.60	0.53	5.13	-	5.13
hydrotreatment of food/feed crops	5.25	-	5.25	-	5.25
ethanol fermentation of food/feed crops	3.16	0.58	3.74	-	3.74
transesterification of UCO and AF	3.09	- 0.88	2.21	-	2.21
hydrotreatment of UCO and AF	-	1.58	1.58	-	1.58
transesterification of intermediate crops	-	2.83	2.83	-	2.83
hydrotreatment of intermediate crops	-	2.42	2.42	-	2.42
transesterification of Annex IX A feedstock	1.06	0.44	1.50	-	1.50
hydrotreatment of tall oil	0.14	0.07	0.21	-	0.21
anaerobic digestion	0.32	1.18	1.50	9.16	10.66
lignin boost of fatty acids	-	0.14	0.14	1.09	1.23
advanced ethanol	0.13	0.19	0.32	1.50	1.83
ATJ	-	0.10	0.10	-	0.10

Technology	Production 2023 (Mtoe/y)	Growth foreseen till 2030 (Mtoe/y)	Total (2030) (Mtoe/y)	Production assumed to fill the gap (2030) (Mtoe/y)	Total incl. filled gap (2030) (Mtoe)
	P	F	P+F	D-P-F	D
gasification + methanol	0.00	0.21	0.21	1.67	1.88
gasification + SNG	0.00	0.03	0.03	0.23	0.26
gasification + FT	-	0.05	0.05	0.41	0.46
pyrolysis	0.04	0.14	0.18	1.10	1.29
HTL	0.00	0.02	0.03	0.19	0.21
Total	**17.79**	**9.64**	**27.43**	**15.35**	**42.79**
Total food/feed crops	13.01	1.11	14.12	-	14.12
Total hydrotreatment, transesterification (Annex IX B)	3.09	5.94	9.03	-	9.03
Total hydrotreatment, transesterification (Annex IX A)	1.20	0.52	1.71	-	1.71
Total anaerobic digestion (Annex IX A and B)	0.32	1.18	1.50	9.16	10.66
Total lignocellulosic advanced biofuels (Annex IX A)	0.17	0.90	1.07	6.19	7.26
Total	**17.79**	**9.64**	**27.43**	**15.35**	**42.79**

Table 2-11 Ways to fill the gap between production forecast and demand (FF55_ESR_RITA) scenario for 2030 (in Mtoe)

Technology	Production 2023 (Mtonnes/y)	Growth foreseen till 2030 (Mtonnes/y)	Total (2030) (Mtonnes/y)	Production assumed to fill the gap (2030) (Mtonnes/y)	Total incl filled gap (2030) (Mtonnes/y)
	P	F	P+F	D-P-F	D
transesterification of food/feed crops	5.20	0.60	5.80	-	5.80
hydrotreatment of food/feed crops	5.00	-	5.00	-	5.00
ethanol fermentation of food/feed crops	4.90	0.90	5.80	-	5.80
transesterification of UCO and AF	3.50	-1.00	2.50	-	2.50
hydrotreatment of UCO and AF	-	1.50	1.50	-	1.50
transesterification of intermediate crops	-	3.20	3.20	-	3.20
hydrotreatment of intermediate crops	-	2.30	2.30	-	2.30
transesterification of Annex IX A feedstocks	1.20	0.50	1.70	-	1.70
hydrotreatment of tall oil	0.13	0.07	0.20	-	0.20
anaerobic digestion	0.27	0.99	1.26	7.70	8.96
lignin boost of fatty acids	-	0.14	0.14	1.09	1.23
advanced ethanol	0.20	0.30	0.50	2.33	2.83
ATJ	-	0.10	0.10	-	0.10
gasification + methanol	0.00	0.45	0.45	3.49	3.94
gasification + SNG	0.00	0.02	0.03	0.19	0.22
gasification + FT	-	0.05	0.05	0.39	0.44

Technology	Production 2023 (Mtonnes/y)	Growth foreseen till 2030 (Mtonnes/y)	Total (2030) (Mtonnes/y)	Production assumed to fill the gap (2030) (Mtonnes/y)	Total incl filled gap (2030) (Mtonnes/y)
	P	F	P+F	D-P-F	D
pyrolysis	0.10	0.35	0.45	2.72	3.17
HTL	0.00	0.03	0.03	0.22	0.25
Total	**20.50**	**10.50**	**31.01**	**18.14**	**49.14**
Total food/feed crops	15.10	1.50	16.60	-	16.60
Total hydrotreatment, transesterification (Annex IX B)	3.50	6.00	9.50	-	9.50
Total hydrotreatment, transesterification (Annex IX A)	1.33	0.57	1.90	-	1.90
Total anaerobic digestion (Annex IX A and B)	0.27	0.99	1.26	7.70	8.96
Total lignocellulosic advanced biofuels (Annex IX A)	0.30	1.44	1.75	10.44	12.19
Total	**20.50**	**10.50**	**31.01**	**18.14**	**49.14**

Table 2-12 Ways to fill the gap between production forecast and demand (FF55_ESR_RITA) scenario in 2030 (in Million tonnes advanced biofuel)

2.5. Check of feedstock availability versus demand

To determine whether sufficient sustainable feedstocks are available to meet the increased demand, a four-step approach was followed:

- Step 1: Determination of feedstock suitability and availability for each of the advanced biofuels production technologies
- Step 2: Subtraction of indigenous feedstocks currently used for biofuels, power and heat production
- Step 3: Determination of advanced biofuel production potential based on feedstock availability minus current use for bioenergy per technology pathway and under assumed feedstock-to-fuel conversion rates.
- Step 4: Comparison of this feedstock based advanced biofuels production potential with the demand as determined in Task 1, with the gap filled as determined in the way as determined in section 2.4 .

Below, these steps are further elaborated.

In the ***first step***, the feedstock availability for each technology was determined, based on the feedstock potential, and the suitability of the feedstock for that technology. The suitability of each feedstock for each technology in 2030 and 2050 was determined together with external experts and reported in feedstock-technology matrices as shown in Annex 1. In these matrices '1' means that the feedstock is suitable for that specific technology pathway. The matrix for 2030, takes into account current technology status, and the matrix for 2050 considers technological development leading to less stringent feedstock requirements.

Basically, all feedstock potentials of the feedstocks that are suitable for a technology pathway are added up. Like in Task 2, a low, medium and a high mobilisation potential is given. Results are given in Table 2-13. The different technology pathways make use of three aggregated groups of feedstocks. These groups are:

- 'wet biomass and manure' – feedstocks for anaerobic digestion
- 'Lipids' – feedstocks for hydrotreatment and transesterification
- 'Lignocellulosic biomass' – feedstock for all other technologies.

Within these groups, technologies share a feedstock pool. For example, for 'Gasification and Methanol Synthesis' the biomass feedstock potential in the '2050 high' scenario is 268.5 Mtoe. This is the same as for 'Gasification +FT'. This means that this potential can be 'filled-up' by 'Gasification+SNG' to 268.5 Mtoe, or to a lower amount, in combination with other technologies.

In the ***second step***, the current indigenous biomass production for heat, power and biofuels is subtracted from these potentials, as these are not available for additional advanced biofuels capacity, if we assume that indigenous feedstock production in the EU27 for heat and power production remains constant until 2030. See Annex 2 for the full explanation of the determination of indigenous biomass production using Eurostat annual data of 2021[1] and other sources. Results of this subtraction of current use of feedstocks for bioenergy production are given in Table 2-14. In the "low" scenario, negative values appear, meaning that in this scenario the lignocellulosic feedstock availability is even below the current use for bioenergy, i.e., in this scenario indigenous biomass production for heat and power will need to reduce between 2023 and 2030, without providing possibilities for expansion of advanced biofuels production based on indigenous lignocellulosic feedstock. However, the sustainable technical potential and medium and high mobilisation scenarios show that there is a substantial potential of lignocellulosic feedstocks for advanced biofuels, provided that it is being mobilised.

Please note that no import or export of biomass for the production of advanced biofuels nor the import of export of advanced biofuels have been considered in this analysis. It is solely an assessment whether sufficient biomass is available in the EU27 to produce sufficient advanced biofuels within the EU27 to meet the EU27 demand.

In the **third step**, the available biomass feedstock for each technology pathway is converted in the equivalent amount of biofuels that can be produced – on an energy basis. For some technology pathways this percentage is roughly 100%, since there is very little biogas lost when it is converted to biomethane. For others, like Gasification+FT, the percentage is lower. It should be noted that this specific method does not say much about the overall efficiency. Many biofuel technology pathways use hydrogen, and using more hydrogen means that more biofuel that can be generated per unit of feedstock. The results are shown in Table 2-15.

In the **fourth** step the biofuel production potential based on feedstock availability minus current use for bioenergy per technology pathway, has been compared with the advanced biofuels scenarios, as further explained below.

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[1] See https://ec.europa.eu/eurostat/databrowser/view/NRG_CB_BM__custom_7693391/default/table

	Wet biomass and manure based	Lipids based		Lignocellulosic biomass based						
	Anaerobic digestion and upgrading of biogas to biomethane	Hydro-treatment	Trans-esteri-fication	Fermentation of lignocellulosic feedstock	Alcohol to Jet (ATJ/MTJ)	Gasification and methanation	Gasification and methanol synthesis	Gasification and FT synthesis	Pyrolysis	Hydrothermal liquefaction
Technical potential 2030	**47.2**	**15.4**	**15.4**	**445.9**	**445.9**	**457.4**	**457.4**	**457.4**	**448.4**	**445.0**
Low 2030	22.3	1.9	1.9	60.2	60.2	63.5	63.5	63.5	59.0	59.8
Medium 2030	28.5	3.3	3.3	123.9	123.9	130.2	130.2	130.2	123.5	124.1
High 2030	38.0	5.9	5.9	216.9	216.9	225.2	225.2	225.2	216.2	216.4
Technical potential 2050	**174.7**	**28.3**	**20.2**	**553.0**	**553.0**	**579.2**	**579.2**	**579.2**	**562.0**	**597.9**
Low 2050	35.3	5.1	2.7	59.2	59.2	72.7	72.7	72.7	63.8	80.1
Medium 2050	66.2	8.9	5.3	129.4	129.4	146.9	146.9	146.9	136.0	156.5
High 2050	111.7	15.5	10.6	245.9	245.9	268.5	268.5	268.5	254.4	281.5

Table 2-13 Biomass feedstock potential for each technology pathway (in Mtoe feedstock)

	Wet biomass and manure based	Lipids based	Lignocellulosic biomass based							
	Anaerobic digestion and upgrading of biogas to biomethane	Hydro-treatment	Trans-esterifi-cation	Fermentation of lignocellulosic feedstock	Alcohol to Jet (ATJ/MTJ)	Gasification and methanation	Gasification and methanol synthesis	Gasification and FT synthesis	Pyrolysis	Hydrothermal liquefaction
Current use	15.1	1.2	1.2	102.4	102.4	102.4	102.4	102.4	102.4	102.4
Potential 2030	**32.1**	**14.2**	**14.2**	**343.5**	**343.5**	**355.0**	**355.0**	**355.0**	**346.0**	**342.6**
Low 2030	7.2	0.7	0.7	-42.1	-42.1	-38.9	-38.9	-38.9	-43.4	-42.5
Medium 2030	13.4	2.1	2.1	21.6	21.6	27.9	27.9	27.9	21.2	21.7
High 2030	22.9	4.7	4.7	114.5	114.5	122.8	122.8	122.8	113.9	114.1
Potential 2050	**159.6**	**27.1**	**19.0**	**450.6**	**450.6**	**476.8**	**476.8**	**476.8**	**459.6**	**495.5**
Low 2050	20.2	3.9	1.5	-43.1	-43.1	-29.6	-29.6	-29.6	-38.5	-22.3
Medium 2050	51.1	7.7	4.1	27.1	27.1	44.6	44.6	44.6	33.6	54.1
High 2050	96.6	14.3	9.4	143.6	143.6	166.1	166.1	166.1	152.1	179.1

Table 2-14 Biofuel feedstock potential minus current use of biomass for bioenergy for each technology pathway (in Mtoe feedstock)

	Wet biomass and manure based	Lipids based		Lignocellulosic biomass based						
	Anaerobic digestion and upgrading of biogas to biomethane	Hydro-treatment	Trans-esterifi-cation	Fermentation of lignocellulosic feedstock	Alcohol to Jet (ATJ/MTJ)	Gasification and methanation	Gasification and methanol synthesis	Gasifica-tion and FT synthesis	Pyrolysis	Hydrothermal liquefaction
Conversion efficiency	100%	100%	100%	41%	40%	71%	58%	40%	65%	70%
Potential 2030[a)]	**32.1**	**14.2**	**14.2**	**140.6**	**135.9**	**252.0**	**206.3**	**142.0**	**224.9**	**239.8**
Low 2030	7.2	0.7	0.7	-17.2	-16.7	-27.6	-22.6	-15.6	-28.2	-29.8
Medium 2030	13.4[b)]	2.1[b)]	2.1	8.8	8.5	19.8 [b)]	16.2	11.2	13.8	15.2
High 2030	22.9[b)]	4.7 [b)]	4.7	46.9	45.3	87.2 [b)]	71.4	49.1	74.0	79.8
Potential 2050[a)]	**159.6**	**27.1**	**19.0**	**184.5**	**178.3**	**338.5**	**277.1**	**190.7**	**298.8**	**346.9**
Low 2050	20.2	3.9	1.5	-17.7	-17.1	-21.0	-17.2	-11.9	-25.1	-15.6
Medium 2050	51.1 [c)]	7.7 [c)]	4.1	11.1	10.7	31.7	25.9	17.8	21.9	37.9 [b)]
High 2050	96.6 [c)]	14.3 [c)]	9.4	58.8	56.8	117.9	96.6	66.4	98.8	125.4 [b)]

[a)] Please note that the feedstock potentials cannot be added up since many technologies make use of the same feedstock base. Negative biofuel production potentials occur if the feedstock potential found in Task 2 (biomass from EU27) is below the current use (including stemwood and import).[b)] These numbers are used for further assessment in Table 2-19 [c)] These numbers are used for further assessment in Table 2-23.

Table 2-15 Biofuel production potential based on feedstock availability minus current use for bioenergy per technology pathway (in Mtoe advanced biofuel)

Feedstock potential versus demand for advanced biofuels

In the previous step (step 3), an effort was made to determine the maximum amount of biofuels that could be produced based on the available amounts of feedstocks, as determined in Task 2, while considering current use of indigenous feedstock for bioenergy and constraints per advanced biofuels production technology. With this information, we can now determine if this availability of feedstocks is sufficient for the envisaged amount of biofuels that is needed in the FF55_RED scenario.

In the next three tables, the amounts of biofuels needed are given per subgroup. Data is derived from the gap analysis (see Table 2-10). We have excluded the conventional biofuels demand from food en feed crops, as these are also not included in the feedstock mobilisation scenarios of Task 2.

Technologies using wet biomass and manure	Biofuel production demand (Mtoe/y)
anaerobic digestion	7.9
Totals subgroup "wet biomass and manure"	**7.9**

Table 2-16: Biofuels demand 2030 FF55_RED scenario for the subgroup "wet biomass and manure"

Technologies using lipids	Biofuel production demand (Mtoe/y)
transesterification of e.g., brown grease	1.5
transesterification of cover crops from marginal lands	2.8
hydrotreatment of tall oil	0.2
hydrotreatment of cover crops from marginal lands	2.4
transesterification of UCO and AF	2.2
hydrotreatment of UCO and AF	1.6
totals subgroup "lipids"	**10.7**

Table 2-17: Biofuels demand 2030 FF55_RED scenario for the subgroup "lipids"

Technologies using lignocellulosic biomass	Biofuel production demand (Mtoe/y)
lignin boost of fatty acids	0.9
advanced ethanol	1.4
ATJ	0.1
gasification + methanol	1.4
gasification + SNG	0.2
gasification + FT	0.3
pyrolysis	0.9
HTL	0.2
Totals subgroup “lignocellulosic biomass”	**5.4**

Table 2-18: Biofuels demand 2030 FF55_RED scenario for the subgroup "lignocellulosic biomass"

Based on this, it is now possible to determine if this demand – according to the FF55-RED scenario for 2030 – can be fulfilled with the available biomass.

Feedstock subgroup	Biofuel production demand (Mtoe/y) (p)	Max feedstock (medium mobilization) (Mtoe/y) (m)	Max feedstock (high mobilization) (Mtoe/y) (h)	Surplus (+) or Shortage (-) medium mobilization (Mtoe/y) (m – p)	Surplus (+) or Shortage (-) high mobilization (Mtoe/y) (h – p)
Wet biomass and manure	7.9	13.4	22.9	5.6	15.0
Lipids	10.7	2.1	4.7	-8.6	-6.0
Lignocellulosic biomass	5.4	19.8	87.2	14.4	81.9

Table 2-19 Assessment of the availability of feedstocks for the needed additional biofuels production capacity in case of the FF55_RED scenario for 2030

In Table 2-19 we see for each of the three sub-groups defined earlier in this paragraph (wet biomass and manure; lipids, and lignocellulosic biomass) the total production of biofuels that is needed to fulfil the total biofuel demand in 2030 as predicted in the FF55_RED scenario. Again, the demand for conventional biofuels is excluded and not part of this assessment.

In the third and fourth column of Table 2-19, we see the total amount of biofuels that can be produced for that subgroup, using the 'medium' and 'high availability' feedstock scenario, and in the last two columns the surplus/shortage). For the biomass feedstock availability, we use the highest numbers as listed in Table 2-15 within each feedstock category (marked green and underlined in Table 2-15). Reason behind this is that if several technologies utilise overlapping feedstock pools, those technologies that can use feedstocks that other technologies cannot use, will do so in case of scarcity. The following can be observed:

- There is sufficient feedstock for biogas transport fuel production, even if we assume that part of the biogas is used for other applications than transport.
- For the lipids – used in hydrotreatment and transesterification – there is even in the high mobilisation scenario not enough biomass for all the needed additional capacity. This will likely be solved by imports, a development that we are already seeing.
- For the biofuels produced from lignocellulosic materials there is enough feedstock available in the medium and high mobilisation scenarios.

In case of 2050, the same comparison between feedstock availability and capacity can be made. Since the forecasted capacity (in Task 3) exceeds the total demand in all three demand scenarios (of Task 1), there is no gap. Therefore the (higher) forecasted 2050 capacity as derived in Task 3 and presented in Table 2-5 is used in this comparison. In the next three tables, the amounts of biofuels needed is given per subgroup.

	Biofuel production demand (Mtoe/y)
Anaerobic digestion	4.5
Totals subgroup "wet biomass and manure"	**4.5**

Table 2-20: Biofuels demand 2050 - forecasted capacity - for the subgroup "wet biomass and manure"

	Biofuel production demand (Mtoe/y)
transesterification of e.g. brown grease	1.5
transesterification of cover crops from marginal lands	2.8
hydrotreatment of tall oil	0.4
hydrotreatment of cover crops from marginal lands	5.4
transesterification of UCO and AF	2.2
hydrotreatment of UCO and AF	1.6
totals subgroup "lipids"	**13.9**

Table 2-21: Biofuels demand 2050 - forecasted capacity - for the subgroup "lipids"

	Biofuel production demand (Mtoe/y)
lignin boost of fatty acids	0.7
advanced ethanol	-
ATJ	7.7
gasification + methanol	2.9
gasification + SNG	0.7
gasification + FT	5.3
pyrolysis	0.8
HTL	1.7
Totals subgroup “lignocellulosic biomass”	**19.8**

Table 2-22: Biofuels demand 2050 - forecasted capacity - for the subgroup "lignocellulosic biomass"

Based on this, it is now possible to determine if this forecasted capacity for 2050 can be fulfilled with the available biomass. In the next table the calculation is made:

Feedstock subgroup	Biofuel production demand (Mtoe/y) (p)	Max feedstock (medium mobilisation) (Mtoe/y) (m)	Max feedstock (high mobilisation) (Mtoe/y) (h)	Surplus (+) or Shortage (-) medium mobilisation (Mtoe/y) (m - p)	Surplus (+) or Shortage (-) high mobilisation (Mtoe/y) (h - p)
Wet biomass and manure	4.5	51.1	96.6	46.6	92.1
Lipids	13.9	7.7	14.3	-6.2	0.4
Lignocellulosic biomass	19.8	37.9	125.4	18.1	105.6

Table 2-23 Availability of sufficient feedstocks for the needed additional biofuels production capacity in case the forecasted 2050 capacity is reached

Table 2-19 shows that given the relatively modest rise of biofuel capacity between the 2030 scenarios and 2050, and the higher rise with respect to availability, sufficient feedstock is available – again using a 'medium' or 'high' mobilization feedstock scenario (see the purple underlined values in Table 2-15). For lipids, the quantities are sufficient only in the high mobilization scenario. For anaerobic digestion, sufficient feedstock are available, also in the low scenario (20.2 Mtoe for anaerobic digestion) and when current use continues.

2.6. Conclusions

In the determination of the needed advanced biofuels activity, demand scenarios for the EU transport sector have been analyzed. Current production data has been identified as well as additional biofuels production capacity foreseen. Out of 10 scenario's three demand scenarios were considered:

- Highest advanced biofuels demand in 2030: scenario: FF55_ESR_RITA
- Lowest advanced biofuels demand in 2030: scenario RePower
- Central scenario: FF55_RED

The gaps between current production and additionally foreseen capacity have been determined and are summarized in Table 2-24 (All data in Mtoe). From this table and the earlier presented data, it is clear that for 2030 the gap between current and planned capacity, and the biofuels demand is very large in the central scenario (FF55_RED) and even higher in the maximum scenario (FF55_ESR_RITA).

Year	Scenario	Demand (D)	Production (P)	Additionally foreseen (F)	gap (D-P-F)
2030	FF55_ESR_RITA	42.8	17.8	9.6	15.4
	FF55_RED	38.1	17.8	9.6	10.6
	Repower	23.4	17.8	9.6	-4.0
2050	FF55_ESR_RITA	46.4	17.8	30.7	-2.1
	FF55_RED	46.7	17.8	30.7	-1.8
	Repower	45.3	17.8	30.7	-3.2

Table 2-24 Summary of the gap analysis (in Mtoe)

In the exercise which was conducted to 'close the gap', a growth factor of 5.4 for the FF55_RED scenario was calculated and a growth factor of 7.8 for the FF55_ESR_RITA. This means that the additionally capacity foreseen by experts between 2023 and 2030 - in lignocellulosic biofuel production pathways - must be multiplied by that factor to achieve the additional volumes of biofuels demanded in these scenarios. Compared to these growth levels, the additional volumes of biofuels needed in 2050 are modest, and similar for all scenarios. For 2050, there is no gap between demand and foreseen production.

The availability of sustainable feedstock which is needed to produce these additional volumes has been investigated based on Task 2 data. Assuming a 'medium' or 'high' mobilization scenario, sufficient feedstock is available for the central scenario (FF55_RED) in 2030 for anaerobic digestion and for pathways that use lignocellulosic biomass. For lipids, the availability is less than the demand even in the 'high' mobilization scenario, meaning that lipids will need to be imported from outside the EU, as is currently already the case.

3. Task 4.2 – analysis of preconditions and critical issues to advanced biofuels capacity development

3.1. Introduction

Task 4.2 aims to provide an in-depth analysis of the preconditions and critical issues that have impact on the industries' willingness to invest in advanced biofuel capacity, thus driving the outlook for new industrial installations and foreseen capacities for 2030 and 2050 and possible additional capacity needed to meet the targeted demand.

The project team and the hired advanced biofuels exerts have performed an initial analysis of critical issues, followed by in depth interviews with 12 advanced biofuels technology and project developers that were already contacted in the frame of Task 3.

The approach is further elaborated in section 3.2 followed by a topic wise presentation of the interviews in section 3.3 . A synthesis with the main conclusions and recommendations from the interviews is provided in section 3.4 .

3.2. Methodology

In our analysis of relevant preconditions and critical factors to increased advanced biofuels capacity the following approach has been followed:

Step 1. Long list of potential critical factors to capacity development

Based on the input from Task 3, i.e. interviews with relevant associations, interviews with Technology Experts, interviews with experts with a broad view, and additions made by the project Team, a long list of possible critical factors hindering the industry to take up investment in advanced biofuels capacity has been made.

Step 2. Prioritisation of potential critical factor by advanced biofuels experts

The contracted advanced biofuels experts (Philippe Marchand, Francisco Girio and Felipe Ferrari) were asked to prioritise and elucidate the most important gaps, by ranking the critical factors on the longlist from 1 (= not to critical) to 5 (very critical), differentiating between advanced biofuels technologies where appropriate. The long list of critical issues and the ranking provided by the technical experts can be found in Annex 2.

Step 3. Interviews with industrial partners

In June and July 2023 interviews with advanced biofuels producers/technology providers were held to discuss *"what factors are most critical to the capacity development of advanced biofuels"*, as open central question, and thereafter discussion with help of the headings of the above-mentioned list of critical factors. During the interviews three topics not initially listed, but provided by the respondents were addressed, and added to the list of critical issues, namely:

- Lack of cooperation of fossil fuel industries to switch to advanced biofuels;
- the position of advanced biofuels versus RFNBOs (as they are part of a joint target in the RED III); and
- the business opportunities for advanced biofuels in the EU versus the USA.

Interviews have been conducted with twelve companies[2] dedicated to the development of specific advanced biofuels technologies. Four of these companies are large multinationals, with several activities, and eight companies are fully dedicated to developing advanced biofuels technologies, and usually much smaller in size than the multinationals. Together these companies cover a broad range of advanced biofuel production technologies, i.e., hydrotreatment, lignin depolymerisation, fermentation of lignocellulosic feedstock, Alcoh0l to Jet (ATJ/MTJ), gasification, fast pyrolysis and hydrothermal liquefaction. Results have generally not been presented in a technology specific way, as to ensure that specific statements are not traceable to specific companies.

These interviews were held in close collaboration with the Task 3 leader, avoiding multiple project staff approaching the same industrial stakeholders shortly after each other.

A brief analysis of the interviews, counting the number of companies providing responses to specific topics and the total number of responses per topic is provided in Chapter 3.3 , followed by a topic wise overview of responses and quoted statements in section 3.3.1 to 3.3.18. The quoted statements may have been edited for the sake of readability and reflect the opinion of one specific respondent.

Step 4. Synthesis and recommendations

Based on the analysis and feedback received, the task leader (BTG) has synthesized the key findings and formulate actions and investments the industry should take in order to be able to meet the targeted demand. A feedback session has been organised through teleconferencing, with the contracted advanced biofuels experts.

3.3. Interviews with advanced biofuels industry

In June and July interviews with advanced biofuels producers/technology providers were held to discuss *"what factors are most critical to the capacity development of advanced biofuels"*, as open central question, and thereafter discussion with help of the headings of the above-mentioned list of critical factors.

The interviews have been analysed, and the number of unique statements related to each topic have been counted. Figure 3-1 shows that "regulatory issues" and "comments on specific EU regulations" (such as RED III, ReFuel Aviation, etc.) were addressed the most during interviews, followed by "access to capital and perceived project risks by the investors" and "research and technology development".

[2] Licella, Renfuel, UPM, Clariant, Lanzatech, Lanzajet, Cortus, Enerkem, IFPEN, Sasol, BTG and BTG-BTL.

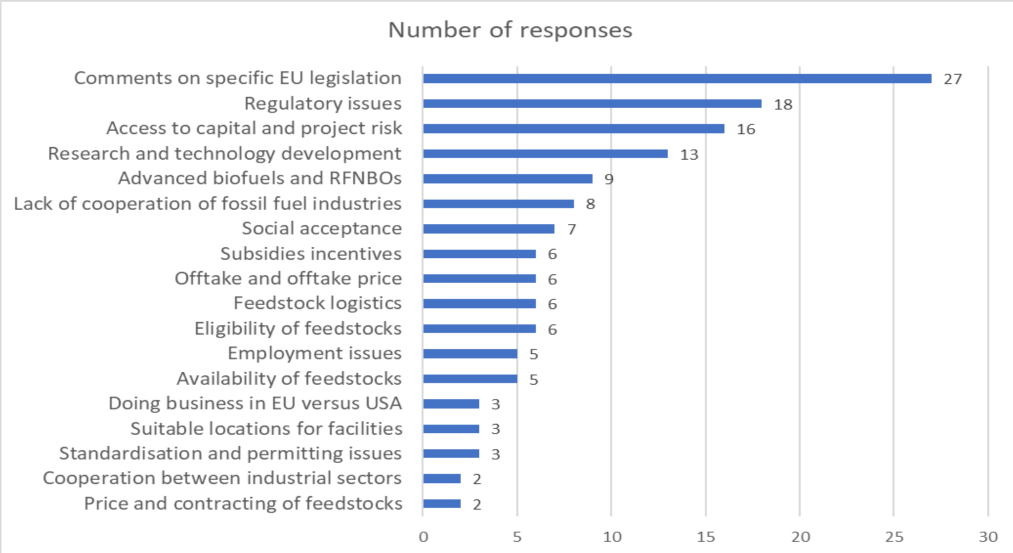

Figure 3-1 Number of responses to the topics addressed during the interviews with 12 companies

Table 3-1 shows the number of respondents that provided one or more reactions as well as the total number of responses. For most topics the number of responses is close to the number of unique respondents, showing a representative coverage of the topics by the different respondents. In case of regulatory issues, and especially in case of specific comments on EU legislation, the number of responses is much higher. In this case 6 respondents made 8, 6, 5, 4, 3 and 1 specific comments, totalling up to 27 comments. It shows that some respondents took the opportunity to provide many rather detailed comments on specific parts of EU legislation.

§	Issue	Number of respondents that provided one or more reactions	Number of responses
	Topics addressed by interviewer		
3.3.1	Availability of feedstocks	4	5
3.3.2	Eligibility of feedstocks	3	6
3.3.3	Price and contracting of feedstocks	2	2
3.3.4	Feedstock logistics	6	6
3.3.5	Standardisation/permitting issues	3	3
3.3.6	Suitable locations for facilities	3	3
3.3.7	Employment issues	5	5
3.3.8	Cooperation between industrial sectors	2	2
3.3.9	Research and technology development	8	13
3.3.10	Access to capital and project risk	11	16

§	Issue	Number of respondents that provided one or more reactions	Number of responses
3.3.11	Offtake and offtake price	6	6
3.3.12	Subsidies and incentives	6	6
3.3.13	Regulatory issues	10	18
3.3.14	Comments on specific EU legislation	6	27
3.3.15	Social acceptance	7	7
	Topics provided by respondent during interview		
3.3.16	Lack of cooperation of fossil fuel industries	5	8
3.3.17	Advanced biofuels and RFNBOs	4	9
3.3.18	Doing business in EU versus USA	3	3

Table 3-1 Number of responses and respondents that provided one or more reactions

In the next paragraphs the responses by the industry are topic wise discussed.

3.3.1. Availability of biomass

Some respondents indicated that advanced feedstocks (lipids) for HVO and HEFA production are becoming scarce, and access to feedstocks is “the game to win”. Woody biomass and agricultural biomass are currently available in sufficient quantities and form no real barrier. In the future this might be a problem though. It is also not very difficult to contract the lignocellulosic biomass at this moment, but that also may change. When more projects are implemented and all the “best” biomass has been taken, advanced biofuels producers will have to utilise lower quality biomass with a lower ash melting point. This comes with additional pretreatment costs. Furthermore, it was stressed by some respondents that there will be limitations in regional availability of lignocellulosic biomass, therefore, therefore some technologies make only sense in certain regions.

3.3.2. Eligibility of feedstocks

The question whether eligibility of feedstocks is a main barrier, resulted in several reactions covering various aspects.

The companies using ethanol as feedstock (e.g. Alcohol to Jet) really regret that first generation ethanol is not allowed in ReFuelEU Aviation and FuelEU Maritime, while the expected demand as a fuel for road transport is expected to decline considerably the coming decades.

The use of intermediate crops and cover crops for advanced biofuels production is seen as an opportunity. Of course, the environmental performance should be OK, which is especially related to fertiliser use. One advanced biofuels producer suggested that the EC could learn from the USA, as they have incentives are in place to produce crops for biofuels production. This type of support to cultivation is very helpful, while the EU is limiting itself to only marginal land and intermediate crops.

One advanced biofuels producer mentions that it would be great if in EU legislation (and in the famous ''cascade'' principle), advanced biofuels could be distinguished and obtain a higher priority than bioenergy. A plant producing biofuels will often also produce bioproducts like an oil refinery.

One advanced biofuel producer expressed that any restriction to woody biomass such as envisaged at a certain point of REDIII discussions would be detrimental.

One advanced biofuels producer fears opposition from NGOs if they would switch to agricultural residues, although rationally there is no objection to use them.

Legislation to use municipal solid waste should be further developed, it is sustainable, but however, much more pretreatment is needed.

One advanced biofuels producer indicated that expansion of Annex IX is nice, but currently not a very limiting factor for them, but this may be the case for other companies.

3.3.3. Price and contracting of feedstocks

Only a few remarks were made on price and contracting of feedstocks. Price differences between regions were mentioned. One respondent pointed out that biomass prices of woody biomass are still high, also due to lower supply of woody biomass from Russia to Scandinavia. Also, the straw prices are high.

3.3.4. Feedstock logistics

The hub-and-spoke model is mentioned a few times, meaning that the first product (e.g., pyrolysis oil, ethanol) can be produced close to the biomass, while the final fuel is produced in a central location. Transport of the intermediate product is not a problem.

One respondent mentioned that the large infrastructure needed for collecting agricultural biomass is often not available and has to be build up during project development and implementation.

Biomass mobilisation and pretreatment as specific activities that should be carried out by a suitable partner, not necessarily by the technology developer/project developer itself.

Furthermore, regional aspects were emphasised, as logistics is a regional affair. One respondent emphasised the importance of transport distance to the Carbon Intensity score (CI), which is important for Science Based Targets (and the RED III).

3.3.5. Standardisation and permitting issues

Permits etc. are not really seen as a key problem. It takes just time to develop a project though. These are seen as the more general issues that hinder capacity development, such as sufficiently skilled staff, and permitting which can certainly be challenging. These are however just examples of the problems project developers must solve.

Nevertheless, the long duration of permit procedures is seen as an obstacle related to achieving the 2030 targets. Inclusion of advanced biofuels to the Net Zero Industry Act would certainly contribute to quicker deployment of advanced biofuels!

One respondent mentioned that Methanol-to-jet has to wait for ASTM approval, which can take 18 months to 3 years.

3.3.6. Suitable locations for facilities

Finding a good location is seen as a challenge but also part of the game, not a showstopper. Quite some preconditions need to be met such as access to hydrogen, natural gas, electricity, and of course the biomass feedsock. One respondent mentioned that they go just for brownfield locations as greenfield locations are hopeless to develop.

3.3.7. Employment issues

Finding staff is a very location specific issue. The biomass is often available in remote areas, so finding the right people can be a challenge that should be seriously addressed, but not a big showstopper. Some staff has to be highly skilled and willing to work in a remote place, which can be a challenge. One respondent mentioned an example of a non-EU project where the local government was happy that not so many employees were needed for the project, given the scarcity of staff in that region. Finding staff for more centralised activities is not seen as a significant challenge.

3.3.8. Cooperation between industrial sectors

Cooperation between industrial sectors was not seen as a problem in the sense of building the plant. Cooperation between the agricultural sector and the advanced biofuels producers was not seen as problematic. The (lack of) cooperation of fossil fuel companies as part of the end users and as competitors is addressed in section 3.3.16.

3.3.9. Research and technology development

One respondent stated that “None of the advanced biofuels technologies are established for decades, so technological development and support for technology development will be necessary especially in the early stages of development”.

Some respondents emphasised the opportunities, the upside if advanced biofuels technologies would be further developed and optimised. Process optimising and yield improvement is well possible. Capacity development is seen as very important for getting costs per unit down. Two or three respondents referred to a study that showed clearly that each doubling of the first-generation bioethanol capacity resulted in a cost reduction of 15 – 20%, and that this also will take place in the case of advanced biofuels.

Some respondents expressed their appreciation for past EU support in research and development of advanced biofuels technology and emphasised the importance of these research programmes.

Several topics for additional research and development were mentioned, mainly related to the use of more difficult feedstock such as MSW and agricultural residues. One respondent emphasised that also research on electrolysers is important, as advanced biofuels producers need the green hydrogen, just like the E-fuel producers.

Several respondents indicate that their main hurdle is to get a full-scale demonstration plant up and running, to show that commercial production is possible. Support to this phase is very important.

One respondent expressed his/her concern that there is a danger that the 2030 targets for SAF will be fully completed by HEFA since this is already fully commercial, and that innovative technologies are being crowded out. It would be great if the EU Innovation fund would be limited to innovative technologies and exclude HEFA.

3.3.10. Access to capital and perceived project risk

Initially this topic was framed as "financial issues", but during the interviews especially the combination of access to capital and perceived project risk by the capital providers is critical.

The respondents from larger companies generally indicate that financing is not a big problem, but for many of the smaller companies this is a serious barrier. One respondent expressed this point as follows: "*Many players in this new area are project developers (and not traditional companies from the oil and gas business), so project financing is a big hurdle for such new players in a "CAPEX intensive'' field. An IPCEI[3] for advanced biofuels (and e-fuels) could be a very appropriate tool to support the large deployment of advanced biofuels. It is missing in EU!"*

The combination of high investment costs and the required speed of capacity development to meet the targets is seen as challenging. As expressed by one respondent *"a major challenge is that technologies have to scale up quickly, and that substantial amounts of risk capital are needed. Banks or "conservative investors" will not finance advanced biofuels project with high technology risks, while there is no time to de-risk by scaling up at a lower speed. Therefore, risk capital is needed, and yes, some projects will fail. For example, DOE has invested 100 million USD in cellulosic ethanol plant, and the project failed. We should not be afraid to make mistakes"*.

Another respondent indicated that *"fast upscaling is needed for instance to produce SAF. A smaller but still considerable demo plant is very expensive. Better to go from pilot to full scale in one go, but this requires a lot of capital, and guts"*.

Another respondent has talked with different refineries. *"Main point is that they need to be willing to take a certain risk. Of course, refineries should not get into technical problems because of the advanced biofuels production."*

One respondent expressed the issue as a 'chicken-and-egg' problem: *"To easily attract sufficient capital, a full-scale reference is required, but to develop this full-scale reference, sufficient capital is required. Capital providers weigh the risks and the potential rewards, and it is our own task to make those risks manageable"*.

One respondent active in SAF: *"A letter of Intent is not enough. We need more binding agreement with airlines as off takers, or a venture capitalist that is willing to invest. Airlines don't have a very long-term vision and apply short term thinking. Difficult corona years, capital intensive sector, margins can be low (although last year was pretty good for them, but they have to take care). Therefore, much hesitation to commit"*.

Several respondents expressed that very clear targets and regulations should be in place. *"Regulations should be fully fixed and clear. A provisional agreement is not sufficient!"*

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[3] Important Project of Common European Interest

Once the targets are clear and the technology is sufficiently "derisked", the money is expected to be available. One respondent indicated that huge investments are needed, so this is a challenge. He trusts that venture capital will go to green technology in general and especially in hard to abate sectors like aviation. *"Currently aviation is responsible for 3% of the global GHG emissions, this share will increase to 20 – 22% in 2050 if nothing happens in aviation while other sectors do reduce GHG emissions"*.

One respondent expressed the point as follows: *"Finance is not really a problem, there is money to invest. However, there is a lack of creativity to develop projects. The creativity has to come from the technology developers"*.

3.3.11. Offtake and offtake price

Once the capacity is developed, no big problems with offtake or the offtake price are expected by the respondents:

"Finding a decent offtake *price is currently not a big hurdle. There is more demand than we can produce."*

"Off-take of the product will not be a problem as our own shareholders alone are willing to ensure the off-take."

"Off-take is not seen as an inhibition. We currently operate on a 20 year off-take agreement, and they could get one again for the first projects at least. There is interest in sustainable fuels in the market".

"Prices of SAF high enough, there will be paid for."

"If mandates are clear, the kerosene users have to simply buy the SAF, even if it is really expensive. The targets are not that high in the early years, and the financial impact on the ticket prices is rather limited, 5 – 25 Euro/ticket. And they got the "ETS discount". Air companies should not complain too much, but they are heard very well".

These statements show a rather high trust that off-take will be guaranteed, especially in the case of SAF. Compared to the challenge to get projects financed, the offtake is not seen as a big barrier by the respondents. Only one respondent indicated that at current stage of development an off-take agreement for 10 years would be great.

3.3.12. Subsidies & incentives

This topic led to a scattered number of statements:

"Government incentives will help for the first one or two plants".

"Advanced biofuels plants are capital intensive, but projects are profitable. So, the issue is the project financial structuring. A contribution of EU or national entities to project equity would help the deployment. Traditional rules to support project at EU level could have exception for this strategic domain in EU."

"Price support would be good".

"Fossil fuel subsidies should be more limited".

It should be noted that several respondents expressed that support in research and development is important. These responses are further elaborated in section 3.3.9 on research and technology development, and not repeated here.

3.3.13. Regulatory issues

Regulatory uncertainty and complexity are two major issues most respondents addressed. In general, it is acknowledged and appreciated that the EU has established an overall framework with support for advanced biofuels in several sectors including maritime and aviation. This is positive, but three main types of issues have been identified:

- Regulatory uncertainty
- Regulatory complexity
- Speed of the regulatory process.

Below the general statements on regulatory uncertainty and complexity are provided. In the next section, detailed comments on specific parts of regulatory texts are provided.

Regulatory uncertainty

The fact that RED III was being developed just after RED II was finalised caused serious regulatory uncertainty. As long as legislation and targets are not fixed, investments in advanced biofuels capacity will be very limited. Various statements were made regarding regulatory uncertainty.

“Regulations should be fully fixed, a provisional agreement is not sufficient to attract investments.”

“Lack of certainty (after publication RED II, immediately start of RED III, amendments, change of feedstock list A and B) creates concern. Use of wood-based biomass uncertain due to changes in RED.”

“Soon after establishment of RED II, with target of 1.75% advanced biofuels, the RED III proposal was published, which meant that the just established target became uncertain again. Soon after publication of the RED III, in 2025, there will be a full evaluation of the Green Deal, which can cause again uncertainty.”

“The regulations need to be constant for a long period. Industrial projects are developed for at least 20 years and business model develop for the same duration. However, the regulations are complex and then also change each 3 - 4 years.”

“Unpredictability of targets. After RED II, advanced biofuels projects could be developed. However, the RED III gave a new period of uncertainty, and now a large role of RFNBOs is foreseen at the cost of advanced biofuels technologies that are already further developed.”

“The role of biomass after 2030 in general is not known. The regulatory framework for 2040, revision of RED III to be discussed after 2027 will be highly important. Maybe cascading use and use as biobased materials and chemicals will become more important on the cost of biofuels.”

Regulatory complexity

Several respondents expressed their concern regarding the complexity of the regulatory framework:

"*The legislative framework for advanced biofuels is really difficult to navigate, difficult to explain to a decision maker within a company. And complexity is increasing. Good - or actually bad - example: RED III starts with rather clear Commission proposal, but in the end advanced biofuels and RFNBO appear in one joint target, and to assess the consequences is rather complex. No institution or industry has called for this, it is just brought in as a kind of compromise. Now we have to await how the Member States will implement the targets. Are they using separate targets for RFNBOs and advanced biofuels or not, this is very difficult to predict."*

"The Advanced Biofuels Coalition has organised "RED III reading sessions" to understand meaning and consequences of the text of the Provisional Agreements".

"Another example of complexity: instead of targets Member States can use GHG intensity calculations to measure their contribution towards the targets. Therefore, the methodological choices of the MS determine whether the outlook for advanced biofuels is more or less favourable".

One respondent expressed good hopes that much of the uncertainty will be temporarily but emphasises the importance of high-quality legislation: *"Setting targets, uncertainty because of the long duration of procedures etc, is temporary. It is however very important that the European Commission harmonises regulations and sets proper procedures. This is their main task."*

Related to RFNBOs and RCFs one respondent indicates that rules for GHG emission reduction are very complex require further explanation. This is not yet available.

One respondent indicated that regulations that apply directly in all Member States (such as ReFuelEU Aviation) are preferred above a Directive (such as the RED) that requires implementation in national law. He understands that Members States need flexibility of a Directive, but in this case of advanced biofuels in RED III, it becomes too complex and uncertain for the industries.

Speed of regulation process

Several respondents indicated that the regulation process is too slow, especially regarding the 2030 targets.

"We wasted too much time while talking and setting the targets, now quick action is needed. Only FAME can deliver SAF targets by 2025, and 2030 is also already very close by".

One respondent gave a detailed timeline to stress the need to take quick action:

- 2023: project setup, looking for partners that can develop and finance it.
- 2024: basic engineering, selection suitable location.
- 2025: detailed engineering + permit application

- 2026: building the plant
- 2027: plant should be operational, it takes some time to attain full production
- 2030: target, full production.

Other general regulatory issues

One advanced biofuels producer with a focus on wastes mentioned that "making biofuels from waste is seen as recovery, not as recycling. In case of recycling, permitting is easier, and the process contributes to recycling targets. However, fuel is used once, and therefore usually seen as recovery. On the other hand, many products from recycling are also only used once. This has to do with (interpretation of) the waste framework directive."

Some advanced biofuels producers recommended strict enforceable obligations: "The most important is an obligation to switch to advanced biofuels, and high fees if targets are not met."

3.3.14. Comments on specific EU legislation

Many respondents took the opportunity to comment on specific pieces of (upcoming) EU regulation, some of them also covered biofuels from recycled carbon fuels (RCF) and RFNBOs. We have included these comments as well, since Task 4 will result in recommendations for both advanced biofuels and RFNBOs. Please note that section 3.3.2 on eligibility of feedstocks also contains some comments on EU legislation, which have not been repeated here.

RED III Provisional agreement

Several respondents commented on the fact that the trilogue negotiations resulted in a joint target for both advanced biofuels and RFNBOs. In general, the respondents expect that there is no big risk that RFNBOs take more than the minimum of 1% in the combined target of 5.5%. But it adds complexity and uncertainty, as the RED III provisional agreement Article 25 point 1, second paragraph states *"Member States are encouraged to set differentiated target for biofuels and biogas produced from the feedstock listed in Part A of Annex IX and RFNBOs at national level in order to fulfil the obligation (…) in a way that the development of both fuels is incentivised and expanded".* Therefore, advanced biofuels producers have to await what Member States decide with regard to this target, and Member States may ask for more than 1% RFNBOs on the cost of advanced biofuels at Member State level.

The reintroduction of double counting was criticized. Double counting was removed in the Commissions' proposal but was reintroduced during the negotiations. According to one respondent is just a very smart measure for policy makers and oil companies as the target is met without much effort. Striking example is that electricity for transport counts 4 times.

One potentially negative provision for advanced biofuels is that Member States may count biogas injected to the grid to the advanced biofuels targets, maybe even if no methane is used as transport fuel (RED III Art 25). According to the respondent, the text is unclear about this, creating uncertainty if Member States will indeed count biogas injected to the grid to meet advanced biofuels targets, without the use of biomethane in transport, even if this is not intended by the legislator.

Two respondents pointed out that recycled carbon fuels (RCF) may be considered by the

Member States (RED III, Art 25, point 1, paragraph 6 under (b)). This means a long period of uncertainty for RCF fuel producers.

ReFuelEU Aviation

ReFuelEU Aviation is generally seen as a real opportunity for the further development of advanced biofuels. However, some specific comments were made.

Several respondents indicated that they would like to see a specific advanced biofuels target in ReFuelEU Aviation. RFNBOs have a specific sub target, while advanced biofuels are part of the general SAF targets that include (a) synthetic aviation fuels, (b) aviation biofuels and (c) recycled carbon aviation fuels.

One respondent regretted that the ReFuelEU Aviation proposal does only allow advanced biofuels and not other forms of ethanol, which limits the growth potential of the technology. He/she pointed out that at this moment there is already 1.5 million tonne/year of spare ethanol production capacity in EU which could be used to produce SAF.

FuelEU Maritime

Not many specific comments were made on FuelEU Maritime. One respondent regarded it as a good technology neutral approach as the sector can decide what measures to take. For RFNBOs as the new kid on the block, a RFNBO target is included, but not for advanced biofuels. One respondent pointed out that first generation ethanol is being equated to fossil fuels, which does not stimulate ethanol based applications, even if they have GHG savings, which is the leading principle of FuelEU Maritime.

Commission Delegated regulations (EU) 2023/1184 and 2023/1185 on GHG calculation and carbon sources for RFNBOs

On the 20th of June 2023 two commission delegated regulations were formally published, determining which hydrogen and CO2 sources are eligible for the production of RFNBOs and RCF. These rules are summarised in chapter 4.3.2 on E-fuels. Please note that the comments below are mainly relevant for producers of RFNBOs.

The main point of criticism is on the eligibility of carbon sources. The delegated regulation on carbon sources for E-fuels ((EU) 2023/1185) states that fossil CO2 sources are not eligible after 2036 (industry under EU ETS) and 2041 (from electricity plants). This hinders the development of the E-fuels sector considerably. The respondent asked about it and the answer from EC was that there will be a review in 2027. However, this does not create any clarity. Even if by that time the dates are moved 5 years forward, there is still the short time span that there is certainty about the source of carbon. A grandfathering clause is needed, meaning that projects that started using a fossil carbon source, can keep using this source once the project has started. In that sense RED II Annex IX is better, as feedstocks cannot be removed, which gives a reasonable amount of certainty.

One respondent indicated that the unclarity and the late implementation rules for RFNBO, caused delays in investments in EU. In EU they now have realised one RFNBO facility while within the same timespan they were able to implement three plants in China.

One responded pointed out that the Commission delegated regulation have just been published, meaning that certification schemes have to be adjusted to be able to certify

RFNBOs and RCF. For example, ISCC is not yet ready for it, this takes time.

RFNBOs can use certificates of origin to green the electricity, while for RCF the grid factor of the last two years has to be taken, not allowing the use certificates of origin. This is a displacement penalty for RCF compared to RFNBOs.

For Recycled carbon fuels it is not clear if the 70% GHG reduction target can be met. Problem is E – ex use factor. Biomass or carbon from landfill is not included, and this is needed to reach the 70% GHG emission reduction. The respondent indicated that they are in contact with the EC about this topic.

Proposal for Net-Zero Industry Act

The Commission proposal of the Net Zero Industry Act (COM(2023) 161[4]) provides a priority status and various types of support like such as shorter permit procedures and increased access to finance for the Strategic Net-Zero Technologies.

Main point of criticism is that the proposed list does not include advanced biofuels. According to some respondents *"it is not understandable that advanced biofuels are not included taking into account the criteria, namely GHG impact, TRL and energy security, but that only biomethane appears in the Annex. It would be much better to have a technology neutral approach among the sustainable technologies"*.

Several respondents stated that especially the fast-track permitting would be very beneficial for the rapid implementation of advanced biofuels projects, as it is very challenging to have sufficient capacity installed by 2030.

Another advanced biofuels producer points out that on the one hand RED III targets are formulated that are quite good, but the exclusion of advanced biofuels in the Net Zero Industry Act is another signal. It seems that the proposal may change for the benefit of advanced biofuels, but nothing is sure at this stage.

EU ETS

One respondent made a specific comment on the EU-ETS5 related to the compensation of the price difference between fossil fuels and SAF.

Article 3c paragraph 6 explains that "for the period from 1 January 2024 until 31 December 2030 a maximum of 20 million (…) allowances can be reserved *in respect of commercial aircraft operators (…) for the use of sustainable aviation fuels (…)".* These allowances shall cover part of or all of the price differential between the use of fossil kerosene and the use of relevant eligible aviation fuels. The allowances shall cover 70% of the remaining prices differential between the use of fossil kerosene and hydrogen from renewable energy sources, and advanced biofuels; and 95% of the remaining difference between fossil kerosene and RFNBOs.

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[4] Proposal for a regulation of the European Parliament and of the Council on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem

[5] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC (Text with EEA relevance)

One of the respondents made the point that this compensation of airlines for the use of SAF, with a total estimated value of 300 – 400 million Euro could better be directly spent to stimulate SAF production capacity. This approach will become very expensive when SAF targets become bigger.

3.3.15. Social acceptance

Social acceptance is a broad term which, following the widely used classification of Wüstenhagen (2007)[6] covers socio-political acceptance (by the general public), community acceptance (of people living near to the production facilities) and market acceptance (by the buyers). During the interview we did not make this differentiation, but for clarity we present the results following these three categories of social acceptance.

Socio-political acceptance

According one respondent "social acceptance of advanced biofuels in the frame of the sustainability discussion is big problem, and also one of the drivers why RFNBOs are currently strongly promoted. Yet, it has to be seen if RFNBOs can deliver, while other advanced biofuels technologies receive less attention. Some years later the industry will observe that there were not sufficient electrolysers, and say sorry but we can't help that we didn't proceed".

Another respondent has put this point as follows: "advanced biofuels are suffering from conventional biofuels' poor fame…"

One respondent observed "there is a certain risk that - once SAF will become more common - SAF will not be accepted as it is only a carbon neutral fuel, and still emits CO2 to the air. The public is mainly keen on electrification, which is regarded as zero emission, which is not the case in reality. This has to be explained well."

Community acceptance

In general, no big issues with community acceptance were mentioned. However, in specific situations it can be a problem. One respondent had to abandon a specific project because it was blocked by local citizens, while other projects were successful.

One respondent indicated that waste-related projects always have to do with increased transport movements etc. Therefore, best to have dedicated partner that also takes care of the local stakeholder consultation.

Market acceptance

One respondent mentioned that "in surveys 90% want to pay more for sustainable product, in practise nobody wants to pay more, especially in case of fuels." This stresses the need for obligatory advanced biofuels targets.

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[6] Rolf Wüstenhagen a, Maarten Wolsink b, Mary Jean Bürer (2007) Social acceptance of renewable energy innovation: An introduction to the concept, Energy Policy, Volume 35, Issue 5, May 2007, Pages 2683-2691. https://doi.org/10.1016/j.enpol.2006.12.001

3.3.16. Lack of cooperation of fossil fuel industries

Lack of cooperation of fossil fuel industries was not initially included in the semi structured questionnaire, but during the interviews several respondents expressed their experiences with the traditional oil companies, covering mainly two points: their perceived lack of willingness to invest and their motivation to keep the status quo by all means.

According to one respondent *"Fossil fuel companies have the power to invest, but they like to keep status quo. There are some exceptions, but there is reason enough to support the smaller companies dedicated to advanced fuels technology and capacity development. They don't have the investment power"*.

"It takes time for them to make a decision. To see that the technology is more than a nice power point presentation".

"Some investors are only interested in turnkey solutions, but technology has not reached that state yet. Others are more interested."

"The more complex the regulations, the better for the conventional oil industries, that have the power to put highly classified staff on it. Example RED III target with RFNBOs together with advanced biofuels."

"Oil companies just want one thing: delay of renewable options and continuation of their main business. Don't underestimate them. They are established long time ago and put very experienced staff on the lobby activities. The CEO is welcome to have a chat with Mr. Timmermans. RFNBOs as new kid on the block is perfect. Parliamentarians love it, and after some years they will say it was too difficult after all, and that more subsidies were needed. Therefore, strict legislation and targets are better than subsidies. Oil companies have the money, more than the EC. A plan should be developed on how the oil companies can be converted to renewable energy companies. On their own they usually have a renewables department, but this comes and goes, as profitability is what counts in the end, not a vision to really decarbonise and switch to renewables. Moreover, governments depend on taxes on petrol, these are high amounts."

"Fossil industries have low readiness to change. They may show a lot of interest one time, while some time later, their interest disappears again. Ultimately, they like to maximise profits on fossil fuels and don't really want to change to advanced biofuels / renewables."

"If mandates are clear the kerosene users have to simply buy the SAF, even if it is really expensive. The targets are not that high in the early years, and the financial impact on the ticket prices is rather limited, 5 – 25 Euro/ticket. And they got the "ETS discount". Air companies should not complain too much, but they are heard very well".

3.3.17. Advanced biofuels and RFNBOs

Given that advanced biofuels and RFNBOs are in one target in the RED III, there were quite some remarks regarding RFNBOs, expressing concerns whether RFNBOs can really deliver, while advanced biofuels are neglected, but also addressing synergies with advanced biofuels production. Below a number of statements are provided that give an impression of the advanced biofuels producers' concerns and possible synergies related to RFNBOs.

Concerns about RFNBOs

“There is a risk that policy makers regard advanced biofuels too difficult and will put their hope on E-fuels, while these are more expensive. It is a challenge to show policy makers and the public the possibilities and opportunities of advanced biofuels”.

“Technology wise new technologies are evolving, including synthetic fuels. Also, biogas/biomethane could play quite an important role in obtaining RED III targets (at the cost of other advanced technologies).”

“Many analysts and even experts working for the EC expect RFNBOs are not available by at scale before 2035. We also work on technology for RFNBO production, so we have nothing against them, but they have a different timeline of implementation. In ReFuelEU Aviation the Parliament came with totally unrealistic targets for RFNBOs.”

“No big risk that RFNBOs take more than the minimum of 1% in the combined target of 5%”.

“Impact joint mandate with RFNBO and expectation on competition from RFNBOs? I Don’t know. That’s the problem.”.

Synergies & common interests

“There are important interlinkages: advanced biofuels need H2; and E-fuels need at some point biological sources of CO2.”

“Limited availability of H2 is a huge problem, in general for advanced biofuels/RFNBOs/RCF. It would be good if nuclear power would be allowed.”

“The development of H2 and E-fuels are important, especially now they are in the same target in the RED III.”

3.3.18. Doing business in EU versus USA

Some respondents made remarks regarding the business climate in the EU versus USA, for example that in the USA there is more willingness to take risky investments.

One respondent stated that competition from e.g. the USA is an issue in case of alcohol-to-jet, since they have lower sustainability requirements (50% GHG reduction) and do not limit themselves to advanced biofuels.

One respondent provided several statements:

“The EU has better targets, the USA has more homogeneous market, so easier to scale up sales in this market”.

“The IRA (Inflation Reduction Act of the USA) does not support advanced biofuels, but the DOE has funds. IRA is 250 Mln Euro, but EU also has fund of 750 billion Euro”.

“Labour is expensive and inefficient in USA. Investing in facility is 1.5 – 2 times more expensive in USA so advanced biofuels production in EU is likely”.

"Culture of USA is that they think in opportunities, but within the EU we are more focussed on the threats".

"Therefore, not all advanced biofuels will be produced in the USA. Both continents are important for advanced biofuels development".

3.4. Conclusions and recommendations

The question *"what factors are most critical to the capacity development of advanced biofuels"*, as open central question to the 12 respondents, resulted in the identification of two main critical risks, namely regulatory issues (mentioned 5 times as most critical factor) and access to capital and project risk (4 times). The remaining three issues are all feedstock related, i.e., eligibility of (1 time), access to (1 time), and mobilisation of (1 time) feedstocks. This prioritisation corresponds well with the prioritization of topics provided by the advanced biofuels experts prior to the interviews (See Annex 2).

This section provides a summary of the main results of the interviews, analysing the most critical issues for developing advanced biofuels capacity. Based on the interviews we have made a classification into highly critical, critical and less critical issues, and have added a number of recommendations, that follow from the interview results.

3.4.1. Highly critical issues

Regulatory issues

In general, it is acknowledged and appreciated that the EU has established an overall framework with support for advanced biofuels in several sectors including maritime and aviation. This is positive, but regulatory uncertainty and complexity are two major issues that most respondents addressed on one or another way.

An example of regulatory uncertainty is that soon after establishment of RED II, with a target of 1.75% advanced biofuels, the RED III proposal was published, which meant that the just established target became uncertain again. Soon after the publication RED III, in 2025, there will be a full evaluation of the Green Deal, which can cause again uncertainty. Industrial projects are developed for at least 20 years and business models are developed for the same duration. However, the regulations are complex and then also change each 3 - 4 years. <u>It is recommended to keep the advanced biofuels targets and related legislation constant for a prolonged period.</u>

An important example of regulatory complexity is that the trialogue negotiations resulted in a joint target for both advanced biofuels and RFNBOs. In general, the respondents expect that there is no big risk that RFNBOs take more than the minimum of 1% in the combined target of 5%. But it adds complexity and uncertainty, as the RED III provisional agreement Article 25 point 1, second paragraph states *"Member States are encouraged to set differentiated target for biofuels and biogas produced from the feedstock listed in Part A of Annex IX and RFNBOs at national level in order to fulfil the obligation (…) in a way that the development of both fuels in incentivised and expanded"*. Therefore, advanced biofuels producers have to await what Member States decide with regard to this target, and Member States may ask for more than 1% RFNBOs on the cost of advanced biofuels at Member State level. <u>It is recommended to limit the freedom of Member States to have their own interpretation of advanced biofuels targets.</u>

Regulations that are directly applicable in all Member States (such as ReFuelEU Aviation) are preferred above Directives (such as the RED) that require implementation in national law. Members States may need the flexibility of a Directive, but in this case of advanced biofuels in RED III, it became too complex and uncertain for the industries.

Clarity is needed about the fact that according to the provisional agreement of the RED III, Member States may count biogas injected to the grid to the advanced biofuels targets, maybe even if no methane is used as transport fuel. The text is unclear about this, creating uncertainty if Member States will indeed count biogas injected to the grid to meet advanced biofuels targets, without the use of biomethane in transport, even if this is not intended by the legislator. Although an open door, it is recommended that the legislative process should result in clear legislation and proper procedures.

The Commission proposal of the Net Zero Industry Act (COM(2023) 161[7]) provides a priority status and various types of support like such as shorter permit procedures and increased access to finance to the Strategic Net-Zero Technologies. The proposed list does not include advanced biofuels, while they meet all underlying criteria such as GHG impact, TRL and energy security. Especially the fast-track permitting would be very beneficial for the rapid implementation of advanced biofuels projects, as it is very challenging to have sufficient capacity installed by 2030. It is recommended to include advanced biofuels as Strategic Net-Zero Technology in the Net Zero Industry Act.

Access to capital and perceived project risks

The combination of (1) high investment costs, (2) the perceived project risk by capital providers and (3) the required speed of capacity development to meet the targets is challenging and requires robust measures.

For larger companies obtaining capital may not be a big problem as such, but for many of the smaller companies this is a serious barrier. Many players in this new area are project developers and not traditional companies from the oil and gas business, and project financing is a big hurdle for such new players in the "CAPEX intensive'' field of advanced biofuels production. They face a "chicken-and-egg" problem: to attract sufficient capital, a full-scale reference is required, but to develop this full-scale reference, sufficient capital is required.

Banks or "conservative investors" will not finance advanced biofuels projects with technological risks, while there is no time to de-risk by scaling up at a lower speed. Risks have to be taken and risk capital is required.

It is recommended to support the development of a full-scale reference plant. Technology developers and advanced biofuels producers are advised to consider support from the EU innovation fund. An IPCEI for advanced biofuels could be a very appropriate tool to support the large deployment of advanced biofuels.

[7] Proposal for a regulation of the European Parliament and of the Council on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem

3.4.2. Other critical issues

Research and technology development

None of the advanced biofuels production technologies are established for decades. Technological development and support for technology development will be necessary especially in the early stages of development. The EU has supported research and development of advanced biofuels technologies, which is well appreciated by the advanced biofuels technology developers. These research programmes are very important. It is recommended to keep research and technology development funds available for advanced biofuels production technologies.

For several technologies, the main hurdle is to get a full-scale demonstration plant up and running, to show that commercial production is possible. It is recommended to provide appropriate support in this phase, for instance by the EU Innovation fund.

There is a considerable upside if advanced biofuels technologies would be further developed and optimised. Process optimising and yield improvement is well possible. Capacity development is very important for getting costs per unit down.

Biomass feedstock eligibility

Although not in the scope of the current project with a focus on advanced biofuels, it is worth mentioning that ethanol-based pathways such as alcohol-to-jet could be developed much quicker if first generation bioethanol would have been accepted in ReFuelEU Aviation and FuelEU Maritime. The use of first-generation bioethanol will decrease and could be made available for maritime and aviation. The use of intermediate crops and cover crops for advanced biofuels production is seen as an opportunity. It is recommended to further develop the possibilities to utilise intermediate crops and cover crops for advanced biofuels production.

Role of advanced biofuels versus RFNBOs

Many advanced biofuels producers have expressed their concerns about the high expectations of RFNBOs at the political level, while RFNBOs may not be available at scale before 2035. It is important to formulate realistic RFNBO targets and measures. For advanced biofuels producers it is important to show policy makers and the public the possibilities and opportunities of advanced biofuels.

Although not directly relevant for advanced biofuels, for RFNBOs the eligibility of carbon sources is a critical point. The delegated regulation on carbon sources for E-fuels ((EU) 2023/1185) states that fossil CO2 sources are not eligible after 2036 (industry under EU ETS) and 2041 (from electricity plants). This hinders the development of the E-fuels sector considerably. It is recommended to include a grandfathering clause, meaning that projects that started using a fossil carbon source, can keep using this source once the project has started.

Other issues regarded important by part of the respondents are:

- Slow regulation process especially related to 2030 targets.
- Role of existing fossil industries that would like to keep the status quo. This requires clear

and strictly enforceable advanced biofuels targets.

- Social acceptance as advanced biofuels are suffering from conventional biofuels' poor fame. It may explain why so much emphasis has been put by EU Parliamentarians on RFNBOs.

3.4.3. Less critical issues

Part of topics the topics were generally regarded as less critical issue, being simply part of project development. These topics include:

- Feedstock availability in the present (except advanced feedstocks for HEFA/HVO);
- Price and contracting of biomass;
- Feedstock logistics;
- Offtake and offtake price. After the hurdle of project financing has been taken and the facility has been developed, advanced biofuels producers do not expect big problems with offtake or the offtake price of their product. In general, there is a rather high trust that off-take will be guaranteed, especially in the case of SAF.
- Standardisation and permitting issues, although time savings by shorter permitting procedures via Net Zero Industry Act would certainly contribute to quicker deployment of advanced biofuels;
- Finding suitable locations for facilities;
- Employment issues;
- Cooperation between industrial sectors, e.g. agriculture.

More information about these topics can be found in the previous sections.

3.4.4. Recommendations

The question *"what factors are most critical to the capacity development of advanced biofuels"*, as open central question to the 12 respondents, resulted in two main critical risks, namely "regulatory issues" and "access to capital and project risk". This prioritisation corresponds well with the prioritization of topics provided by the advanced biofuels experts prior to the interviews.

The following recommendations were formulated based on the interview results:

- It is recommended to keep the advanced biofuels targets and related legislation constant for a prolonged period.
- It is recommended to limit the freedom of Member States to have their own interpretation of advanced biofuels targets.
- It is recommended to include advanced biofuels as Strategic Net-Zero Technology in the

Net Zero Industry Act.

- Although an open door, it is recommended that by the end of the day the legislative process results in clear legislation and proper procedures.

- It is recommended to support the development of a full-scale reference plant. An IPCEI for advanced biofuels could be a very appropriate tool to support the large deployment of advanced biofuels.

- It is recommended to keep research and technology development funds available for advanced biofuels production technologies.

- For several technologies, the main hurdle is to get a full-scale demonstration plant up and running, to show that commercial production is possible. It is recommended to provide appropriate support in this phase, for instance by the EU Innovation fund.

- It is recommended to further develop the possibilities to utilise intermediate crops and cover crops for advanced biofuels production.

- For advanced biofuels producers it is important to show policy makers and the public the possibilities and opportunities of advanced biofuels.

- It is recommended to include a grandfathering clause for the use of CO2 from fossil sources, meaning that projects that started using a fossil carbon source, can keep using this source once the project has started.

These recommendations based on interviews by the sector have been used as relevant input to chapter 5 : strategic research recommendations.

4. Task 4.3 Capacity development E-fuels

4.1. Introduction

Advanced biofuels and renewable fuels derived from renewable hydrogen and/or renewable electricity (hereafter called: RFNBOs or E-fuels) both contribute to the demand for alternatives to fossil fuels for transport. If one of these fuel categories may contribute less than expected to the overall targeted demand for alternatives to fossil fuels for transport, the other fuel category may be able to compensate this and provide a larger share of total demand. Therefore, insight in the capacity development of renewable fuels capacity, especially within the EU27 is needed and evidence is required to underpin this capacity development.

To estimate the likeliness that the capacities of RFNBOs are really available by 2030 (and 2050) insight in the status of the pipeline of planned renewable fuel production installations is required. How much capacity is still in the planning phase, are the investment decisions already taken, permits obtained, how many plants are already under construction? For reasons of simplification, a distinction will be made between planned capacity at any stage before the investment decision (planned capacity) or after the investment decision (capacity under development). In accordance with the report of Concawe and Aramco8 as well as the report of TNO9, the following renewable fuel pathways are considered in the scope of this subtask:

- **E-hydrogen**, final product for fuel cell electric vehicles and feedstock for other e-fuels.
- **E-kerosene (and E-diesel)**, mainly via Fischer-Tropsch and methanol-to-jet pathways
- **E-methanol**, through electrolysis and electrochemical processes.
- **E-ammonia**, synthesis of E-hydrogen and nitrogen in a Haber-Bosch reactor.
- **E-methane**, produced by methanation of syngas.

Desktop research

As an initial step, an Artificial Intelligence (AI) tool was used to extract relevant information from the web. It served as an exploration step and provided a direction for further research. Databases such as the demo-plant database of BEST[10], the IEA Hydrogen Projects Database[11], the CCU projects database of CO2ValueEurope[12] and the PtX Atlas[13] were accessed in May and June 2023, as well as renewable fuel outlook reports. Identified announced and implemented capacities were collected in a dataset template and subsequently structured in a table for the discussions with industrial stakeholders and the subcontracted renewable fuel experts.

Interviews with industrial stakeholders/sector associations

To complement the collected evidence from the desktop research step and to gain insights of the renewable fuels sector, interviews with industrial stakeholders and sector associations were conducted. A set of guiding questions were developed, and potential stakeholders have been contacted. The following stakeholders have been interviewed:

- E-fuel alliance
- SkyNRG
- Electrochaea
- Hydrogen Europe

The industrial stakeholders and sector associations were requested to verify the list of identified implemented and announced capacities, to share their view on the likelihood of

[8] Alba Soler, et al., E-fuels: A techno-economic assessment of European domestic production and imports towards 2050. Concawe, November 2022.
[9] Karin van Kranenburg, et al., E-fuels: towards a more sustainable future for truck transport, shipping and aviation. TNO, July 2020.
[10] https://demoplants.best-research.eu/
[11] https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database
[12] https://database.co2value.eu/
[13] https://maps.iee.fraunhofer.de/ptx-atlas/

capacity realization, and what conditions must be met for announced capacities to be realised.

Validation by renewable fuel experts

The subcontracted renewable fuel experts were requested to assess the credibility of the collected evidence and elaborated on key issues that could hinder the realisation of the renewable fuels capacities. The following renewable fuel experts were consulted:

- Franziska Müller-Langer (DBFZ)
- Remko Detz (TNO)

Overall, the team met online four times. The initial results were either shared before the meeting or were presented during the meeting, after which each of the experts shared their views on the aforementioned topics.

4.2. Definition, eligibility criteria and targets for RFNBOs

4.2.1. What is an RFNBO?

According to the RED II[14], Article 2 (36) Renewable liquid and gaseous transport fuels of non-biological origin (RFNBO) means “liquid or gaseous fuels which are used in the transport sector[15] other than biofuels or biogas, the energy content of which is derived from renewable sources other than biomass”. In the context of this report, renewable fuels, synthetic fuels, e-fuels, Power-to-liquid (PtL) are all taken as synonyms for RFNBO. Please note that Recycled Carbon Fuels (RCF) are not in the scope of this assessment.

4.2.2. Eligibility criteria for RFNBOs

An important question is which electricity and carbon sources quality for the production of RFNBOs? The basic conditions are set in RED II Article 27 (3). Detailed rules for the production of RFNBOs are found in Delegated regulation 2023/1184[16] and calculation rules for the required GHG emission reduction compared to the fossil comparator of 70% can be found in Delegated regulation 2023/1185[17]. Please note that these detailed rules have been formally adopted only since the 20th of June 2023, and often not fully considered in the plans for capacity development, which are mainly based on 2022 data.

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[14] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast)

[15] According to the proposal for the RED III, found in the Fit for 55 package, this limitation of the use of RFNBOs to the transport sector will be removed. The definition will thus apply to RFNBOs used in all sectors.

[16] Commission Delegated Regulation (EU) 2023/1184 of 10.02.2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin.

[17] 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 greenhouse gas emissions savings of recycled carbon fuels and by specifying a methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin from recycled carbon fuels.

Regarding the use of renewable electricity for RFNBO productions, three cases qualify:

1. Electricity obtained from **direct connection** to an installation generating renewable electricity may be fully counted as renewable electricity, where it is used for the production of RFNBOs, provided that the installation:

- comes into operation not earlier than 36 months before the installation producing the RFNBO. This is the so-called "additionality requirement" avoiding use of existing renewable electricity sources, which would indirectly lead to an increase in fossil-based electricity use in other market segments, and (1) is not connected to the grid or (2) is connected to the grid but evidence can be provided that the electricity concerned has been supplied without taking electricity from the grid.

2. **Average grid electricity** can be used for the production of RFNBOs. In this case the average share of electricity from renewable sources in the country of production, as measured two years before the year in question, shall be used to determine the share of RFNBOs in total production. This option is only attractive if the share of renewable electricity is very high in the respective Member State, or the respective bidding area.

3. **Renewable grid electricity (via PPAs)** may be counted as fully renewable provided that it is produced exclusively from renewable sources and the renewable properties and other appropriate criteria, such as additionality, temporal correlation and geographical correlation criteria have been demonstrated as elaborated in the Delegated Regulation (2023/1184).

RFNBO producers may use national schemes or international voluntary schemes recognised by the European Commission to prove compliance with the rules established in the Delegated Regulations. At the time of writing (August 2023) these schemes are not yet available.

The above description only sketches the main requirements to the renewable electricity to be used for production of RFNBOs. Please refer to the RED II and Delegated Regulation 2023/1184 for the full set of rules[18].

Eligibility criteria CO2 for RFNBOs

Regarding the use of CO2 for the production of RFNBOs, in principle any source can used as long as the emissions saving of at least 70% compared to the fossil fuel comparator (of 94 gCO2-eq/MJ) is met, following the methodology as found in Delegated Regulation 2023/1185, which is summarised in Annex 3. The main outcome of application of this methodology is that in practise CO2 from fossil energy-based electricity plants can be used until 2036, and that CO2 from other EU-ETS companies can be used until 2041. After that date CO2 from bioenergy installations and direct air capture will be the main eligible sources of carbon for RFNBOs.

Installations starting to use fossil CO2 before 2036 or 2041 will have to stop using this fossil CO2 after these dates, as no grandfathering clause is in place. This means that fossil sources

[18] https://ptx-hub.org/delegated-acts-on-art-27-and-28-explained/ gives a more detailed summary of the requirements to the renewable electricity.

can be used only for a short time span. Therefore, we expect that RFNBO projects will mainly be based on CO2 from bioenergy installations or direct air capture.

Please note that, according to the RED III Provisional Agreement, article 27.3 point 6, by 1 July 2028 the Commission will evaluate the impact of above-described rules on the availability and affordability or RFNBOs for industry and transport, and modify the rules if needed to facilitate the ramp up of the hydrogen industry.

4.2.3. Targets and demand for RFNBOs

Starting point for determination of the targets for RFNBOs are the provisional agreements on the RED III, ReFuelEU Aviation and FuelEU Maritime, as known at the time of writing (August 2023). Please note that none of these documents are in force yet. We used the main scenario (FF55_RED)[19] of fuel demand development as provided by E3Modelling (Task 1) to determine the demand created from RED III, ReFuelEU Aviation and FuelEU Maritime.

Targets aviation – ReFuelEU Aviation

Table 4-1 summarises the SAF and synthetic aviation fuels targets as found in the provisional agreement text of the ReFuel EU Aviation Regulation[20].

Year	SAF	Synthetic sub-target (ReFuelEU Aviation provisional agreement) (1)	Total Demand aviation (FF55 RED scenario) (Mtoe) (2)	Demand synthetic aviation fuels (Mtoe) x (2)
2030	6%	1.2%	43.5	0.5
2032	6%	2.0%	43.3 *	0.9*
2035	20%	5%	43.2	2.2
2040	34%	10%	43.8	4.4
2045	42%	15%	44.7	6.7
2050	70%	35%	45.5	15.9

* Interpolation BTG, as FF55 RED scenario only for 5-year periods available.

Table 4-1 SAF and RFNBO targets as found in ReFuelEU Aviation (provisional agreement)

Assuming the total aviation fuel demand as found in the FF55 RED scenario, these targets result in a demand of 0.52 Mtoe in 2030 growing to 15.9 Mtoe in 2050.

[19] See TASK 1

[20] European Parliament 2019-2024 Committee on Transport and Tourism, 16.6.2023, PROVISIONAL AGREEMENT RESULTING FROM INTERINSTITUTIONAL NEGOTIATIONS, Proposal for a regulation of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport (ReFuel EU Aviation (COM(2021) 0561 – C9-0332/2021 – 2021/0205(COD))

Targets maritime sector - FuelEU Maritime

The provisional agreement of FuelEU Maritime[21] introduces GHG intensity reduction requirement for the period 2025 – 2050. The Provisional Agreement Article 4a point 3 states *"if the share of renewable fuels of non-biological origin (…) for reporting period 2031 is less than 1%, a subtarget of 2% for such fuels in the yearly energy used on-board by a ship shall apply from 1 January 2034 (…)"*. Article 4a point 1 states that *"As provided for in Annex I for the calculation of the greenhouse gas intensity of the energy used on-board by a ship from 1 January 2025 to 31 December 2033, a multiplier of "2" can bey used to reward the ship for the used of RFNBOs".* This multiplier impacts the GHG calculation, but not the sub-target as such.

Given the expected energy consumption of 44.4 Mtoe in 2030 (FF55 RED scenario), considering that the double counting is only related to the GHG target of FuelEU Maritime and not to the share of RFNBO in the fuel mix, the effective target of 1% RFNBOs in 2031, would lead to a demand for **0.44 Mtoe RFNBOs** in the maritime sector in 2031.

Please note that this target is not very hard, as article 4a point 5 of the Provisional Agreement of FuelEU Maritime describes that *"if (…) there is evidence of insufficient production capacity and availability in the maritime sector, uneven geographical distribution or too high prices of renewable fuels of non-biological origin, the subtarget [for RFNBOs] shall not apply"*.

Targets road/rail/maritime/aviation - RED III

RED III Provisional agreement[22] Article 25.1 formulates that the combined share of advanced biofuels and biogas produced from the feedstock listed in Part A of Annex IX and of renewable fuels of non-biological origin in the energy supplied to the transport sector is at least 1 % in 2025 and 5,5 % in 2030, of which a share of at least 1% of RFNBOs in 2030 (RED III, Art 25.1).

It is important to realise that - whilst the denominator of the RED III target is based on energy consumed in road and rail transport - this target can be met by supply of energy from renewable sources to all transport modes, i.e. including the maritime sector, international marine bunkers, and aviation (RED III, Art 27.2(b)). Supply to maritime sector is promoted, as RED III Article 25 states that Member States with maritime ports shall endeavour to ensure that as of 2030 the share of renewable fuels of non-biological origin in the total amount of energy supplied to the maritime sector is at least 1.2%.

RFNBOs (like advanced biofuels) are counted twice towards the transport targets. Moreover, RFNBOs supplied to the maritime and aviation sectors shall be considered to be 1.5 times their energy content (advanced biofuels a factor 1.2) (RED III, Art 27.2 (c) and (i)).

[21] European Parliament, 2019-2024, Committee on Transport and Tourism, 26.4.2023, PROVISIONAL AGREEMENT RESULTING FROM INTERINSTITUTIONALNEGOTIATIONS, Subject: 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 (COM(2021)0562 – C9-0333/2021 – 2021/0210(COD))

[22] https://www.consilium.europa.eu/en/press/press-releases/2023/03/30/council-and-parliament-reach-provisional-deal-on-renewable-energy-directive/

The transport sector, consisting of road and rail transport in the RED III has a total estimated fuel demand of 225 Mtoe in 2030 (FF55 RED scenario)[23]. Taking into account the target of 1% and the double counting of RFNBOs, it means that the RED III generates a demand of 1.12 Mtoe to be supplied to road and rail transport, <u>or</u> 0.75 Mtoe of RFNBOs to be supplied to aviation and maritime sectors (taking into account the multipliers of 1.5).

The RFNBOs needed to meet the targets for aviation as formulated in ReFuelEU Aviation, can at the same time be used to meet the RED III targets. Therefore, if sufficient RFNBOs are supplied to meet the 1.2% synthetic sub-target for ReFuelAviation (0.52 Mtoe) in 2030, only 0.75 minus 0.52 is 0.23 Mtoe of RBNBOs have to be supplied to the Maritime sector or 0.34 Mtoe to the road sector.

Fuel EU Maritime creates an effective demand of 0.44 Mtoe RFNBOs in the maritime sector in 2031 (or 0.88 Mtoe in 2034), meaning that the RED III RFNBO target for transport can be fully met by supply of RFNBOs to maritime and aviation sectors. It also means that - at least <u>at EU level - there is no need to introduce RFNBOs in road or rail transport, to meet the RED III RFNBO target for transport</u>.

Targets RFNBOs in industry – RED III

Next to the use of RFNBOs in the transport sector, the RED III provisional agreement creates demand for RFNBOs, mainly hydrogen in the industry. RED III article 22a states that *"Member states shall ensure that the contribution of renewable fuels of non-biological origin used for final energy and non-energy purposes shall be at least 42% of the hydrogen used for final energy and non-energy purposes in industry by 2030 and 60% by 2035"* Excluded from this target are hydrogen for production of conventional transport fuels, biofuels; hydrogen that is produced by decarbonizing industrial gases and hydrogen produced as a by-product. Article 22b provides specific conditions under which the targets can be reduced by 20%, resulting in RFNBO targets in industry of 33.6% in 2030 and 48% in 2035.

	Total hydrogen demand*	Included in industry target RFNBOs	Total demand under RED III target	2030 (33.6%)	2030 (42%)	2035 (48%)	2035 (60%)
	Mtoe	%	Mtoe	Mtoe	Mtoe	Mtoe	Mtoe
Refining	12.5	0%	0.0	0.0	0.0	0.0	0.0
Ammonia	7.3	100%	7.3	2.4	3.1	3.5	4.4
Methanol and other chemicals	3.1	100%	3.1	1.0	1.3	1.5	1.9
Other	1.1	100%	1.1	0.4	0.5	0.5	0.7
Energy[2)]	0.9	0%	0.0	0.0	0.0	0.0	0.0
Transport sector	0.004	0%	0.0	0.0	0.0	0.0	0.0

[23] Source:TASK 1
Road: 214.5 Mtoe; rail and inland naviation: 10.4 Mtoe; Rail and inland naviation are not provided as separate numbers. Therefore, we have combined road, rail and inland navigation to 225 Mtoe, leading to a slight overestimation as inland navigation is included.

	Total hydrogen demand*	Included in industry target RFNBOs	Total demand under RED III target	2030 (33.6%)	2030 (42%)	2035 (48%)	2035 (60%)
Total	**25.0**		**11.5**	**3.9**	**4.8**	**5.5**	**6.9**

1) Source: Hydrogen Europe (2022), data of the year 2020; [2)] Hydrogen burned for its energy content, mostly produced as by-product from ethylene, styrene, chlorine, or sodium chlorate production.

Table 4 2 First order of magnitude estimation of the amount of hydrogen needed to meet the RED III Article 22a targets for hydrogen in the industry

The total demand for hydrogen in 2020 has been estimated at 8.7 million tonnes (Hydrogen Europe 2023)24, which equals 25 Mtoe. Table 4-2 shows the distribution of this demand by the different sectors as reported by Hydrogen Europe (2022), and our estimation of the share of this hydrogen demand that will fall under the RED III target for industrial RFNBOs. Given that refineries mainly produce transport fuels, and that the hydrogen as results of processes is excluded, we assume the hydrogen demand in refineries is excluded from the target for industrial RFNBOs. The last four columns show our first order of magnitude estimation of the demand for RFNBOs, being 3.9 – 4.8 Mtoe in 2030 and 5.5 – 6.9 Mtoe in 2035. This is a considerable demand compared to the demand for RFNBOs for transport.

Summary

The demand for RFNBOs in the different sectors is summarised in Table 4-3. This demand will be used for comparison with the expected RFNBO production capacities development for the transport sector. The total demand for RFNBOs in 2030 is at least 0.98 Mtoe, which could most efficiently be met by 0.54 Mtoe RFNBOs in aviation and 0.44 Mtoe in shipping, meeting the targets of ReFuelEU Aviation, FuelEU Maritime and the RED III (all based on the provisional agreement texts). The RED III targets for industry are presented as well as these targets are relevant in the evaluation of capacities, as RFNBOs production capacity can be used either for e-fuels or chemicals production.

Legislation		ReFuel EU Aviation	FuelEU Maritime	RED III	RED III
Basis for target		Aviation	Shipping	Road and rail[a)]	H2 in industry[d)]
Total fuel consumption 2030	Mtoe	43.5	44.4	225	11.5
RFNBO target 2030	%	1.20%	1%	1%	33.6% - 42%
Multiple counting	factor	1	1	2 to 3[b)]	1

[24] Hydrogen Europe (2022) Clean hydrogen monitor 2022 https://hydrogeneurope.eu/wp-content/uploads/2022/10/Clean_Hydrogen_Monitor_10-2022_DIGITAL.pdf

Legislation		ReFuel EU Aviation	FuelEU Maritime	RED III	RED III
Effective RFNBO demand	Mtoe	0.52	0.44	0.75 – 1.12	3.9 – 4.8
Demand can be met by		RFNBOs for aviation	RFNBOs for shipping	RFNBOs for all transport modes	RFNBOs in industry (non-transport)
Net demand	Mtoe	0.52	0.44	0[c] – 1.12	3.9 – 4.8

a) Inland navigation also included in this figure. [b] Next to double counting for all RFNBO, another factor 1.5 shall be applied if RFNBOs are supplied to maritime or aviation sectors. [c] The RED III RFNBO target is already met if ReFuel EU Aviation and Fuel EU maritime targets are met. [d] See Table 4-2.

Table 4-3 Summary of RFNBO demand in 2030 as a result of the provisionally agreed ReFuelEU Aviation, FuelEU Maritime and RED III legislation

At this moment only the ReFuelEU Aviation creates a substantial demand for RFNBOs in transport beyond 2030, increasing to 15.9 Mtoe in 2050. The RED III is focused on 2030 targets, and FuelEU Maritime provisional agreement promotes RFNBO from 2034 on with a target of 2% RFNBOs that does not increase further.

4.3. Capacity outlook for 2030

This section analyses the pipeline of e-fuel projects as found in the different databases (IEA, Hydrogen Europe) and other public sources, focussing on:

- E-hydrogen (§4.4.1)
- E-kerosene (§ 4.4.2)
- E-methanol (§ 4.4.3)
- E-ammonia (§ 4.4.3)
- E-methane (§ 4.4.5)

In section 4.5 technology specific considerations are provided (status and TRL) and a comparison is made between the pipeline of project and the demand arising from the 2030 EU targets for RFNBOs.

4.3.1. E-hydrogen

Renewable hydrogen can be directly applied as transport fuel and in the industry, is the key energy carrier for the production of more complex RFNBOs (E-kerosene, E-methanol, E-ammonia, E-methane) and also used for the production of several types of advanced biofuels (such as upgraded pyrolysis oil, gasification and FT). Therefore, in this section we give an impression of the total planned and implemented capacity of renewable hydrogen projects, followed by a specific overview of hydrogen projects aiming direct end use in transport.

While Power-to-Hydrogen (PtH) technology has been available and utilized for decades, it is only now emerging as a future technology for large-scale hydrogen production. By August 2022, Hydrogen Europe[25] identified 143 PtH sites in operation in the EU, EFTA[26], and the UK amounting to 162 MW_{el} or 29 kt/year of capacity. So far, they are a marginal part of the market constituting only 0.25% of the total installed European hydrogen production capacity of 11.5 Mt in 2020.

Total hydrogen projects according to Hydrogen Europe

As shown in Figure 4-3, according to Hydrogen Europe, in Europe there are 379 Power-to-Hydrogen projects in various stages of development totalling 31,170 MW by 2025, 628 PtH projects with announced start dates amounting to 138,554 MW by 2030, growing to 191,364 MW of electrolyser installed power by 2040 (i.e., 644 projects), and an extra 2,233 MW (i.e., 41 projects) with an unspecified start date.

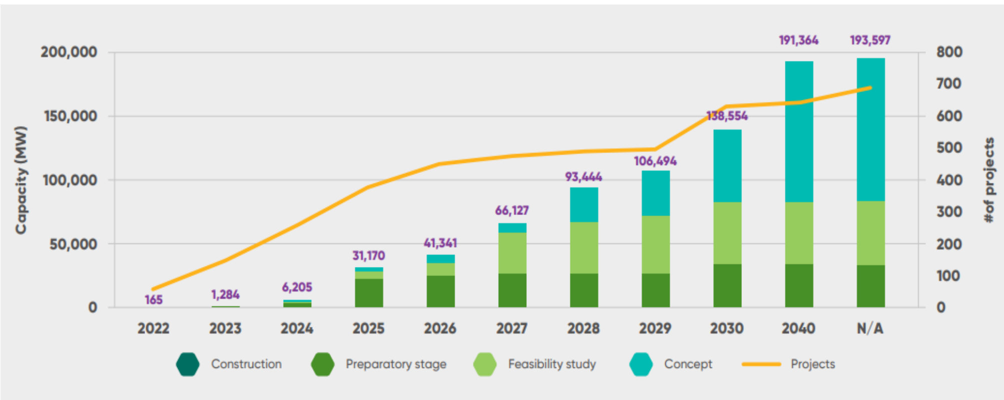

Figure 4-2 Cumulative planned PtH projects from 2022 to 2040 in MW and number of projects. Source: Hydrogen Europe[5]

The average expected project size in 2023 is 13 MW and is expected to increase to 44 MW in 2024 and 205 MW in 2025. When all these projects come to fruition, it would result in the average project size increasing almost 16 times within two years. The average yearly addition between 2026 and 2030 is 21,477 MW of PtH capacity with the largest expected additions planned for 2028 and 2030. The total PtH capacity over this period is divided over 248 projects, which converts to an average of 432 MW per project. The average project size differs significantly between the years. In 2026, the 10,171 MW is divided between 71 projects, which converts to an average of 143 MW per project. In 2028, the 27,317 MW of additional capacity derives from only 17 new projects, averaging 1,607 MW per project. These results suggest that project developers will increase their ambitions to build multi-GW projects in the second half of the decade. According to Hydrogen Europe, many of these projects will be expansions of existing installations.

[25] Clean Hydrogen Monitor 2022, Hydrogen Europe.
[26] Iceland, Liechtenstein, Norway and Switzerland.

The project pipeline of hydrogen production projects keeps steadily growing until 2030, showing a combined PtH capacity of 138.5 GW_{el}, which amounts to approximately 10 Mt of e-hydrogen. Out of the total announced capacity, approximately 32 GW is either under construction or is in preparatory stage and 106 GW undergoes a feasibility study or is in concept phase. Here, concept indicates that companies have announced their consideration for electrolyser project development. Feasibility study stage is somewhat more concrete than concept and includes those projects that undergo, for instance, a techno-economic assessment. Projects in preparatory stage include those that have received a final investment decision or are prior to a final investment decision (i.e., somewhere in the front-end loading or front-end engineering design stage). Therefore, any project that is at least before the preparatory stage could still significantly change, or even be cancelled. In fact, the capacity projections by Hydrogen Europe were determined in 2022, without considering the requirements on the sourcing of hydrogen and CO2 as set in commission delegated regulations 2023/1184[27] and 2023/1185[28]. It is expected that most project developers will undertake a reassessment to see if their projects can meet the new requirements as set in the above-mentioned delegated regulations. It is currently uncertain what share of these projects will meet these requirements.

Total hydrogen project according to IEA database of hydrogen projects

The hydrogen projects database of the IEA (International Energy Agency)[29] has also been consulted which covers all hydrogen projects commissioned worldwide since 2000, as well as projects that are in planning or construction phase. It is an open-source database that reports on project specific capacities, their status, and anticipated end-use. The IEA database allocates, where possible, the hydrogen product to one or more of the following end-uses: 1) Refining, 2) Ammonia, 3) Methanol, 4) Iron & Steel, 5) Other Industry, 6) Mobility, 7) Power, 8) Grid injection, 9) CHP, 10) Domestic heat, 11) Biofuels, 12) Synfuels, 13) CH4 grid injection, and 14) CH4 mobility. Data regarding hydrogen capacities was collected for mobility, ammonia, methanol, synfuels and CH4 mobility, and was constrained to EU-27 only. Considering all 14 end-uses, IEA reports on a total normalised capacity of 102 GW_{el}, which is 36.5 GW_{el} less compared to data from Hydrogen Europe. Such discrepancy may be the result of an information gap as Hydrogen Europe has access to confidential data from its members, as well as existing data gaps in the IEA hydrogen projects database. Regarding the selected end-uses, IEA reports on a total normalised capacity of 27.5 GW_{el} and constitutes a quarter of the overall hydrogen production capacity in EU-27. The total group of projects that indicated mobility as end use has a normalised capacity of 15.6 GW, covering 15% of all planned, under development and implemented capacity.

Figure 4-3 and Table 4-4 show the hydrogen production capacity in relation to their status and intended end-use. Direct use of hydrogen for mobility (i.e., road, off-road, rail, maritime, or aviation) is the leading end-use category with 7.65 Mtoe/year (or 2,671 kton/year), of which 7.5 Mtoe concerns projects in “concept or feasibility study” stage. Evidently, hydrogen for ammonia production seems to be almost exclusively intended as chemical feedstock (i.e., for

[27] Commission Delegated Regulation (EU(2023/1184) supplementing Directive (EU) 2018/2021 of the European Parliament and of the Council by establishing a Union methodology setting out rules for the production of renewable liquid and gaseous transport fuels of non-biological origin.
[28] Commission Delegated Regulation (EU) 2023/1185 supplementing Directive (EU) 2018/2021 of the European Parliament and of the Council by establishing a minimum threshold for greenhouse gas emissions savings of recycled carbon fuels and by specifying a methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin and from recycles carbon fuels.
[29] https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database

fertilizer production) instead of fuel for mobility, and is the second leading end-use category with 4.64 Mtoe/year (or 1.618 kton/year) of hydrogen production capacity. Despite of it being the second leading end-use- category, hydrogen for methanol projects are more advanced compared to ammonia as most projects are at the concept or feasibility stage.

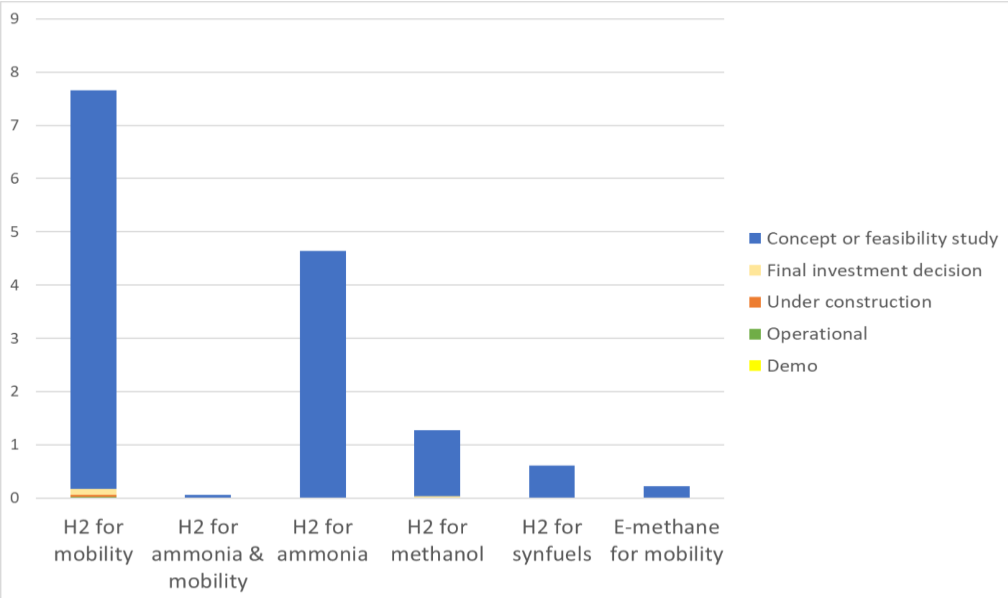

Figure 4-3 Hydrogen production capacity in Mtoe/year per intended end-use

In ktoe/year	H2 for mobility	H2 for ammonia & mobility	H2 for ammonia	H2 for methanol	H2 for synfuels	E-methane for mobility
Demo	4	0	0	2	0	0
Operational	22	0	10	1	1	3
Under construction	32	0	0	6	10	0
Final investment decision	115	0	5	27	0	0
Concept or feasibility study	7485	59	4623	1243	600	218
Total	**7657**	**59**	**4638**	**1279**	**610**	**221**

Table 4-4 Capacities found for various hydrogen applications as found in IEA database (in ktoe/year)

Direct use of hydrogen for mobility

The hydrogen for mobility capacity, as implemented, under development and planned is presented in Table 4-5. A complete overview of hydrogen projects anticipated for direct use in mobility is given in Annex 4. Obviously, more than 97% of the capacity is planned, meaning a concept or in feasibility study phase.

	MW capacity	ktonnes H2	ktoe
Implemented	56	9	25
Capacity under development	309	51	146
Planned capacity	13817	2612	7485
Total	**14182**	**2671**	**7657**

Table 4-5 Capacities of hydrogen for mobility as found in IEA database (in ktoe/year)

4.3.2. E-kerosene

As with most e-fuels, renewable energy, water and carbon dioxide (CO_2) are the main constituents for the production of E-kerosene. E-kerosene can be synthesized via two main production pathways, namely the Fischer-Tropsch (FT) pathway and the methanol (also referred to as methanol-to-jet) pathway. Both pathways require the input of a synthesis gas or “syngas” that primarily consists of a mixture of carbon monoxide and hydrogen. Syngas can be produced by means of the reverse water gas shift (RWGS) process or via co-electrolysis (SOEC). Co-electrolysis is a more efficient process due to heat recovery and integration with the FT synthesis step.

The FT pathway to synthetic jet fuel is already used in Gas-to-liquid, Coal-to-Liquid and Biomass-to-Liquid (BtL) processes, in which the syngas is produced via gasification of biomass or coal and subsequent RWGS. The product, FT-crude, requires upgrading to jet fuel and other hydrocarbons via hydrocracking, isomerization, and distillation. Currently, FT synthetic paraffinic kerosene is ASTM approved up to 50% jet fuel blends.

An alternative pathway to produce e-kerosene is via the intermediate product methanol. The process converts methanol to olefins and olefins to distillates. The pathway builds on industrially proven processes already used for decades in various large-scale applications, such as natural gas reforming and synthesis to methanol (e.g., methanol-to-gasoline). E-kerosene derived via the methanol pathway still requires approval for use in commercial aviation according to ASTM D7566.

Table 4-6 depicts a list of existing and announced e-kerosene production facilities, mainly using the FT, and some the methanol-to-jet pathway. As of today, two pilot-scale (i.e., TRL 5-6) e-kerosene production facilities have been implemented, both using the FT pathway, having a combined production capacity of 550 ton/year (or 0.56 ktoe/year). In addition, six facilities are under development with a combined capacity of 61,333 ton/year (or 62.7 ktoe/year). Two out of these six facilities (i.e., Caphenia and Synhelion) are scaling-up novel technologies developed from previous European funded projects. Large-scale demonstration facilities are planned from 2026 and beyond with Spark e-Fuels as one of the largest facilities planned for 2030 (see Figure 4-4). In total, 1.1 Mt/year (or 1.13 Mtoe/year) of additional e-kerosene capacity is in the planning phase. Noticeably, the majority of the announced facilities will use the FT-synthesis pathway and will ramp up significantly with some large-scale projects announced, reaching commercial-scale before 2030. Although the MtJ pathway’s separate parts are, for the most part, mature technologies, they have not yet been combined to produce e-kerosene and have not been ASTM approved yet. Based on our findings of implemented and announced facilities, a total sum of 1.17 Mt (or 1.19 Mtoe) per year of implemented and planned e-kerosene capacity has been identified in 2030.

E-kerosene	Capacity			
Company/Project	**tonnes/year**	**PJ/year**	**ktoe/year**	**Start-up year**
Implemented				
Atmosfair (DE, Werlte)	350	0.01	0.357	2021
P2X-Europe (NextGate)	200	0.01	0.204	2022
Total implemented	**550**	**0.023**	**0.56**	
Capacity under development				
Caphenia (EnZaH2 project)**	1,080	0.05	1.1	2025
Ineratec (DE, Frankfurt)	10,000	0.43	10.2	2024
Nordic Electrofuel (E-fuel1)	8,000	0.34	8.18	2025
Norsk E-fuel (Alpha Plant)	40,000	1.71	40.9	2026
Repsol	2,133	0.09	2.18	2024
Synhelion**	120	0.01	0.12	2024
Total under development	**61,333**	**2.63**	**62.7**	
Planned capacity				
Arcadia eFuels	66,000	2.82	67.47	2026
CAC synfuel (KEROSyN100)*	550	0.02	0.56	2030
Concrete Chemicals (CEMEX)	35,000	1.50	35.78	n/k
HyKero	50,000	2.14	51.11	2026
Nordic Electrofuel (E-fuel2)	150,000	6.42	153.34	2030
Norsk E-fuel	160,000	6.85	163.56	2030
P2X-Europe	80,000	3.42	81.78	2026
PtX-Lab Lausitz	10,000	0.43	10.22	n/k
Reuze Project (Engie/Infinium)	100,000	4.28	102.23	2026
SAS/Vattenfall**	50,000	2.14	51.11	2027
SkyFuelH2 (Uniper)	80,000	3.42	81.78	2028
SkyNRG (Synkero)	50,000	2.14	51.11	2027
SkyNRG/SCHWENK Zement	50,000	2.14	51.11	2028
Spark e-Fuels	222,000	9.50	226.94	2030
Synhelion**	1,000	0.04	1.02	2026

E-kerosene	Capacity			
Company/Project	**tonnes/year**	**PJ/year**	**ktoe/year**	**Start-up year**
Zenid	280	0.01	0.29	n/k
Total planned	**1,104,830**	**47.29**	**1,129.42**	
Grand total	**1,166,713**	**49.94**	**1,192.68**	

* Methanol-to-Kerosene project, ** Novel pathways

Table 4-6 Capacity development of existing and announced (mainly FT-based) e-kerosene, projects

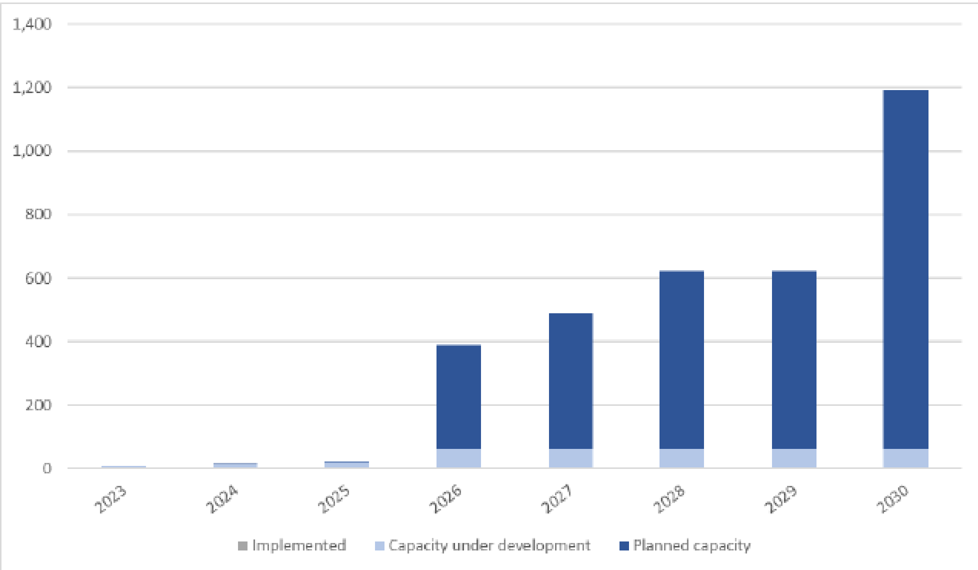

Figure 4-4 Cumulated evolution of e-kerosene production capacities (ktoe/year)

4.3.3. E-methanol

There are a number of pathways to produce e-methanol through electrochemical processes. E-methanol can be produced from CO_2 in either one or two steps. In the conventional two step approach, CO_2 is converted to CO by using the reverse water gas shift reaction, followed by hydrogenation of CO into methanol. In the one step approach, these two reactions take place simultaneously with direct methanol synthesis. This pathway is able to achieve a higher conversion efficiency, however, is less developed compared to “conventional” methanol synthesis.

In principle, methanol synthesis is a commercially proven process. The first methanol synthesis plant, using syngas made from coal, was commissioned in 1923 in Leuna, Germany. For the hydrogenation of CO_2 to e-methanol, catalysts are commercially available. Alternative concepts to produce conventional syngas are in an early development phase and include direct electrochemical reduction of CO_2 and electrocatalytic co-reduction of CO_2 to

CO and water to hydrogen. The current TRL of this pathway is relatively low (TRL 5-6). Sunfire will demonstrate this concept at 1 MW in a running FCHUU project “MegaSyn”.

Table 4-7 depicts a list of existing and announced e-methanol production facilities. Currently, three small-scale facilities have been implemented with a combined capacity of 4,930 ton/year (or 2.59 ktoe/year). Carbon Recycling International in Iceland already started production in 2012 using almost exclusively decarbonized electricity from the grid and CO_2 captured in a geothermal power plant. An additional 157.9 kton/year of e-methanol capacity is under development and is expected to start up in the near term. Technology scale-up to large-scale demonstration and/or commercial scale is expected from 2025 onwards and are currently in the planning phase, with a total of 1.27 Mt/year (or 666.2 ktoe/year) production capacity (see Figure 4-5). Based on our findings of implemented and announced facilities, a total of 1.43 Mt (or 751.8 ktoe) per year of e-methanol capacity has been identified for 2030.

E-methanol	Capacity			
Company/Project	ton/year	PJ/year	ktoe/year	Start-up year
Implemented				
Carbon Recycling International (CRIO) and HS Orka (Island)	4,000	0.09	2.1	2012
FReSMe Project	333[a)]	0.01	0.17	2019
MefCO2	333[a)]	0.01	0.17	2019
Power2Met	263.7	0.006	0.14	2020
Total implemented	**4,930**	**0.11**	**2.59**	
Capacity under development				
European Energy (Aabenraa)	32,000	0.70	16.8	2023
GreenLab	7,910	0.17	4.16	2022
North-C-Methanol project	44,000	0.97	23.12	2024
Orsted	50,000	1.10	26.27	2025
Power to Methanol BV (ENGIE/port of Antwerp)	8,000	0.18	4.2	2023
Reintegrate ApS	10,000	0.22	5.25	2023
ZASt	6,000	0.13	3.15	2023
Total under development	**157,910**	**3.47**	**82.97**	
Planned capacity				
CRI	100,000	2.20	52.55	2025
Dow	200,000	4.40	105.1	2027
e-CO2Met project	500	0.01	0.26	2022
GEG/Proman (Cromarty Clean Fuels Project)	20,000	0.44	10.51	2026
HyNetherlands	15,000	0.33	7.88	2026
Hynovi project	200,000	4.40	105.1	2025
Iberdrola	10,000	0.22	5.25	2026
ICODOS	3,000	0.07	1.58	2024
Jangada project (Hy2Gen)	61,000	1.34	32.1	2026
Liquid wind	100,000	2.20	52.55	n/k
Liquid wind (FlagshipTWO)	130,000	2.86	68.31	2026
RHYME project (Wacker)	15,000	0.33	7.88	2024

E-methanol	Capacity			
Company/Project	ton/year	PJ/year	ktoe/year	Start-up year
Swiss Liquid Future	80,000	1.76	42	n/k
Westkuste100	333,333	7.33	175.15	n/k
Total planned	**1,267,833**	**27.89**	**666.2**	
Grand total	**1,430,410**	**31.47**	**751.76**	

a) FReSMe and MefCO2 are two different projects using the same facility.

Table 4-7 Capacity development of E-methanol, based on announced projects.

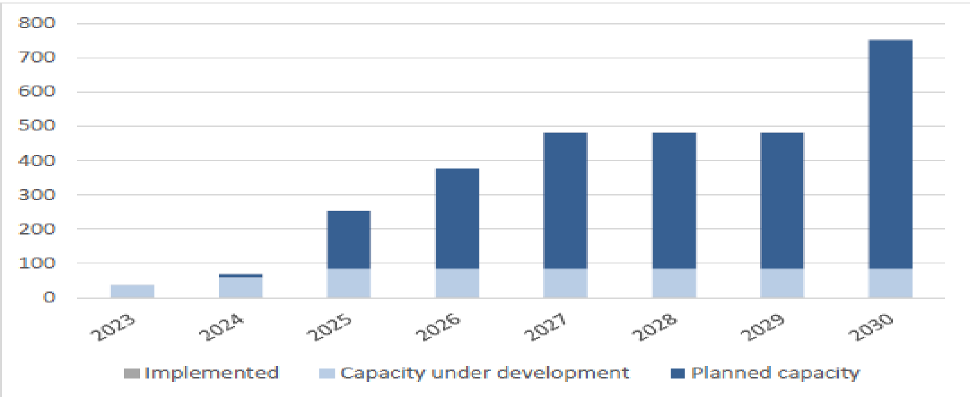

Figure 4-5 Cumulated evolution of e-methanol production capacities (ktoe/year).

4.3.4. E-ammonia

Ammonia is synthesized from nitrogen and hydrogen. The best available source of nitrogen is air, while hydrogen is mostly derived from fossil fuels either via steam methane reforming or partial oxidation, depending on the fossil feedstock in use, e.g., natural gas or coal. By far, the most common method to obtain hydrogen for ammonia production, especially in the EU, is via steam reforming of natural gas. Nitrogen and hydrogen are synthesized to ammonia in the Haber-Bosch reaction, which is a process already used for decades to produce fertilizers.

The main pathway for e-ammonia is to produce e-hydrogen through water electrolysis and then use the e-hydrogen as feedstock to the existing Haber-Bosch synthesis loop described above. The use of e-hydrogen for ammonia production is not new. As early as 1920, renewable ammonia has been produced with electricity from hydropower. In 1930, renewable ammonia accounted for around one-third of the global ammonia production. Yet, most electrolysis-based ammonia plants were abandoned when cheap natural gas became abundantly available. Currently, only one commercial renewable ammonia plant is in operation. Operating since 1965, the Cusco plant in Peru produces less than 0.02 Mt of ammonia annually as feedstock for ammonium nitrate.

In the last few years, numerous new renewable ammonia projects have been announced, with the majority to be constructed and operated in Australia. Approximately half of the projects listed in Table 4-8 are revamps of existing fossil-based plants, while the other half are new, greenfield projects (greenfield projects are indicated with an *). One revamp project is currently implemented in Puertollano at one of Fertiberia's existing fertilizer production sites. Fertiberia has further plans to expand their capacity at Puertollano (i.e., Puertollano II) and replicate this at its Palos de la Frontera site. The greenfield renewable ammonia projects appear at commercial scale from 2025 onwards (see Figure 4-6). This year, in 2023, the first greenfield plant is expected to start operations in Western Jutland, Denmark. Based on our findings of implemented and announced facilities, a total of 2 Mt (or 38.35 PJ) per year of e-ammonia capacity has been identified for 2030.

E-ammonia	Capacity			
Company/Project	ton/year	PJ/ year	ktoe/ year	Start-up year
Implemented				
Puertollano (Fertiberia, Iberdroal)	4,000	0.07	1.78	2021
Total implemented	**4,000**	**0.07**	**1.78**	
Capacity under development				
Haldor Topsoe/Aquamarine*	300	0.005	0.13	2024
Heroya plant (Yara)	20,500	0.38	9.11	2023
North Ammonia*	100,000	1.86	44.42	2027
Palos de la Frontera	61,000	1.13	27.1	2023
Western Jutland plant*	5,000	0.09	2.22	2023
Yara/Orsted	75,000	1.39	33.32	2025
Total under development	**261,800**	**4.86**	**116.3**	
Planned capacity				
Catalina project (phase 1*)	200,000	3.72	88.85	n/k
First Ammonia/Haldor Topsoe*	500,000	9.3	222.13	2025
Iverson eFuels AS*	200,000	3.72	88.85	2027
Maersk/CIP*	650,000	12,09	288.76	2026
Palos de la Frontera II	99,000	1.84	44	2027
Puertollano II	56,000	1.01	24.88	2025
Varanger Kraft*	91,000	1.69	40.43	2024
Total planned	**1,796,000**	**33.4**	**797.88**	
Grand total	**2,061,800**	**38.35**	**915.96**	

* Greenfield facilities

Table 4-8 Capacity development of E-ammonia, based on announced projects.

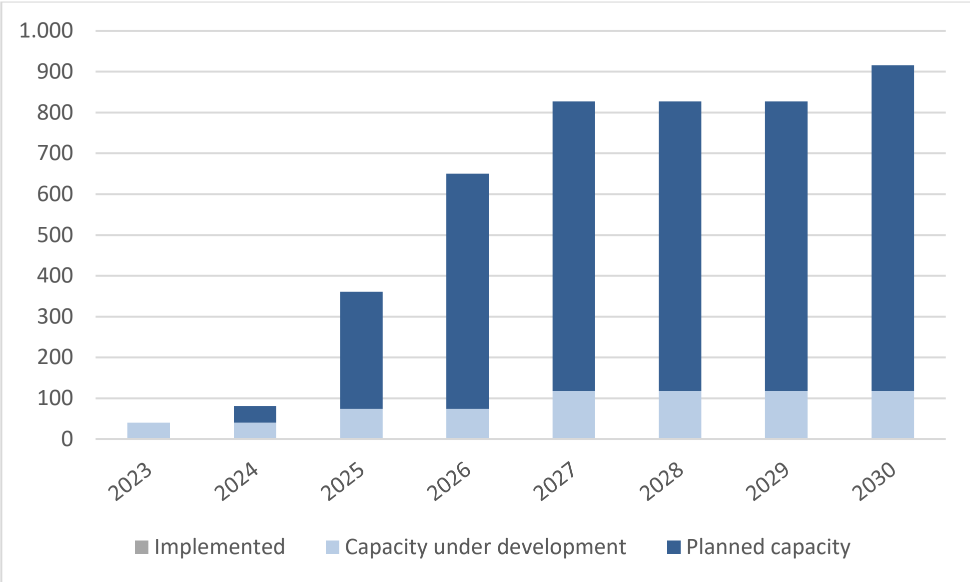

Figure 4-6 Cumulated evolution of e-ammonia production capacities (ktoe/year).

4.3.5. E-methane

Methane (CH_4) in the form of natural gas is one of the most important energy vectors of our society, which is used to produce heat and electricity as well as value-added chemicals. E-methane can be produced by combining water electrolysis for H_2 production with methanation process in a two-step approach. In the first step, H_2 is produced using renewable energy, such as solar and wind power. In the second step, CO_2 is hydrogenated in a methanation process to produce methane. Reactors that can carry out methanation can be divided into two groups, namely catalytic and biological reactors and can be realised as hybrid reactors that allow using biogas including the Co2 to increase the methane yield and thus avoiding the additional efforts for CO2 capture before. In catalytic reactors, thermochemical conversion takes place, assisted by catalysis to improve the kinetics of the process. This procedure is known as the Sabatier process. In biological-type reactors, the fundamental idea is very different from the catalytic process. In this case, catalysis is carried out by microorganisms. The microorganisms used are the autotrophic hydrogenotrophic methanogens (Archaeal bacteria), already known to be used in the methanogenic phase of the anaerobic digestion for the production of biogas.

A total of 87 e-methane projects/production facilities have been identified that are currently implemented.[30] As far as power-to-gas is concerned, it can be said that there is still substantial room for improvement. In fact, there is not yet the confidence regarding the technical-economic feasibility required to establish projects on a large-scale. Apart from a few cases, most projects have a size that is less than 1 MW of electrolyser capacity. The vast majority of methanation reactors are catalytic, but the presence of biological reactors is not

[30] Andrea Barbaresi, et al., Review on the Status of the Research on Power-to-Gas Experimental Activities. Energies, 2022.

negligible. Table 4-9 depicts a list of those existing and announced e-methane production facilities with an electrolyser capacity of greater or equal to 1 MW[31]

E-methane	Capacity		
Company/Project	Million m^3/year	ktoe/year	Start-up year
Implemented			
Werlte plant, Atmosfair (former Audi e-gas project)	1.17	1.0	2014
Jupiter 1000	0.47	0.4	2023
Electrochaea (BioCat project)	0.47	0.4	2016
HyCAUNAIS project	0.47	0.4	2019
PFI Germany	0.44	0.38	2016
Store&Go (Germany)	0.47	0.4	2018
Store&Go (Italy)	0.47	0.4	2017
Infitnity 1	0.62	0.53	2020
Methfuel	0.47	0.4	2020
Swisspower	1.05	0.9	2018
Total implemented	**6.1**	**5.2**	
Capacity under development			
Amprion/OGE	50.3	43	2023
Total under development	**50.3**	**43**	
Planned capacity			
Element Eins	50.3	43	2030
Columbus project	38.6	33	2025
Luebesse-energie	1.6	1.4	2025
Power to Gas Hungary Kft.	4.7	4	n/k
Biocat Roslev	4.7	4	n/k
Total planned	**99.9**	**85.4**	
Grand total	**156.3**	**133.6**	

Table 4-9 Capacity development of E-methane, based on announced projects ≥ 1MW electrolyser capacity

[31] For the conversion to ktoe and MCM/year, it is assumed that 22 MWh of electricity is required per tonne product, given an input of 0.5 kg of hydrogen per kg of product and an electrolysis efficiency of 68% (assumed efficiency in 2030). Full-load hours (i.e., 8000 hours/year) for the electrolyser is assumed.

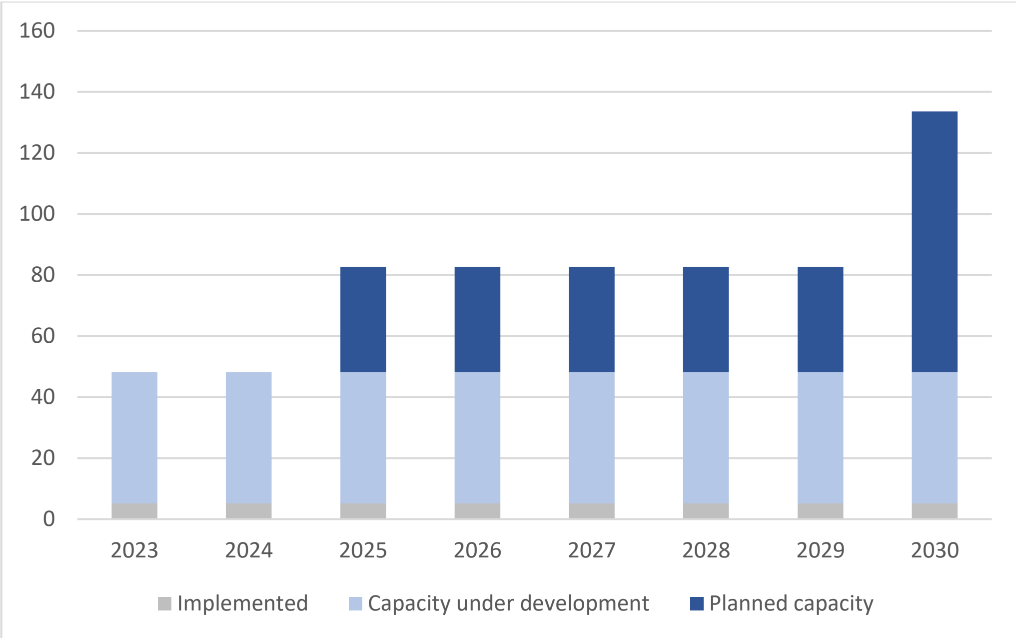

Figure 4-7 Cumulated evolution of e-methane production capacities (ktoe/year).

Currently, 10 facilities with an electrolyser capacity ≥ 1 MW have been implemented with a combined capacity of 6.1 mcm/year (or 5.2 ktoe/year). Of these 10 facilities, the Audi -gas facility is the largest and was already implemented in 2014. Only one facility is under development, with a few other projects in the pipeline. Based on our findings of implemented and announced facilities, a total of 156.3 million m^3 (or 133.6 ktoe) per year of e-methane capacity is identified for 2030.

4.3.6. Other projects

A few projects have been identified that report on the production of no specific or multiple fuels, and therefore, cannot be categorized in any of the above-mentioned fuels. These projects have been referred to as PtL (Power-to-Liquid) and are shown in Table 4-10.

PtL	Capacity				
Company/Project	ton/year	PJ/year	m3/year	Start-up year	Reported fuels
Sunfire	60	0,003	75	2014	e-diesel & e-gasoline
P2X project (Energy Lab 2.0)	0,16	0,00001	0,20	2022	not specified
Green Fuels for Denmark	275.000	11,77	343.750	2030	e-methanol & e-kerosene

Table 4-10 Capacity development of other identified PtL fuels, based on announced projects

4.3.7. Conclusions

The capacity development of all e-fuels has been determined by literature analysis and was scrutinized by the renewable fuel experts and interviews with industrial stakeholders. The capacities of hydrogen for mobility as end use have been directly taken from the IEA database without detailed screening. An overview of the total capacity for e-fuels, is summarized in Table 4-11 (including E-hydrogen for mobility) and visualized in Figure 4-8 (excluding E-hydrogen for mobility).

Capacity e-fuels	e-H2 for mobility	e-kerosene	e-methanol	e-ammonia	e-methane	Total
Implemented	0.025	0.001	0.003	0.002	0.005	0.04
Under development	0.146	0.063	0.083	0.116	0.043	0.45
Planned	7.485	1.129	0.666	0.798	0.085	10.16
Total capacity	**7.657**	**1.193**	**0.752**	**0.916**	**0.134**	**10.65**

Table 4-11 Capacity development of all assessed e-fuels for 2030, based on announced projects (in Mtoe)

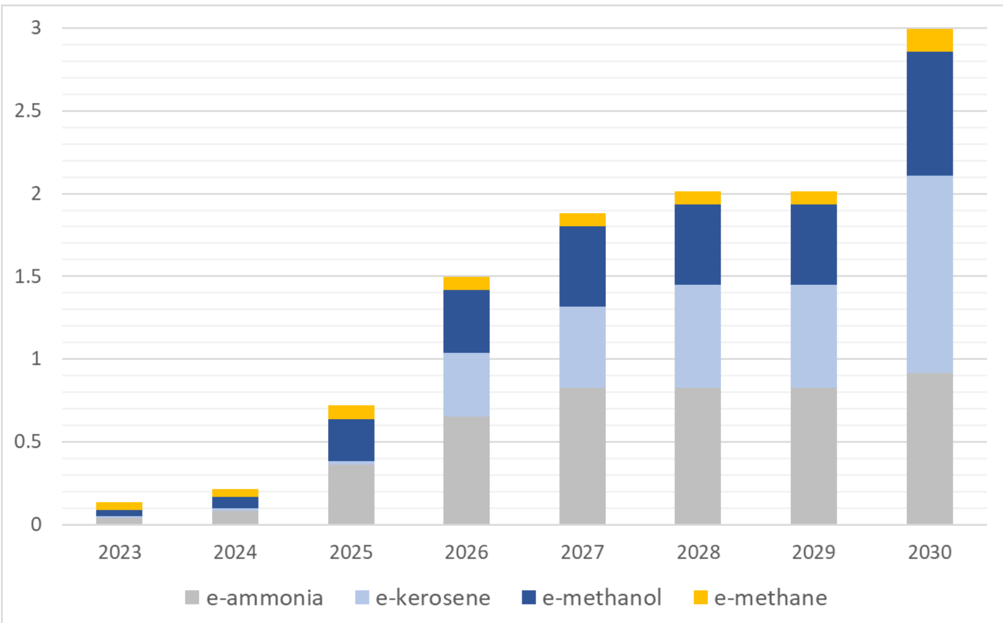

Figure 4-8 Cumulated evolution of all assessed e-fuel production capacities (Mtoe/year) including capacities for industrial applications, excluding direct use of e-hydrogen

We have identified 0.04 Mtoe/year of e-fuel capacity that has been implemented and 0.45 Mtoe is under development. Based on announcements, a 10-fold increase in e-fuel capacity is planned in 2030, reaching 10.65 Mtoe/year. Notably, a fair share of e-methane capacity is already implemented, however, e-methane does not seem to increase so much in capacity by 2030 compared to the other e-fuels. It is acknowledged that not all capacity announcements will come to fruition or that all e-fuels will be used as transportation fuel. Furthermore, it can be reasonably assumed that pilot-scale facilities will not continue full operation after significant scale-up of the technology and will therefore not be accounted for in the projections for 2030.

4.4. RFNBO capacity development versus demand in 2030

In this section, first we will discuss some key aspects on the applicability of the different E-fuels, after which the capacities are compared with the targeted demand in 2030.

4.4.1. Technology specific considerations

E-Hydrogen

Two sources have been considered to determine hydrogen capacity development towards 2030. According to Hydrogen Europe, the expected total planned capacity of PtH projects in Europe is 138,5 GW_{el} by 2030 and would provide 10 Mton of e-hydrogen per year which converts to 28.66 Mtoe/year. The IEA hydrogen projects database reports on a total normalised capacity of 102 GW_{el} in the EU by 2030, leaving a gap of 36.5 GW_{el} compared to Hydrogen Europe. Such discrepancy may be the result of an information gap as Hydrogen Europe has access to confidential data from its members, as well as existing data gaps in the IEA hydrogen projects database. The data from the IEA database suggests that approximately a quarter of the announced hydrogen production capacity in the EU is intended for e-fuels production, including e-ammonia, e-methanol, e-kerosene and e-methane.

It is apparent from both data sources that most of the announced capacities are at the concept or feasibility stage and are therefore susceptible to change or can even be cancelled. In fact, the plans for 138,5 GW of electrolyser capacity as reported by Hydrogen Europe were developed with the Repower EU hydrogen ambition of 10 Mt renewable hydrogen production in the EU27 by 2030 in mind, but this ambition has not been put forward in the provisional agreements. In addition, due to the new requirement on the sourcing of hydrogen as set in the commission delegated regulation 2023/1184, it is uncertain what share of the projects will actually come to fruition.

E-kerosene

According to our estimates, a total of 1.19 Mtoe/year of e-kerosene capacity is either under development or planned by 2030. However, a recent SAF outlook study published by SkyNRG[32] suggest that only half of the announced production capacities will be deployed by 2030. This is further supported by interviews with main industrial stakeholders and the renewable fuel experts. According to them, it is reasonable to assume that any capacity beyond the mandated target for synthetic aviation fuels in 2030 will not be realized, due to its significant production costs compared to fossil-based jet fuel and biomass-based jet fuels, especially HEFA and Alcohol-to-Jet. The sub-target for synthetic aviation fuels as implemented in the ReFuelEU Aviation directive is 1.2% of total demand by 2030, which converts to 0.52 Mtoe.

The product slate of the FT-synthesis pathway consists of e-kerosene, e-diesel and naphtha

[32] Sustainable aviation fuel market outlook 2023. SkyNRG, May 2023.

in a ratio of 60%, 20%, and 20%, respectively[33]. TNO (2022)[34] estimates the product slate can be optimised to 85% jet fuel. Considering that the sub-target of 1.2% of synthetic aviation fuels may well be met (due to overcapacity, based on announcements) primarily through the FT-synthesis pathway, 0.1 Mtoe/year of e-diesel will be produced as by-product by 2030. It is uncertain whether the road transport sector is open to accept premium prices for e-diesel due to its significant higher price compared to alternatives. Without off-takers for the by-products generated in the FT-synthesis pathway, e.g. naphtha, there is no viable business case.

E-methanol

E-methanol is not solely seen as a renewable fuel for the transportation sector, and in particular the maritime sector. Methanol is also a critical chemical intermediate for the production of plastics, fibres, and resins. For instance, Iberdrola announced that their e-methanol facility will be co-located at Foresa's plants in Galicia, which will use the e-methanol to replace the imported methanol currently used for the production of wood glues and resins[35]. Dow and Wacker are also considering internal use of e-methanol as a base chemical[36,37]. In addition, most announcements for planned capacities remain inconclusive to which sector their product will serve. Therefore, it remains unclear what percentage of the technical potential would be available as renewable fuel for the transport sector by 2030.

E-ammonia

As previously indicated, half of the announced e-ammonia projects are considered to be revamps while the other half are new greenfield projects. Greenfield projects have a combined announced capacity of 0.77 Mtoe/year by 2030, while revamp projects have a combined announced capacity of 0.14 Mtoe/year by 2030. Revamp projects are mostly dedicated to the production of green fertilizers while greenfield projects could produce e-ammonia for both the fertilizer and shipping industries. On the individual basis, the intended end-uses of e-ammonia from greenfield projects are often indistinct. At least one greenfield project announced their intention to produce e-ammonia for the fertiliser industry (i.e., Catalina project)[38], while another project announced by Maersk and CIP will provide 600.000 tonnes/year of e-ammonia to the fertiliser industry out of the 650.000 tonnes of total capacity. The remaining 50.000 tonnes/year will be used as fuel for the shipping industry[39]. According to the IEA hydrogen projects database, only 1% of the ammonia product indicated mobility as end-use, while the other 99% is specified as a chemical feedstock (see Figure 4-3).

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[33] Clean Skies for Tomorrow: Delivering on the Global Power-to-Liquid Ambition. WEF, May 2022.
[34] TNO (2022) Renewable Fuels of Non-Biological Origin (RFNBO) for transport - Exploration of options to fulfil the obligation in the Netherlands, TNO report 2022 P10989. https://www.rijksoverheid.nl/documenten/rapporten/2022/11/22/2022259905-3-tno-rapport-invulling-rfnbo-subdoelstellingen
[35] https://www.iberdrola.com/press-room/news/detail/iberdrola-foresa-plan-investments-renewable-hydrogen-production-green-methanol-galicia
[36] https://www.fastwater.eu/media/attachments/2021/07/06/10-large-scale-renewable-methanol---jens-schmidt-dow.pdf
[37] https://www.wacker.com/cms/en-us/about-wacker/research-and-development/rhyme-bavaria/detail.html
[38] https://hydrogen-central.com/catalina-project-hydrogen-green-ammonia-large-scale-spain-enagas-naturgy-fertiberia-vestas/

[39] https://www.maritimeprofessional.com/news/maersk-backs-plan-green-ammonia-365447

E-methane

A total of six e-methane projects have been announced with increased capacities compared to the 1MW electrolyser scale currently in operation. Two of these six projects (i.e., Amprion/OGE and Element Eins) have received a rejection from Germany's Federal Network Agency (BNetzA), while the Lübesse-energie project is continuously being delayed. The remaining four projects shared their intention to inject the produced e-methane into the grid to be used for either the industry or the transportation sector. Therefore, the maximum e-methane production capacity in the EU intended for use as renewable fuel for the transport sector is estimated at 0.04 Mtoe/year by 2030.

4.4.2. Implemented and planned capacities versus 2030 targets

Table 4-12 presents an initial comparison between the capacity development based on the inventory of implemented, developing and planned projects as found in chapter 4.4 , and the expected demand for e-fuels and RFNBOs for industrial purposes as elaborated in section 4.3.3. We have assumed an optimistic 90% capacity utilisation factor to derive to the maximal potential production of e-fuels based in implemented, under development and planned projects.

e-fuels production at 90% capacity utilisation (in Mtoe)	e-hydrogen	e-kerosene	e-methanol	e-ammonia	e-methane
Implemented	0.023	0.001	0.002	0.002	0.005
Under development	0.131	0.056	0.075	0.105	0.039
Planned	6.737	1.016	0.600	0.718	0.077
Total capacity	**6.891**	**1.073**	**0.677**	**0.824**	**0.120**
Demand e-fuel/chemical					
Sector e-fuel demand	Road	Aviation	Maritime	Maritime	Maritime
Targeted transport demand provisional agreement	1.12	0.52	0.44	0.44	0.44
Percentage target met with e-fuel	100%	100%	90%	2%	8%
Transport demand for e-fuel	1.12	0.52	0.40	0.01	0.04
Industrial RFNBO demand - RED III	n.a.	n.a.	1.13*	2.67*	n.a.
Total demand	**1.12**	**0.52**	**1.53**	**2.68**	**0.04**
Percentage of demand covered by identified capacity (at 90% capacity utilisation)					
Implemented	**2%**	**0.1%**	**0.2%**	**0.1%**	**13%**
Under development	**12%**	**11%**	**5%**	**4%**	**109%**
Planned	599%	195%	39%	27%	217%
Total	613%	206%	44%	31%	339%

* Please note that the demand for hydrogen for e-methanol and e-ammonia in Table 4-2 has been converted to a demand for e-methanol and e-ammonia.

Table 4-12 Matching capacities with demand for RFNBOs as targeted in 2030 (own elaboration) (in Mtoe)

Aviation

In case of e-kerosene, currently only 0.1% of the target of 0.52 Mtoe can be met, and 11% of the target if all projects under development would be realised. It means that, in addition, 50% of the planned e-kerosene projects need to be realised to meet the projected demand in 2030..

Maritime

In case of e-fuels for the maritime sector, after discussion with the hired e-fuels experts, considering the technical, financial and logistical feasibility (more info in section 0) we have assumed that the demand in 2030 will be covered by e-methanol (90%), e-ammonia (2%) and e-methane (8%). We have added the industrial RFNBO demand for methanol and ammonia production, induced by RED III Article 22a (See Table 4-2, 2030 target of 42% RFNBOs).

In case of **e-methanol** next to the estimated demand of 0.44 Mtoe from the maritime sector, the industry requires 1.13 Mtoe of e-methanol. The total envisaged capacity of 0.677 Mtoe (at 90% capacity utilisation) does not cover this demand, and additional capacity is needed. If all e-methanol would go solely to the maritime sector, there would be enough capacity to meet this demand, however this is not realistic.

The total implemented, under development and planned **e-methane** capacity values 0.120 Mtoe (at 90% capacity utilisation), which could in theory cover 27% of the 2030 RFNBO demand of 0.44 Mtoe in the marine sector. However, most e-methane projects will provide e-methane to the grid. The RED III makes it possible to use biogas injected to the grid, but does not have provisions on the use of e-methane. Moreover, due to competition with other applications, we have estimated the use of e-methane to cover maximally 8% of the RFNBO target for the maritime sector, i.e., 0.04 Mtoe, which could be reached if about 29% of all e-methane projects supply to the maritime sector.

The industrial demand for **e-ammonia** of 2.67 Mtoe is much larger than the expected demand in the transport sector of 0.01 Mtoe in 2030, and the total implemented, developing and planned capacities do not meet this combined demand. However, the shipping sector only needs a modest share of the total e-ammonia capacity. Therefore, technical feasibility and safety issues are expected to be the limiting factor for application in shipping in 2030 rather than availability of e-ammonia.

Road transport

As explained in section 4.3.3 the RED III RFNBO target for transport can solely be met by the use of RFNBOs in aviation and the maritime sector. It is, however, interesting to assess the status of **e-hydrogen for direct use in mobility**. If we assume that all hydrogen for direct use in mobility is directed to road transport, the implemented capacity is sufficient to meet 2% of the targeted demand of 1.12 Mtoe for RFNBOs. Projects under development could cover 12% of the demand. There are sufficient plans to cover 6 times the targeted demand.

Furthermore, we have to realise that during e-kerosene production also a fraction is co-produced that is suitable for road transport. If the aviation target of 0.52 Mtoe is met, most likely about 15 – 20% **e-diesel** can be produced, sufficient for 0.08 – 0.10 Mtoe, which is 7 – 9% of the RED III RFNBO target of 1.12 Mtoe.

Conclusion

It can be concluded that in total 0.036 Mtoe of e-fuels production capacity has been implemented, which could produce 0.032 Mtoe of e-fuels at 90% capacity utilisation, which covers only 3 – 4% of the total RED III target of 0.75 – 1.12 Mtoe in 2030, depending on the type of double counting. If all 0.41 Mtoe of projects under development are added (at 90% capacity utilisation), about 36 – 54% of the RED III RFNBO target for transport could be met. It means that a significant number of planned projects has to reach the implementation phase, otherwise the RED III target will not be met.

In case of aviation, due to the enforceable ReFuelEU Aviation targets, and the availability of sufficient planned projects, it can be expected that the 0.52 Mtoe will be realised in 2030. In case of the maritime sector, the RFNBO target is formulated in a more tensile way, i.e., if the 1% target of 2031 is not met, it will be replaced by a higher RFNBO target of 2% from 2034 on. Moreover, the number of implemented, under development and planned e-methanol projects - being the main RFNBO pathway in the maritime sector - covers altogether only half of the targeted demand for RFNBOs for transport and industry. Of all RFNBOs, with an estimated production of 0.023 Mtoe, the direct application of hydrogen for (road) transport is currently the most developed, and a large number of projects are planned as is shown in Annex 4. Obviously, of all RFNBOs, e-hydrogen is the easiest to produce, although its distribution and end use is more challenging, it has good possibilities to be implemented at a larger scale.

4.5. Capacity outlook towards 2050

Concrete evidence (i.e., announced) of additional capacity development for those that have received a final investment decision or are at any stage before the final investment decision is limited to a timeframe until 2030. Any estimations of the future capacity development beyond 2030 are therefore based on potential technological progress and market outlooks for the transport sectors.

The deployment of RFNBOs towards 2050 depends on various factors, among others:

- Targets and subsequent demand for RFNBOs.
- The applicability of e-fuels, i.e., technical readiness level, technical and financial feasibility of the various RFNBO production technologies and their end use application.
- The availability of renewable hydrogen produced from eligible electricity sources, which depend on the development of renewable electricity capacity available for RFNBO production.
- The availability and eligibility of CO2
- The demand of RFNBOs in the industry versus transport
- The role of import of RFNBOs
- Regulatory complexity and uncertainty.

These aspects have been assessed in this chapter. The findings are based on inputs of the two hired renewable fuel experts, interviews with sector organisations such as the E-fuel alliance and Hydrogen Europe, an interview with SkyNRG and an e-fuel technology developer, as well as our own assessment of relevant literature sources.

4.5.1. Targets and demand for RFNBOs in 2050

The uptake of synthetic fuels after 2030 is supported by the ReFuelEU Aviation regulation, which reached an agreement between the EU Parliament and the Council in April 2023. The EU jet fuel blend will need to contain a minimum share of synthetic fuels, which increases over time, with a total mandated share of 35% by 2050. As described in section 4.3.3 on page 63, this results in an estimated demand of 15.9 Mtoe synthetic aviation fuels in 2050.

The uptake of renewable fuels is also supported by the FuelEU Maritime regulation, which aims to support the decarbonisation of the shipping industry. The deal included a clause that mandates a 2% renewable fuels target for shipping from 2034 if RFNBO use amounts to lower than 1% of shipping's overall fuel mix by 2031.

Regarding road transport, or all sectors together, in the coming five years targets will be formulated for 2040, i.e. the "RED IV". However, at the time of writing no general transport targets beyond 2030 are available.

4.5.2. Applicability of e-fuels for road, shipping and aviation

The applicability of e-fuels for road transport (especially heavy-duty vehicle long distance transport), shipping, and aviation depends on various factors. TNO[40] reported on the suitability of e-fuels for these sectors, using three Key Performance Indicators (KPIs). These included (1) practical application and safety (i.e., vehicle modifications, impact on infrastructure and operations, and safety), (2) environmental impact (i.e., GHG emissions and pollutants), and (3) economics (i.e., production costs of fuel, storage, and distribution). Based on their analysis, hydrogen, e-methanol, e-diesel, and e-LNG are attractive options for both trucking and shipping, while e-ammonia is considered applicable only for the shipping sector. For aviation, e-kerosene is regarded as the only viable e-fuel option (see Figure 4-9). The main reason for the latter observation is that other e-fuels have higher volume and space requirements and require an adapted or completely new distribution system, including distribution infrastructure.

[40] Karin van Kranenburg, et al., E-fuels: towards a more sustainable future for truck transport, shipping and aviation. TNO, July 2020.

Hydrogen	For short distances, in case of high electricity and CO_2 costs		
E-methanol	Feasible		
E-diesel			
E-LNG			
E-ammonia	Unsafe	In case of high CO_2 cost	
E-kerosene			Only feasible option

Figure 4-9 Applicability of e-fuels for the road transport, shipping, and aviation sectors[21].

Aviation

The aviation sector is the only sector envisaged to use e-kerosene as a fuel. Conversely, e-kerosene is the only viable e-fuel option for aviation (seeFigure 4-9) at least until 2050, which is further supported by the interviewed industrial stakeholders as well as the renewable fuel experts. It is acknowledged that e-hydrogen could potentially be used as e-fuel in hydrogen-powered commercial aircraft, as Airbus announced their ambition to develop such aircraft by 2035[41], however it will require an entire new airport fuelling infrastructure. For aviation, a high-energy density fuel is required as both mass and volume are very much limited. A plane can devote up to 30% of its take-off weight to fuel. Doubling this fuel weight and tripling its volume (as would be in the case for e-methanol, cryo-e-LNG, and e-ammonia) would effectively reduce the passenger/cargo mass volume by around 50%[21]. For short-range planes, it would be less dramatic, but the losses are still too high to consider this a realistic option. Batteries require a lot of space and are currently too heavy to be practical for longer flights.

Maritime transport

For the energy transition in the maritime transport sector, there are many options for e-fuels, such as e-ammonia, e-diesel, e-hydrogen, e-methane, and e-methanol. Key barriers for the uptake of these e-fuels need to be addressed, which include the development of onboard fuel technologies, the lack of bunkering infrastructure, high fuel prices, and the additional demand for onboard storage space. The severity of such barriers varies between fuels. Safety is also a primary concern, with the absence of prescriptive rules and regulations complicating the implementation of required technology on board. Currently, 0.56% of ships in operation and 15% of ships on order can operate on alternative fuels. It has been observed that the uptake, by number of ships, is dominated by battery/hybrid ships together with LNG fuel. It must be noted that in gross tonnage terms, LNG fuel dominates, which suggests that battery/hybrid solutions are mostly applied on smaller vessels.[42] An increase in methanol and LPG uptake, as well as hydrogen-fuelled newbuilds have also been observed. LNG is a popular fuel choice for the car carrier and container ship segments, and significant uptake is

[41] https://www.airbus.com/en/innovation/low-carbon-aviation/hydrogen/zeroe

[42] Maritime forecast to 2050; Energy Transition Outlook 2022. DNV, 2022

also being foreseen for the tankers and bulk carrier segments. E-methane has to compete with bio-LNG/bio-methane, which is expected to be the cheaper alternative.

Methanol has previously been used as a fuel for tankers in the methanol trade, however, significant uptake is observed for the container ship segment (i.e., a total of 104 on order). Hydrogen is only foreseen for the short-sea segment. Notably, ammonia uptake does not show up in the statistics despite its decarbonisation potential and relatively low production cost. According to the e-fuel cost projections of Maersk Mc-Kinney Moller center for Zero Carbon Shipping (MMMZCS), e-ammonia is the least costly energy-dense e-fuel.

This is due to the fact that ammonia is made from N2 feedstock, which is readily available and cheaper to obtain than the CO2 needed for other e-fuels, such as e-methanol and e-methane[43]. The main reasons why ammonia uptake is lacking in the maritime sector is due to the low maturity of onboard fuel technologies and the corresponding safety regulations for onboard use. Currently, neither 2-stroke nor 4-stroke engines that use ammonia as a fuel are commercially available. There are significant development efforts being made to get these engines to market within the next couple of years[44,45]. Methanol, on the other hand, has already been used in dual-fuel-2-stroke methanol engines for propulsion since 2017[46]. Furthermore, it is expected that MAN Energy solutions starts offering methanol retrofits for 4-stroke engines from 2024[47]. With regards to safety regulations, e-methanol has gained an advantage over other e-fuels. Currently, there are well established international regulation and Class rules for the use of methanol as fuel onboard ships. Ammonia, for instance, is a highly toxic compound at a very low concentration, and there are no existing regulations, rules and guidelines regarding the use of ammonia as fuel. In addition, a recent report of Together in Safety[48] identified a number of risks for ammonia that were classified as intolerable, and as such the hazards should be eliminated, substituted or controls put in place to reduce the risk to a medium or low risk rating. The report further concluded that methanol poses the least risk, followed by LNG and hydrogen.

Road transport

Direct use of renewable hydrogen, e-methane, e-methanol and diesel fractions coproduced with synthetic aviation fuels are all technically feasible but have to compete with direct use of electricity in cars. Direct use of hydrogen in vehicles will be a preferred option considering energy efficiency. However, the vehicle needs to be suitable for storage and usage of hydrogen. Opportunities for other e-fuels exist especially for long distance transport with heavy duty vehicles. The production of jet e-fuels results in fractions that are suitable for e-diesel product for road transport, thereby supporting the business case of synthetic aviation fuels. E-LNG can be applied in heavy duty road transport as well. While methanol can be used in conventional ICE vehicles, it can also be a fuel for advanced hybrid and fuel cell vehicles. In that case, methanol is reformed on board a vehicle to hydrogen, which is fed to a fuel cell to charge batteries in an electric vehicle (EV) or provide direct propulsion in a fuel cell vehicle (FCV). To date, methanol is the only liquid fuel that has been demonstrated on a

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[43] Position Paper: Fuel option scenarios. Maersk Mc-Kinney Moller Center for Zero Carbon Shipping, October 2021.
[44] https://www.man-es.com/company/press-releases/press-details/2021/11/29/man-energy-solutions-upgrading-four-stroke-engines-for-green-future-fuels
[45] https://www.wingd.com/en/news-media/press-releases/wingd-sets-development-timeframe-for-methanol-and-ammonia-engines/
[46] Maritime forecast to 2050; Energy Transition Outlook 2022. DNV, 2022
[47] Methanol Institute (May 2023), Marine methanol: Future-Proof Shipping Fuel
[48] Future Fuels Risk Assessment. Together in Safety

practical scale in fuel cell-based transport application. On the other hand, when FCV is applied, it is more efficient to use the hydrogen directly.

RFNBO production costs and total transport costs

The total costs of the RFNBO in transport will be an important driver of the future application of different RFNBOs. Detailed assessment of the production costs and total costs of use is outside the scope of this study. However, in this section a rough picture of the costs of the different RFNBOs is made. Figure 4-10 and Figure 4-11 show that e-fuel production costs as envisaged by TNO (2020)[49] in 2030 are highly sensitive to the costs of green electricity and CO2.

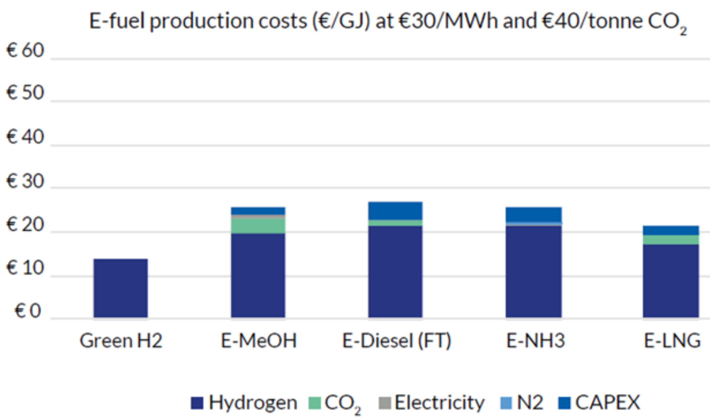

Figure 4-10 E-fuel production costs at low electricity and CO2 costs (Source: TNO (2020))

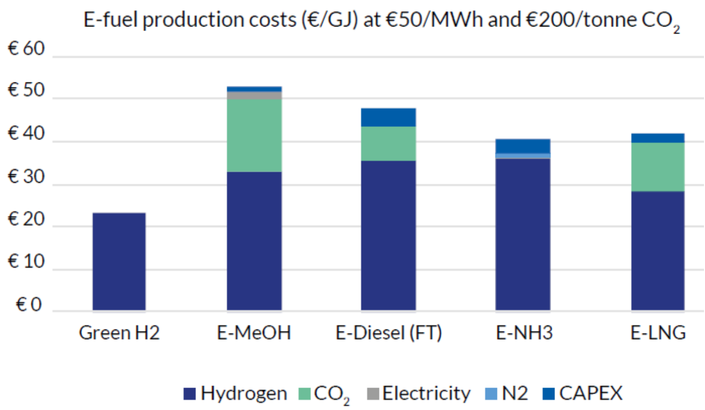

Figure 4-11 E-fuel production costs at high electricity and CO2 costs. Source: TNO (2020)

[49] TNO (2020) E-fuels: towards a more sustainable future for truck transport, shipping and aviation.

Figure 4-12 shows that direct use of hydrogen in trucks is relatively expensive due to vehicle costs increase. Figure 4-13 shows a very limited difference in costs of transport between the different e-fuels.

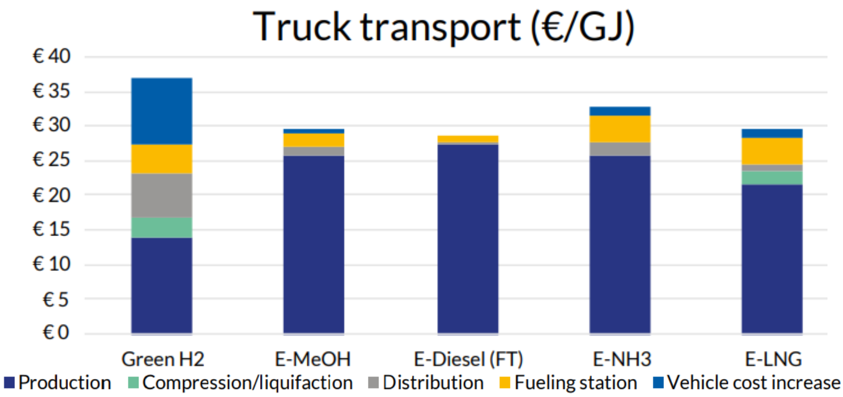

Figure 4-12 Estimated truck transport costs in 2030. Source: TNO (2020)

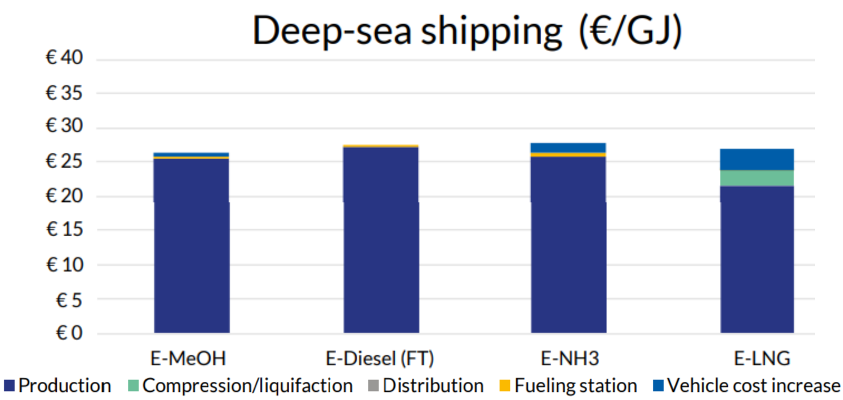

Figure 4-13 Estimated maritime transport costs in 2030 using different e-fuels. Source: TNO (2020)

4.5.3. Availability of hydrogen and renewable electricity

Availability of electricity

Availability of green electricity is currently seen as an important bottleneck to the capacity development of e-fuels. Given the total energy efficiency, direct electrification will be preferred over the use of e-fuels. The electricity infrastructure is under high pressure and grid extensions take a considerable amount of time, i.e., think in decades not in years. Since the electricity price is an important input in the total price of an e-fuel, producers will look for the locations with the lowest prices of green electricity. Key locations within the EU may be wind parks at sea and areas with a lot of sun and space, as can be found in Spain. The fact that electricity has to come from new projects that are additional to existing renewable electricity capacity, is an extra challenge for e-fuel producers. Another challenge is that renewable electricity is available in an intermittent way, while the production processes of hydrogen and most e-fuels require a constant flow of inputs.

For the targeted production of 15.9 Mtoe synthetic aviation fuels in 2050, 19.9 Mtoe hydrogen is needed (using methanol-to-jet, that consumes 1.2 MJ hydrogen/MJ fuel[50]). Assuming an electrolyser efficiency of 75% in 2050 (Concawe 2022) this leads to an associated electricity demand of 33.4 Mtoe or 388 TWh. If wind power is used, that has, say, 4000 full load hours/year[51], about 97 GW wind power is needed. If solar PV is used with, say, 1500 full load hours/year, this corresponds to a capacity of 259 GW of solar panels.

In order to set these numbers in perspective we compare them with the EU electricity production and the potential of renewable electricity production. In 2021 the total net electricity generation in the EU27 was 2785 TWh, of which 381 TWh (13.7%) from wind and 161 TWh (5.8%)[52] from solar power. It means that all wind capacity installed by 2021 would be needed to meet the demand of 15.9 Mtoe synthetic aviation fuels in 2050. On the other hand, as shown in Figure 4-14 the German Environmental Agency (2022) estimates that the technical potential of renewable electricity generation is 22,000 TWh/a. To cover the demand for synthetic aviation biofuels in 2050 only 1.8% of the technical potential of renewable electricity is required.

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[50] Calculation BTG based on inputs taken from Concawe (2022)

[51] Value used for Dutch Wind at Sea parks. https://www.rvo.nl/sites/default/files/2016/04/A4-Posters%20Rijk_WoZ_februari%202016.pdf

[52] Source: Eurostat, see https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_production,_consumption_and_market_overview#Electricitygeneration

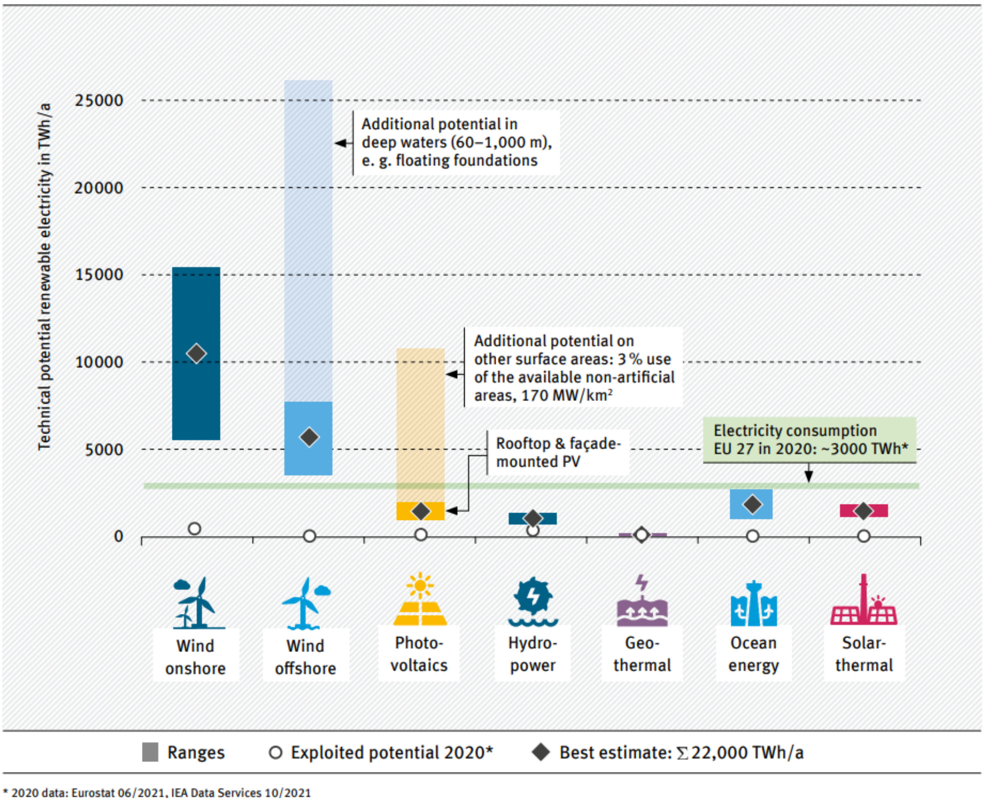

Figure 4-14 Technical renewable electricity generation potential in Europe. Source: German Environmental Agency (2022)

Availability of hydrogen

For project developers, availability of hydrogen is an issue and seen as an important bottleneck. There is a strong need for more electrolyser capacity. The industry has a high demand for hydrogen as well, but it is expected that e-fuel producers can generally pay a higher price than industrial producers.

4.5.4. Availability of CO2

For the targeted production of 15.9 Mtoe synthetic aviation fuels by ReFuelEU Aviation Regulation, in the order of 49.2 Mtonnes CO2 are required. The final cost of e-fuels, and thus their financial feasibility, is also heavily dependent on the supply costs of CO2. By far the cheapest source of CO2 would be to use the CO2 point captured from the (energy intensive) industry or power plants, however the long-term sustainability of this pathway might be problematic. Delegated regulation 2023/1185 determines de facto that CO2 from fossil sources is not allowed anymore after 2041. On the long run, CO2 from biogenic resources and direct air capture will be the main CO2 sources. On the one hand, the limitation of industrial CO2 sources can be understood as these sectors need to reduce their CO2 emissions dramatically. On the other hand, some industries, such as the cement sector will hardly be able to reduce their CO2 emissions. In 2020 the cement sector in the EU received

109 Mtonnes CO2 allowances[53], and thus an important source of CO2. To promote the ramp up of e-fuel projects, it is recommended to introduce a grandfathering clause, meaning that e-fuel projects developed before a certain date can keep using fossil CO2.

Direct air capture

For the first years sufficient biogenic CO2 are available, but on the long term direct air capture is unavoidable.

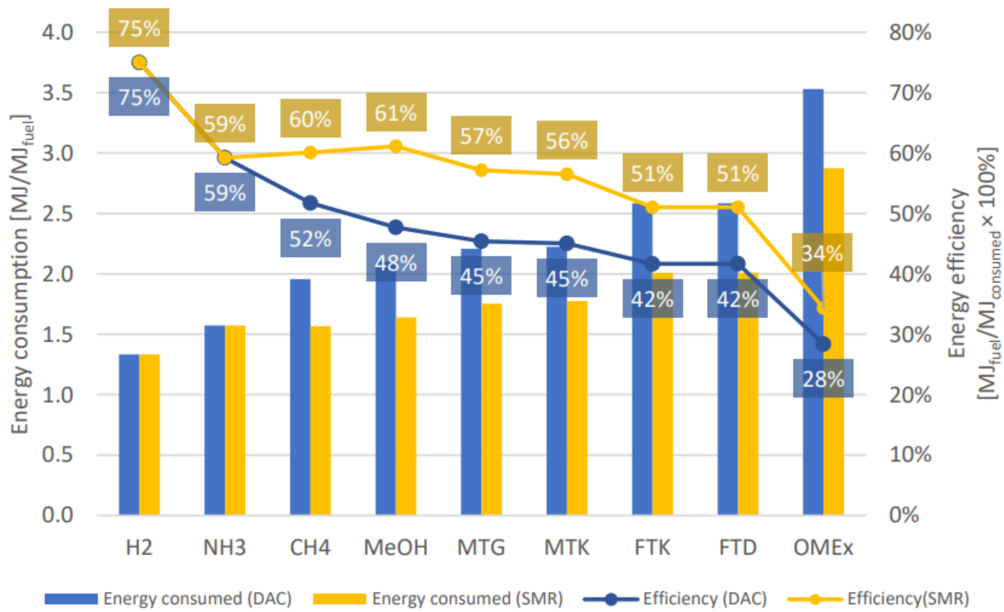

Figure 4-15 Comparison of energy consumption and energy efficiency for e-fuels production when using Co2 from direct air capture (DAC) and a concentrated CO2 source. Source: Concawe (2022)[54]

As illustrated in Figure 4-15, direct air capture requires more energy than the capture of CO2 from point sources, which will have consequences for costs and GHG emission reduction of the e-fuel.

Galimova, T, M. Ram et al (2022) review the results of current studies on CO2 availability, and Figure 4-16 indicates that they expect a growing role for direct air capture, as supplier of more than 60% of the required CO2 in 2050. One of the renewable fuel experts recommends starting the further development of direct air capture right away, and not wait until all fossil and biogenic sources are utilised.

[53] See https://re4industry.eu/eiis-interactive-map/

[54] Concawe (2022) E-fuels: a technoeconomic assessment of Eruopean domestic production and imports towards 2050, report no. 17/22.

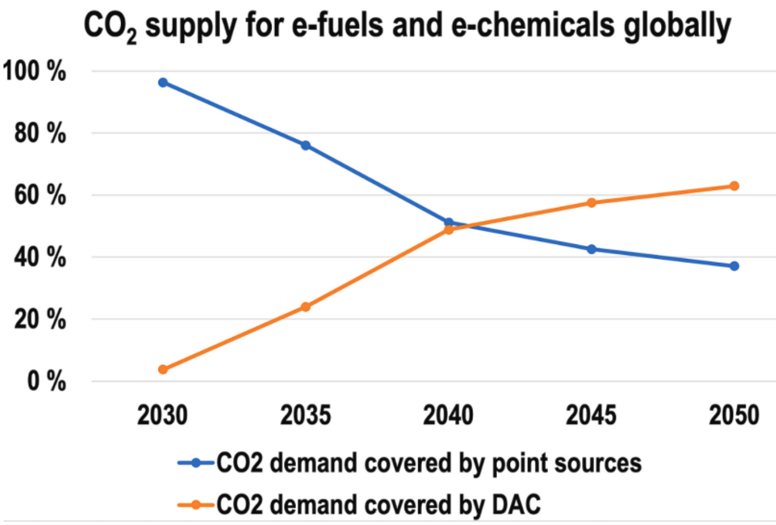

Figure 4-16 CO2 supply for e-fuels and e-chemicals globally. Source: Galimova, T, M. Ram et al (2022)[55]

Direct air capture is interesting for specific regions with a lot of renewable sources available (solar, wind) but with a lack of industrial CO2 emitters, say the more rural areas.

Role of CCS

If fossil fuel production processes plus carbon capture and storage is cheaper than production of RFNBOs for transport and industry, this could be a threat for RFNBO production. However, so far not many CCS projects have been developed, and CCS depends on location specific geological conditions.

4.5.5. RFNBOs for industry versus transport

It is observed that many current hydrogen projects are related to the transport sector (See Annex 4). Given the obligatory transport targets and penalties if no RFNBOs are used, it is expected that the transport sector can compete with the chemical sector for renewable hydrogen. E-fuels development, for example e-methanol, could support the development of the use of RFNBOs in the chemical sector as well. Currently refineries produce fuels as main product and naphtha as by-product, which forms a cheap input for the chemical industry. If on the long term, oil refineries will be phased out, this cheap source will not be available anymore, and more expensive e-/bio-methanol and e-/bio-naphtha will become the alternative.

[55] Galimova, T, M. Ram et al (2022), Global demand analysis for carbon dioxide as raw material from key industrial sources and direct air capture to produce renewable electricity-based fuels and chemicals, Journal of Cleaner Production, Volume 373, 2022,133920, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2022.133920

4.5.6. The role of import of RFNBOs

The development of RFNBOs for industry and transport is expected to have a considerable impact on the future locations of fuels and chemicals production. For example, e-ammonia - that does not require CO2 as input - will likely be produced in areas with high supply of solar or wind power. This could be Spain, but also North Africa and the Middle East may have a strong position. The ammonia can be shipped to the EU and converted in fertilisers and used as e-fuels. The PtX global atlas[56] of Fraunhofer gives more details of potential production locations of e-fuel production outside the EU. The transport and handling of pure hydrogen is more complex than e-fuels like methanol or e-LNG. Therefore, import of pure hydrogen is expected to be limited, as shipping of hydrogen is complex, and it takes time to develop pipeline connections. Some of the consulted e-fuel experts - however - expect that the main share of e-fuels may be imported and not be produced within the EU, and that the share of imported E-fuels will be relatively higher than the share of imported advanced biofuels. It is however difficult to assess how e-fuels production will exactly develop. Some creative solutions could be developed as well. For example, the TES-hydrogen project[57] developed the idea to produce e-LNG in the Middle East, ship it to the EU and bring back the captured CO2 to the Middle East for e-LNG production.

4.5.7. Other considerations

During the interviews with advanced biofuels producers, of which some are also active in RFNBO and RCF projects, the most important legal barriers were already addressed, such as the limits on eligibility of fossil CO2 as source, requirements on additionality of used renewable electricity, regulatory complexity and uncertainty. In addition, the current legislative framework is not yet fully developed to cover hybrid solutions, in which CO is used from a biomass plant instead of CO2, or to utilise gases from municipal waste processing are used, that are partly fossil and partly biogenic. Compared to RFNBOs, RCFs have to deal with some additional regulatory complexity and uncertainty.

A radical but difficult to implement solution to promote renewables in all sectors is to put a tax on fossil fuels just after its mining. This way all fossil fuels become more expensive and all the renewable alternatives cheaper.

In addition, it could be worthwhile to consider the rare raw material requirements of each e-fuel and of electric transport. Both batteries for electric vehicles and catalysts for the production of e-fuels require rare materials, and there are also differences in the type and amount of rare materials needed for the production of catalysts for e-fuels.

4.5.8. Conclusions

Many factors play a role in the development of RFNBOs for transport in the EU27. There will be an urgent need for alternatives for fossil fuels such as RFNBOs and advanced biofuels to achieve the targeted greenhouse gas emission reductions. RFNBOs are however not a cheap solution, and given the required inputs, expected to be always more expensive than the current fossil fuels, and most advanced biofuels. Regarding e-fuel production technologies we observed the following:

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56 https://maps.iee.fraunhofer.de/ptx-atlas/
57 https://tes-h2.com/

- Direct use of hydrogen in vehicles will be a preferred option considering efficiency losses. However, the vehicle needs to be suitable for storage and usage of hydrogen.

- Methanol as the potential to become a future commodity for fuels and chemical production. E-methanol has a great potential as it serves a wider array of applications, such as marine bunker fuel and chemical feedstock.

- The methanol-to-jet pathway is more selective towards kerosene range hydrocarbons compared to FT-synthesis.

- FT-synthesis requires a by-product market (diesel and naphtha). Producers will need to seek out high-value end markets for the by-products to make a positive business case. Off-takers for diesel/gasoline could include heavy duty vehicles. Off-takers for light ends could include the chemical industry to produce olefins, which are the precursor monomers for plastics. Currently, the average product slate of a FT-synthesis facility is 60% jet fuel, 20% diesel, and 20% naphtha. Optimization up to 85% jet fuel is possible.

- E-diesel can still be used as fuel for trucking as the use of e-fuels in internal combustion engines (ICE) will be allowed after 2035.

- E-ammonia can potentially be used as marine fuel for chemical tankers that transport ammonia, and therefore have experience with handling. It is a globally traded commodity with around 17 – 18 Mt traded annually by ships[58]. This was also the case for methanol where the first movers were chemical tankers exporting methanol. Still the safety risks need to be addressed, and regulations need to be in place. If CO2 is not available or affordable, e-ammonia would be the preferred fuel in the shipping industry.

- E-methane could be used in LNG fuelled vessels and for heavy duty truck transport, and we observe a significant increase in LNG fuelled vessels. It has a lower applicability in the chemical sector than methanol though.

We have observed impressive lists of announced and planned projects for hydrogen production and various e-fuels. However, the installed capacities are still very low. Only if the legislative framework with targets is fully in place, final investment decisions will be made to develop capacity. Availability of hydrogen produced from eligible renewable electricity sources is an important barrier to RFNBO capacity development. On the long run availability of CO2 will be more critical. The switch to direct air capture requires additional supply of renewable electricity.

5. Task 4.4 Recommendations for strategic research directions

5.1. Methodology

The aim to this task is to provide reasoned recommendations for strategic research directions for novel and improved technologies of conversion and feedstock diversification for advanced biofuels and renewable fuels that will be necessary to achieve the EU 2030 and 2050 GHG reduction targets in transport. Specific focus will be on bridging the possible gaps between

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[58] Source: IEA Ammonia Technology Roadmap, towards more sustainable nitrogen fertiliser production.

capacity foreseen in 2030 and 2050 by the industry and the targeted demand, as specified in Subtasks 4.1 and 4.2 for advanced biofuels and Subtask 4.3 for renewable fuels.

The recommendations collected in section 5.2 have various sources:

- The extensive assessment of interviews with the advanced biofuels industry has resulted in the formulation of recommendations that are displayed in section 3.4 .
- Within Task 3, also a number of recommendations have been formulated, based on interviews held with various groups of experts and stakeholders, such as experts with a broad view, sector organisations and technology developers.
- Within chapter 4 several recommendations on the further development of RFNBOs can be found.
- Considerations obtained from technology experts, the industry survey and association interviews of Task 3 on the further development of specific advanced biofuels production technologies.

In this chapter the recommendations from these tasks are collected and presented in a coherent manner.

5.2. Recommendations

The recommendations have been classified in the following groups:

- Recommendations related to legislation;
- Recommendations related to the feedstock base;
- Recommendations related to incentives;
- Recommendations for RFNBOs;
- Advanced biofuels technology specific considerations.

These draft recommendations are subject to further discussion with the consortium and European Commission.

5.2.1. Recommendations related to legislation

Recommendation 1: Keep the advanced biofuels targets and related legislation constant for a prolonged period.

In general, it is acknowledged and appreciated that the EU has established an overall framework with support for advanced biofuels in several sectors including the maritime sector and aviation. This is positive, but regulatory uncertainty and complexity are two major issues that most respondents addressed in some way. An example of regulatory uncertainty is that soon after establishment of RED II, with a target of 1.75% advanced biofuels, the RED III proposal was published, which meant that the just established target became uncertain again. Soon after the publication RED III, in 2025, there will be a full evaluation of the Green

Deal, which can cause again uncertainty. Industrial projects are developed for at least 20 years and business models are developed for the same duration. However, regulations are complex and apparently change every few years.

Recommendation 2: Limit the freedom of Member States to have their own interpretation of advanced biofuels targets.

Regulations that are directly applicable in all Member States (such as ReFuelEU Aviation) are preferred above Directives (such as the RED) that require implementation in national law. Members States may need the flexibility of a Directive, but in the case of advanced biofuels in RED III it became too complex and uncertain for the industries.

An important example of regulatory complexity is that the trilogue negotiations resulted in a joint target for both advanced biofuels and RFNBOs. In general, the respondents expect that there is no big risk that RFNBOs take more than the minimum of 1% in the combined target of 5%. However, it adds complexity and uncertainty, as the RED III provisional agreement Article 25 point 1, second paragraph states *"Member States are encouraged to set differentiated target for biofuels and biogas produced from the feedstock listed in Part A of Annex IX and RFNBOs at national level in order to fulfil the obligation (…) in a way that the development of both fuels in incentivised and expanded"*. Therefore, advanced biofuels producers have to await what Member States decide with regard to this target, and Member States may ask for more than 1% RFNBOs at the expense of advanced biofuels targets at Member State level.

Recommendation 3: Clear legislation and proper procedures

For example, clarity is needed about the fact that according to the provisional agreement of the RED III, Member States may count biogas injected to the grid towards the advanced biofuels targets, maybe even if no methane is used as transport fuel. The text is unclear about this, creating uncertainty if Member States will indeed count biogas injected to the grid towards advanced biofuels targets without the use of biomethane in transport, even if this is not intended by the legislator.

Recommendation 4: Include advanced biofuels as Strategic Net-Zero Technology in the Net Zero Industry Act.

The Commission proposal of the Net Zero Industry Act (COM(2023) 161[59]) provides a priority status and various types of support such as shorter permit procedures and increased access to finance to the Strategic Net-Zero Technologies. The proposed list does not include advanced biofuels, while they meet all underlying criteria such as GHG impact, TRL and energy security. Especially the fast-track permitting would be very beneficial for the rapid implementation of advanced biofuels projects, as it is very challenging to have sufficient capacity installed by 2030.

5.2.2. Recommendations related to incentives

Recommendation 5: Support the development of full-scale reference plants for each relevant advanced biofuels production technology

The combination of (1) high investment costs, (2) the perceived project risk by capital providers and (3) the required speed of capacity development to meet the targets is

[59] Proposal for a regulation of the European Parliament and of the Council on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem

challenging and requires robust measures. For larger companies obtaining capital may not be a big problem as such, but for many of the smaller companies this is a serious barrier. Many players in this new area are project developers and not traditional companies from the oil and gas industry, and project financing is a big hurdle for such new players in a “CAPEX intensive’’ field like advanced biofuels production. They face a “chicken-and-egg” problem: “To easily attract sufficient capital, a full-scale reference is required, but to develop this full-scale reference, sufficient capital is required. Banks or “conservative investors” will not finance advanced biofuels projects with technological risks, while there is no time to de-risk by scaling up at a lower speed. Risks have to be taken and risk capital is required. For several technologies, the main hurdle is to get full-scale demonstration plants up and running, to show that commercial production is possible.

The **EU Innovation Fund**[60] is one of the world’s largest funding programmes for the demonstration of innovative low-carbon technologies. The EU Emissions Trading System (EU ETS) is providing the revenues for the Fund by auctioning emission allowances. The Innovation Fund finances breakthrough technologies for renewable energy, energy-intensive industries, energy storage, and the capture, use and storage of carbon. The Innovation Fund[61] supports demonstration projects that focus on bringing new, promising, innovative technologies to the market and advanced R&D projects that are close to the commercialisation phase (pilots). The fund does not support projects that are still in the research phase or projects that involve advanced technologies that already entered the market, or projects that are already rolling out an innovation on a large scale. Four biofuels/biorefinery related projects have been funded so far, namely W4W, FirstBio2Shipping, Biozin, and Sol[62]. Advanced biofuels technology developers and fuel producers are recommended to consider these funds and EC is recommended to keep the fund open for advanced biofuels projects.

An **IPCEI** (Important project of Common European Interest) for advanced biofuels could be a very appropriate tool to support the large deployment of advanced biofuels. These IPCEIs concern predominantly research and development as well as projects of first industrial deployment. Since its introduction in 2018, IPCEIs have been approved in the field of microelectronics, batteries, hydrogen and communication technologies.

Recommendation 6: Keep research and technology development funds available for innovative advanced biofuels production technologies.

None of the advanced biofuels production technologies are established for decades. Further technological development and support for that will be necessary especially in the early stages of development. The EU has supported research and development of advanced biofuels technologies, which is well appreciated by the advanced biofuels technology developers. These research programmes within the frame of e.g. Horizon Europe are very important.

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[60] https://cinea.ec.europa.eu/programmes/innovation-fund_en
[61] https://www.egen.green/grants/innovation-fund/?utm_source=google-ads&utm_campaign=Innovation%20Fund&utm_agid=125710205034&utm_term=eu%20innovation%20fund&creative=638198933249&device=c&placement=&gclid=EAIaIQobChMInLeyh7frgQMVMeTmCh20SwO3EAAYASAAEgKGjPD_BwE
[62] See https://dashboard.tech.ec.europa.eu/qs_digit_dashboard_mt/public/sense/app/6e4815c8-1f4c-4664-b9ca-8454f77d758d/sheet/bac47ac8-b5c7-4cd1-87ad-9f8d6d238eae/state/analysis for a map with all funded projects.

Recommendation 7: Utilize the window of opportunity for investment in advanced biofuels on the short term.

If the regulatory environment is adapted and successfully triggers investors' appetite, advanced biofuels production capacities can be expanded as needed to reach the 2030 targets. A high number of companies with background from different sectors (chemicals, pulp & paper, refining) is developing various technologies for the production of transport biofuels. The companies interviewed were all well prepared to support industrial deployment of advanced biofuels production once conditions are favourable. There is a window of opportunity for such investments right now, since EU regulation is just being finalized, and will remain unchanged until the next cabinet of the European Commission will be established and could pursue different priorities towards the end of 2024.

Recommendation 8: Step up efforts and offer strong incentives to avoid production capacity to move outside the EU27

As has been noted by several associations and companies, the policy environment provided by the USA seems to be much more attractive to investors than the European regulations. There is a risk that investments will be made there instead of Europe. The long political discussions on upcoming legislation (which still is not published) will leave only very little time for the erection of advanced biofuel production facilities to achieve the 2030 targets for renewable energy and advanced biofuels in particular. EU will have to step up efforts and offer strong incentives such as e.g. premium selling price for the first years of production if we are to meet the targets from domestic biofuel production.

Recommendation 9: Promote the development of a broad range of advanced biofuels technologies

The high diversity of biofuel technologies, the sourcing of feedstocks from different sectors (agriculture, forestry, pulp & paper, agro-processing, wood processing, waste processing, industrial flue gases and potentially also aquatic biomass/algae) and the flexibility of most technologies in terms of final product is a strong asset, since this will allow to adapt to changing market needs. Also, the multitude of technology providers is an asset, increasing the chances of reaching the advanced biofuels targets even if some of the facilities to be installed will likely fail economically. We as a society must be prepared to lose some money through failures for the benefit of developing and deploying the best-performing technologies.

Recommendation 10: For meeting 2030 targets, be fast, short-term incentives and investments are required

The development of viable production technologies can take years to decades, as can be seen from the time that many of the actors are already active in the biofuels sector. Also, the lead time for viable projects is quite significant, with up to 2 years for pre-feasibility and feasibility studies often needed to e.g. allow sufficient access to biomass feedstock, and up to 3 years from final investment decision to full operation ability at nameplate capacity of the facility. This leaves us with little time to set up advanced biofuel production facilities that can still contribute to achieving the 2030 targets. It is high time to publish the final regulations and put in place bold incentives to stimulate this deployment.

5.2.3. Recommendations related to the feedstock base

Recommendation 11: Develop the possibilities to utilise intermediate crops and cover crops for advanced biofuels production, while keeping targets for lignocellulosic feedstock intact.

Although not in the scope of the current project with a focus on advanced biofuels, it is worth mentioning that ethanol-based pathways such as alcohol-to-jet could be developed much quicker if first-generation bioethanol would have been accepted in ReFuelEU Aviation and FuelEU Maritime. The use of first-generation bioethanol in road transport will decrease and could be made available for maritime and aviation. The use of intermediate crops and cover crops for advanced biofuels production is seen as an opportunity and should be explored in more detail.

Recommendation 12: Increase UCO collection from households in the EU27

Feedstock supply is expected to be an issue with respect to scaling up the production of SAF. Since these will have to be based on wastes and residues, the availability of UCO will largely determine initial SAF production capacity through the HEFA pathway. Measures should be taken to increase UCO collection from households in Europe, as to be less dependent from UCO supply from (mainly) Asia.

Recommendation 13: Reconsider ATJ to be produced only from waste and residue-based ethanol

The ATJ pathway relies on ethanol and given the very low availability of waste and residue-based ethanol in Europe, imports will be needed to fulfil SAF demand. This could be avoided if the list of raw materials eligible for SAF production was revised.

Recommendation 14: Promote research and development on difficult to process feedstock such are agricultural residues and wastes fractions

The feedstock-technology matrices in Annex 1 show that the ability of technologies to utilise difficult to process feedstocks is expected to increase substantially in 2050 compared to 2030, thereby unlocking a substantial additional feedstock potential. In order to enable the utilisation of these feedstocks substantial additional research and technology development efforts are needed.

Recommendation 15: Consider GHG emission in considerations on feedstock eligibility

Prescribing a list of eligible feedstocks for advanced biofuels production rather than performance criteria such as GHG emission reductions or severity of risk of ILUC poses a barrier to innovation and moreover misses out on driving technologies to optimize on GHG emission reductions. Modern conventional ethanol facilities can deliver 95% GHG emission reductions, more than probably can be achieved when producing ethanol from agricultural residues. Europe could produce biomass feedstocks at very low risk of ILUC if e.g. cover crops were eligible. Finally, if SAF can only be based on wastes and residues, there is a risk that ATJ facilities will not be deployed in Europe, since availability of appropriate ethanol is low. If Europe does not develop and deploy ATJ facilities, we will have to rely on imports.

Recommendation 16: Work on large scale biomass mobilisation

It is recommended to make optimal use of the hub-and-spoke model, meaning that the first product (e.g., pyrolysis oil, ethanol) can be produced close to where the biomass feedstock is sourced, while the final fuel is produced in a central location. Transport of biomass can be costly, while transport of the intermediate product is a lesser problem. Secondly, for several biomass types, no large collection infrastructure exists, so it should be further developed.

5.2.4. Recommendations for RFNBOs

Recommendation 17: Include a grandfathering clause for use of fossil CO2

Although not directly relevant for advanced biofuels, for RFNBOs the eligibility of carbon sources is a critical point. The delegated regulation on carbon sources for E-fuels ((EU) 2023/1185) states that fossil CO2 sources are not eligible after 2036 (industry under EU-ETS) and 2041 (from electricity plants). This hinders the development of the E-fuels sector considerably. There will be a review in 2027, but this does not create any clarity yet. It is recommended to include a grandfathering clause, meaning that projects that started using a fossil carbon source, can keep using this source once the project has started.

Recommendation 18: Invest in green electricity and hydrogen supply

Green electricity and hydrogen is expected to be the most relevant short term bottleneck for further development of e-fuels.

Recommendation 19: Create markets for renewable road fuels along with aviation fuels

FT-synthesis for aviation fuels and many other advanced biofuels pathways require a by-product market (for green diesel and naphtha). Producers will need to seek out high-value end markets for the by-products to make a positive business case. Off-takers for diesel/gasoline could include trucking. Off-takers for light ends could include the chemical industry to produce olefins, which are the precursor monomers for plastics. Currently, the average product slate of a FT-synthesis facility is 60% jet fuel, 20% diesel, and 20% naphtha. Optimization up to 85% jet fuel is possible but may not deliver the most optimal overall yield. Note that this recommendation is also relevant for FT-synthesis of lignocellulosic feedstock and other technologies.

Recommendation 20: Create realistic perspectives for both advanced biofuels and RFNBOs

There are high expectations of RFNBOs at the political level, while RFNBOs may not be available at scale before 2035. It is important to formulate realistic RFNBO targets and measures. For advanced biofuels producers it is important to show policy makers and the public the possibilities and opportunities of advanced biofuels, as they have the inherited some of the bad fame of first-generation biofuels.

Recommendation 21: Seek synergies between advanced biofuels and RFNBOs

Advanced biofuels production requires green hydrogen, while advanced biofuels production processes could become suppliers of CO2 that is eligible for RFNBOs - also on the long term. Moreover, RFNBOs and advanced biofuels make partly use of the same technology, for example FT and methanol synthesis. Therefore, it is recommended to seek for further possibilities for synergies in production of both advanced biofuels and RFNBOs.

Recommendation 22: Promote hybrid solutions

The current legislative framework is not yet fully developed to cover hybrid solutions, e.g., when CO is used from a biomass plant instead of CO2, or when gases from municipal waste processing are used that are partly fossil and partly biogenic.

Recommendation 23: Investigate rare material requirements of e-fuels and electric vehicles

It could be worthwhile to consider the rare raw material requirements of each e-fuel and of electric vehicles. Batteries for electric cars require rare materials, but there are also differences in the type and amount of rare materials needed for the production of catalysts for e-fuels.

5.2.5. Advanced biofuels technology specific considerations

This section contains considerations obtained from technology experts, the industry survey and association interviews of Task 3 on the further development of specific advanced biofuels production technologies. Further details are provided in Task 3 report.

Anaerobic digestion

Anaerobic digestion is a mature technology and widely deployed in Europe.

Emerging technologies in the anaerobic digestion sector mainly relate to specific components or specific substrates. Here the recent full-scale developments have been looking into improving the substrate pre-treatment, biogas upgrading and carbon dioxide purification and liquification. In biogas systems that have hydrogen available for methanation, the CO2 in the biogas can be deoxidised to methane, which increases the output of the plant. Here systems with biological methanation (in-situ and ex situ) and thermochemical conversion with catalyst have been applied.

A different approach is used with the reformation of biogas into hydrogen. In this case the gaseous energy carrier is hydrogen, and all CO2 can be separated and e.g. used in CCS systems or provided to the production of RFNBOs. Whether this approach will be applied in the future mainly depends on H2 infrastructure and CO2 prices. The technology has been demonstrated and is ready to be implemented in larger numbers, if conditions are right.

These technologies are in the demonstration phase and add to the available options in the sector. Utilization of the carbon dioxide might become a technology used commonly if the prices for the CO2 are high enough to cover the costs of purification and liquification.

Lipid-based pathways (HVO, HEFA, FAME, conventional and advanced)

The production of lipid-based biofuels is already established on an industrial scale. Technological development will include waste-based feedstock processing, process optimisation and product improvement (especially by-product quality or alternative application of the same). Further, research is needed in the field of upscaling technologies, efficiency improvements, co-processing (to overcome blending limitations), and conversion technologies related to SAF and CCS/U to increase GHG savings.

New technologies are associated with a combined or separate use of the biodiesel by-product glycerol/glycerine as e.g. fertilizer or for biogas production. These alternative production pathways will allow an increase in biofuel production without competing with already established production capacities. Another potential new technology is HVO production from solid biomass.

Fermentation pathways (conventional and advanced ethanol, ATJ)

Conventional ethanol production is a mature technology. However, there is continuous research in efficiency improvement and GHG emission reductions.

Further R&D topics include improvement of quality of high-protein food (for human consumption), CO2 capture and utilization, e.g. for RFNBO production, or storage, sustainability hubs (resilient ecosystems) and processing of lignocellulosic feedstocks.

Advanced ethanol production, especially via the enzymatic hydrolysis of lignocellulosic feedstocks, still remains challenging and has just proven feasibility in Europe. More technological learning at large scale is needed to fully develop the technology.

The conversion of ethanol to SAF via ATJ pathways seems to be technically feasible but requires further development and upscaling.

Gasification pathways (SNG, methanol/DME, FT)

The gasification technology is demonstrated at pre-industrial scale. Further R&D on pathways could include catalytic hydrothermal gasification and upgrading to hydrogen or biomethane and gasification and upgrading to bioethanol. Technology development is required to improve yields, develop further feedstock diversification, integrate tech components and to upscale gasification pathways. Biomass supply chains have to be organized at industrial scale.

Further R&D is required for safe use of ammonia and blending limits for ships.

Note that the FT synthesis is flexible and can be used to process syngas from biomass gasification as well as CO2 and H2, thereby potentially producing RFNBOs.

Pyrolysis pathways

Fast pyrolysis bio-oil (FPBO) production is demonstrated at commercial scale, and further upgrading to transport fuels has recently proven technical feasibility. FBPO can be used for coprocessing in refineries. FBPO upgrading to transport fuels especially for shipping and aviation is developing but still requires large scale demonstration.

On the medium term, competition may exist with energy uses of FPBO, i.e. use as industrial boiler fuel and co-processing in refineries. The pathway ‘pyrolysis-gasification-FT synthesis’ is treated as emerging technology in this context less to its technical maturity (which is rated at least TRL 6) but rather due to the likelihood that other FPBO uses will prevail on the medium term.

It is expected that with an increase in FPBO production capacity and also a potential extension to less favourable feedstocks there will be an increased availability of FPBO with lower quality, which is still suitable as gasifier fuel. It is reasonable to assume that there are more large-scale gasifiers available towards 2050 that are or can be equipped to also feed in liquid fuels such as FPBO.

Another emerging technology is ‘intermediate pyrolysis-hydrodeoxygenation’. It is also rated around TRL 6 with a promising application to produce advanced biofuels from sewage sludge. This technology produced an intermediate product, which is well-suited for co-processing in refineries.

Hydrothermal pathways

Biomass hydrothermal liquefaction is a multistep process. For commercialization, further innovation and validation of several of the steps is still needed, including feed pre-treatment - including size reduction to avoid reactor clogging -, lignocellulose biomass pre-processing, heat-exchanger designs, products separation, process waste treatment, removal of nitrogen and oxygen from the bio-crude via upgrading or their reduction in the feedstock before conversion, HTL reaction optimization, catalysts choice, and desalting.

An additional important issue that needs rapid investigation is the study of the HTL supply chains, as in many cases the raw material is distributed and HTL conversion and bio-crude upgrading could take place at different sites. For example, a dedicated HTL conversion facility will produce raw bio-crude and the upgrade will be done in already installed commercial fossil fuel refinery.

One of technically most promising feedstocks for HTL conversion is algal biomass. Currently, algal biomass is used to produce food or biomaterials rather than biofuels, due to the high costs of algae cultivation. However, if technology development proceeds, the aviation sector could potentially purchase algae-based fuels.

APPENDIX 1 Feedstock-technology matrices

Feedstock data		**Ability of technology to utilise feedstock (2030)**										
Code	**Short name**	Anarobic digestion	HVO/HEFA (advanced feedstocks)	FAME (advanced feedstocks)	Advanced ethanol	Alcohol to Jet (ATJ)	Gasification + SNG	Gasification + methanol/DME	Gasification + FT	Pyrolysis (co-feeding)	Pyrolysis (upgrading)	HTL
1200	Prim_forest_residues				1	1	1	1	1	1	1	1
1220	Prim_forest_stumps				1	1	1	1	1	1	1	1
2101	Ligno_crops_unused_land				1	1	1	1	1	1	1	
2102	Oil_crops_unused_land		1	1								
2103	Woody_crops_unused_land				1	1	1	1	1	1	1	1
2201	Prim_res_cereal_straw				1	1	1	1	1	1	1	1
2202	Prim_res_other_straw				1	1	1	1	1	1	1	1
2203	Prim_res_sugar_leaves	1			1	1						1
2204	Prim_res_perm_crops				1	1	1	1	1	1	1	1
2301	Animal_solid_manure	1										
2302	Animal_liquid_manure	1										
4111	Sec_res_sawdust				1	1	1	1	1	1	1	1
4112	Sec_res_other_sawmill				1	1	1	1	1	1	1	1
4121	Sec_res_semi_woodbp				1	1	1	1	1	1	1	1
4122	Sec_res_other_wood				1	1	1	1	1	1	1	1
4131	Sec_res_bark				1	1	1	1	1	1	1	
4132	Sec_res_black_liquor						1	1	1			
4201	Sec_res_rice_husk											
4202	Sec_res_grapes	1			1	1	1	1	1	1	1	1
4203	Sec_res_cereal_bran	1			1	1	1	1	1	1	1	1
4204	Sec_res_maize_cobs				1	1	1	1	1	1	1	1
4205	Sec_res_olive_stones						1	1	1	1	1	1
4206	Sec_res_sgb_bagasse				1	1	1	1	1	1	1	1
4215	Sec_res_DDGS	1	1	1								
4217	Sec_res_Cglycerin	1	1									
5101	Organic_waste_sepa	1										
5102	Organic_waste_mixed	1										
5103	Waste_retail_wholesale	1			1	1						1
5108	Waste_sewagesludge_org	1										
5211	Post_cons_wood_hazard						1	1	1	1	1	1
5212	Post_cons_wood_non_hazard				1	1	1	1	1	1	1	1
6101	Prim_res_fish	1										
7101	Sea_algea_micro	1										
7102	Sea_algea_macro	1										
	Total Annex IX, part A											
2104	Ligno_crops_degraded_land				1	1	1	1	1	1	1	1
2105	Oil_crops_degraded_land		1	1								
2106	Woody_crops_degraded_land				1	1	1	1	1	1	1	1
4210	Sec_res_ADRW	1			1							

Feedstock data		Ability of technology to utilise feedstock (2030)											
Code	Short name	Anarobic digestion	HVO/HEFA (advanced feedstocks)	FAME (advanced feedstocks)	Advanced ethanol	Alcohol to Jet (ATJ)	Gasification + SNG	Gasification + methanol/DME	Gasification + FT	Pyrolysis (co-feeding)	Pyrolysis (upgrading)	HTL
4216	Sec_res_ani_fats12		1	1								
5106	Waste_UCO		1	1								
	Total Annex IX, part B											
2107	Intermediate_crop_Sorg				1	1	1	1	1	1	1	1
2108	Intermediate_crop_oil		1	1								
2109	Cover_crop_ligno				1	1	1	1	1	1	1	1
2205	Prim_res_damaged_crops	1			1	1	1	1	1	1	1	1
4207	Sec_res_olive_pommace	1			1	1	1	1	1	1	1	1
4208	Sec_res_BSG	1			1	1						
4209	Sec_res_LWP	1										
4211	Sec_res_Bakery	1			1	1						
4212	Sec_res_ddrink_prod	1										
4213	Sec_res_vinasse	1			1	1						
4214	Sec_res_DUR	1			1	1						
5104	Waste_fruit_vegetable	1			1	1						
5105	Waste_starchy_effluents	1			1	1						
5107	Waste_brown_grease		1	1								
5109	Waste_mun_otherSS	1										
7103	Land_algea_oil		1	1								
7104	land_algea_cyanobac											
	Total Annex IX, part B, new											
1100	Stemwood				1	1	1	1	1	1	1	1

Feedstock data		Ability of technology to utilise feedstock (2050)										
Code	**Short name**	Anarobic digestion	HVO/HEFA (advanced feedstocks)	FAME (advanced feedstocks)	Advanced ethanol	Alcohol to Jet (ATJ)	Gasification + SNG	Gasification + methanol/DME	Gasification + FT	Pyrolysis (co-feeding)	Pyrolysis (upgrading)	HTL
1200	Prim_forest_residues				1	1	1	1	1	1	1	1
1220	Prim_forest_stumps				1	1	1	1	1	1	1	1
2101	Ligno_crops_unused_land				1	1	1	1	1	1	1	1
2102	Oil_crops_unused_land		1	1								
2103	Woody_crops_unused_land				1	1	1	1	1	1	1	1
2201	Prim_res_cereal_straw	1			1	1	1	1	1	1	1	1
2202	Prim_res_other_straw	1			1	1	1	1	1	1	1	1
2203	Prim_res_sugar_leaves	1			1	1	1	1	1	1	1	1
2204	Prim_res_perm_crops				1	1	1	1	1	1	1	1
2301	Animal_solid_manure	1					1	1	1			1
2302	Animal_liquid_manure	1										1
4111	Sec_res_sawdust				1	1	1	1	1	1	1	1
4112	Sec_res_other_sawmill				1	1	1	1	1	1	1	1
4121	Sec_res_semi_woodbp				1	1	1	1	1	1	1	1
4122	Sec_res_other_wood				1	1	1	1	1	1	1	1
4131	Sec_res_bark				1	1	1	1	1	1	1	
4132	Sec_res_black_liquor						1	1	1	1	1	1
4201	Sec_res_rice_husk				1	1	1	1	1	1	1	
4202	Sec_res_grapes	1			1	1	1	1	1	1	1	1
4203	Sec_res_cereal_bran	1			1	1	1	1	1	1	1	1
4204	Sec_res_maize_cobs				1	1	1	1	1	1	1	1
4205	Sec_res_olive_stones						1	1	1	1	1	1
4206	Sec_res_sgb_bagasse	1			1	1	1	1	1	1	1	1
4215	Sec_res_DDGS	1	1	1								
4217	Sec_res_Cglycerin	1	1									
5101	Organic_waste_sepa	1	1									1
5102	Organic_waste_mixed	1					1	1	1	1	1	1
5103	Waste_retail_wholesale	1			1	1	1	1	1	1	1	1
5108	Waste_sewagesludge_org	1					1	1	1			1
5211	Post_cons_wood_hazard				1	1	1	1	1	1	1	1
5212	Post_cons_wood_non_hazard				1	1	1	1	1	1	1	1
6101	Prim_res_fish	1	1	1	1	1						1
7101	Sea_algea_micro	1	1	1	1	1						1
7102	Sea_algea_macro	1	1	1	1	1						1
	Total Annex IX, part A											
2104	Ligno_crops_degraded_land				1	1	1	1	1	1	1	1
2105	Oil_crops_degraded_land		1	1								
2106	Woody_crops_degraded_land				1	1	1	1	1	1	1	1
4210	Sec_res_ADRW	1			1	1						

Feedstock data		Ability of technology to utilise feedstock (2050)											
Code	**Short name**	Anarobic digestion	HVO/HEFA (advanced feedstocks)	FAME (advanced feedstocks)	Advanced ethanol	Alcohol to Jet (ATJ)	Gasification + SNG	Gasification + methanol/DME	Gasification + FT	Pyrolysis (co-feeding)	Pyrolysis (upgrading)	HTL
413201	[none]		1	1								
413202	[none]					1						
	Total Annex IX, part A new											
4216	Sec_res_ani_fats12		1	1								
5106	Waste_UCO		1	1								
	Total Annex IX, part B											
2107	Intermediate_crop_Sorg				1	1	1	1	1	1	1	1
2108	Intermediate_crop_oil		1	1								
2109	Cover_crop_ligno				1	1	1	1	1	1	1	1
2205	Prim_res_damaged_crops	1			1	1	1	1	1	1	1	1
4207	Sec_res_olive_pommace	1			1	1	1	1	1	1	1	1
4208	Sec_res_BSG	1			1	1						1
4209	Sec_res_LWP	1										
4211	Sec_res_Bakery	1			1	1						1
4212	Sec_res_ddrink_prod	1			1	1	1	1	1	1	1	1
4213	Sec_res_vinasse	1			1	1						
4214	Sec_res_DUR	1			1	1	1	1	1	1	1	1
5104	Waste_fruit_vegetable	1			1	1						1
5105	Waste_starchy_effluents	1			1	1						
5107	Waste_brown_grease		1	1								
5109	Waste_mun_otherSS	1										1
7103	Land_algea_oil	1	1	1								
7104	land_algea_cyanobac				1	1						
	Total Annex IX, part B, new											
1100	Stemwood				1	1	1	1	1	1	1	1

APPENDIX 2 Determination of indigenous biomass production

Current production of lignocellulosic biomass in the EU27

Building on the information provided by Task 2, Eurostat have been used data to determine the indigenous production of biomass for heat and power, expressed in Mtoe/year.

The Eurostat data (Supply of biomass – annual data, online data code: NRG_CB_BM)[63] is available in thousand cubic meters and in TJ. However, the dataset in thousand cubic meters is much more complete, e.g., many countries have reported only in thousand cubic meters and not in TJ. Therefore, we have decided to use the biomass data expressed in thousand cubic meters and multiply it with a realistic conversion factor that was determined in the following way. For each biomass type we have decided to assess the (weighted) average conversion factors used by each country that provided both the data in cubic meters and in TJ. After that, this average conversion factor was applied to the data in thousand cubic meters provided by all countries (including those that reported only in thousand m^3 and not in TJ).

The definitions of the different biomass types reported on in Eurostat can be found in the reporting instruction that Eurostat provides to the Member States (Eurostat 2021)[64]. Since various biomass types are part of larger categories, we have displayed their hierarchy below, applying the numbering used in the Eurostat reporting instruction, and between brackets the identifier used in the Eurostat database.

1. Solid biofuels / forest biomass used for energy production[65] (R5100)

- 1a Primary biomass – from forest (R5101)
    - 1ai Branches and treetops (R5102)
    - 1aii Stumps (R5103)
    - 1aiii Roundwood (R5104)
        - 1aiii-I Industrial roundwood (R5105)
        - 1aiii-II Fuelwood (R5106)
- 1b Forest-based industry co-products (R5107)

[63] See https://ec.europa.eu/eurostat/databrowser/view/NRG_CB_BM__custom_7693391/default/table for the exact data source used.
[64] Eurostat (2021) Biomass reporting under annex IX, Part 1 (m) to Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 december 2018 on the Governance of the Energy Union and the Climate action. See https://ec.europa.eu/eurostat/documents/38154/13437164/Biomass-questionnaire-instructions-2020.pdf/c26a8d10-e490-fbed-e76c-b87855bdc84a?t=1634715494028 , which is found under main page https://ec.europa.eu/eurostat/web/energy/methodology#Annual%20data
[65] It is observed that the Eurostat database uses the term “Solid biomass”, while the reporting instruction uses “Forest biomass used for energy production” as overall term for category 1.

- 1bi Bark (R5108)
- ibii Chips, sawdust and other wood particles (R5109)
- ibiii Black liquor (R5140)

- 1c Post-consumer wood (R5112)
- 1d Processed wood-based fuel, produced – from feedstocks [not accounted under point (1a, b or c)] (R5113)
  - 1di Charcoal (R5160)
  - 1dii Wood pellets (R5111)

2. Agricultural biomass (R5151)

- 2a Energy crops for electricity or heat (including short rotation coppice) (R5152)
  - 2ai Energy crops for electricity or heat – from food and feed feedstocks (R5153)
- 2b Agricultural crop residues for electricity or heat (R5154)

3. Organic waste biomass (W6205)

- 3a Renewable fraction of industrial waste (R5118)
- 3b Renewable municipal waste (W6210)
- 3c Waste sludges (W6230)

For the determination of the indigenous biomass production for heat and power, we have decided the most detailed biomass classification for which statistical data is available. The result is presented in Table A2 - 1.

Cat.	Total biomass use for energy – most detailed – to be used in report	'000 m^3	GJ/ m^3	PJ	Mtoe
1ai	Branches and treetops	22,332	4.45	99	2.4
1aii	Stumps	304	4.37	1	0.0
1aiii-I	Industrial roundwood	51,442	6.23	321	7.7
1aiii-II	Fuelwood	176,304	8.62	1,520	36.3
1bi	Bark	35,509	5.76	204	4.9
ibii	Chips, sawdust and other wood particles	64,685	7.07	457	10.9
ibiii	Black liquor	46,000,658	0.01	520	12.4

Cat.	Total biomass use for energy – most detailed – to be used in report	‘000 m^3	GJ/ m^3	PJ	Mtoe
2a	Energy crops for electricity or heat (including short rotation coppice)	2,879	6.45	19	0.4
2b	Agricultural crop residues for electricity or heat	41,324	3.55	147	3.5
1di	Charcoal	873	11.61	10	0.2
1dii	Wood pellets	29,740	11.58	344	8.2
3a	Renewable fraction of industrial waste	34,863	3.29	115	2.7
3b	Renewable municipal waste	171,023	2.88	493	11.8
3c	Waste sludges	7,578	4.62	35	0.8
	Total	**46,639,515**		**4,286**	**102.4**

Table A2 - 1 Total indigenous biomass production for heat and power (Source: calculations BTG based on Eurostat data)

The final number of 102.4 Mtoe is used as proxy for the part of the biomass potential that is already used for electricity and heat production, and thus not available for advanced biofuels production. The found value is in line with the statistical reporting as performed by Bioenergy Europe, that is summarised in Table A2 - 2 below. The consumption of solid biomass (103.0 Mtoe) and municipal waste (renewable fraction) (11.4 Mtoe) adds up to 114.4 Mtoe, which is in line with the 102.4 Mtoe indigenous solid biomass production that we have obtained from Eurostat. The remaining gap can be explained by imports of biomass.

	Power only	CHP	Bioheat	Total
Solid biomass	5.8	18.4	78.8	103.0
Municipal waste, renewable fraction	2.4	5.4	3.6	11.4
Bioliquids	0.6	0.5	1.1	2.2
Biogas	2.8	7.7	4.0	14.6
Total	**11.6**	**32.0**	**87.5**	**131.2**

Table A2 - 2 Biomass use for heat and electricity production in the EU27. Source: compilation BTG based on annual reports[66] of Bioenergy Europe.

Current production of biogas in the EU27

No Eurostat data was found on biogas production in the EU. According to bioenergy Europe’s “Biogas Statistical Report 2023”[67], in 2021, the European biogas market reached 15.075 ktoe in terms of gross inland energy consumption of combined biogas and biomethane. Assuming

[66] Annual reports of Bioenergy Europe on pellets, biomass supply, bioheat and bioelectricity. Available to Bioenergy Europe Members.
[67] Press release on launch of Bioenergy Europe’s “Biogas Statistical Report 2023” https://www.bioenergy-news.com/news/bioenergy-europe-releases-biogas-statistical-report-2023/

that the biogas consumption equals its production, the following division can be made between the different plant and thus feedstock types (See Table A2 - 3).

Biogas plant type	Percentage[a)]	Mtoe
Agriculture (manure, crops)	64%	9.6
Sewage sludge	7%	1.1
Landfill	14%	2.1
Organic municipal solid waste	0.85%	0.1
Industrial waste	1.33%	0.2
Other	0.25%	0.0
Unknown	13%	2.0
Total	100%	15.1

a) source: Biogas Statistical report 2023 Bioenergy Europe

Table A2 - 3 Biogas production per biogas plant type

Current use of feedstocks for advanced biofuels in the EU27

No Eurostat data was found on the feedstocks for advanced biofuels production in the EU. According to the 2023 production data (see Table A2 - 4), it involves the following categories:

- Transesterification of UCO and AF
- Transesterification of e.g., brown grease
- Hydrotreatment of tall oil

For three other categories in the list ("hydrotreatment of UCO and AF", "hydrotreatment of cover crops from marginal lands", and "transesterification of cover crops from marginal lands") the current advanced biofuels production is negligible.

Key question is how much of these advanced biofuels are made from domestic (EU27) originating feedstocks. For this, ISCC (2021)[68] data is used. ISCC is a certification scheme, which maintains a database of the origin and use of lipids for advanced biofuels production.

Results are shown in the next table. Data on Waste/UCO, Animal fat, and brown grease is taken from the ISCC data. For tall oil, it is assumed that all tall oil used in EU for advanced biofuels production is originating from EU. To convert tonnes to Mtoe, the same conversion factors as used in T2 are used.

Type of Feedstock	Originating from EU27 (t/y)	Originating from EU27 (Mtoe/y)
Waste/UCO	596,397	0.52
Animal fat	145,203	0.13
Brown grease	509,988	0.44

[68]https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/voluntary-schemes_en#documents

Type of Feedstock	Originating from EU27 (t/y)	Originating from EU27 (Mtoe/y)
Tall oil	130,000	0.11
Current use lipids for biofuels		**1.20**

Table A2 - 4 Current use of feedstocks for advanced biofuels in the EU27

From the same ISCC database, the imports of UCO and brown grease in the EU27 in 2021 were respectively 3 million and 1 million t/y.

APPENDIX 3 Long list of critical factors and ranking by advanced biofuels experts

Based on the input from Task 3 as available on 31st of May, and additions made by the project Team, a long list of possible critical factors hindering the industry to take up investment in advanced biofuels capacity has been made. The contracted advanced biofuels experts (Philippe Marchand, Francisco Girio and Felipe Ferrari) were asked to prioritise and elucidate the most important gaps, by ranking the critical factors from 1 (= not to critical) to 5 (very critical) and differentiating between advanced biofuels technologies where appropriate. Table A3 - 1,

Table A3 - 2 and Table A3 - 3 on the next pages shows the resulting list. The combined results were used as inputs to focus the further discussion with industries already contacted in Task 3.

#	issue	Anaerobic digestion & upgrading	Hydrotreatment (adv. feedst.)	Transesterification(adv. feedst.)	Fermentation of lignocel. feeds.)	Alcohol to Jet (ATJ/MTJ)	Gasification and methanisation	Gasification and methanol synth.	Gasification and FT-synthesis	Pyrolysis	Hydrothermal liquefaction
1	**Availability of feedstocks**										
1.1	Availability of certain types of feedstocks (e.g. sawdust)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1.2	Competition with other sectors, e.g. pellet combustion, material applications	1.5	2.0	3.0	3.3	3.3	4.0	4.0	4.0	4.0	4.0
1.3	Mandate not to burn agricultural residues in the field needed.	3.0			1.7	1.7					
1.4	UCO collection could be made obligatory for households. This feedstock is high in demand while still underutilised.		3.3	3.3							
2	**Eligibility of feedstocks**										
2.1	Policies regarding intermediate crops (new in Annex IX-A), what is eligible, what not.	1.5	4.3	4.3	4.3	4.3	4.3	4.3	4.3	3.7	3.7
2.2	Only non-food feed crops for aviation and maritime fuels limits the use of sugar/starch crops, which could result in high GHG reduction.		4.3	4.0	4.3	4.3					
2.3	Sustainability/biodiversity requirements could make less biomass residues available for advanced biofuels production	3.5	3.5	3.5	5.0	5.0	5.0	5.0	5.0	5.0	3.0
3	**Price & contracting of feedstocks**										
3.1	Biomass demand for fuels for road, maritime and aviation will rise, “there will be a run on it” prices can rise substantially, causing uncertainty.	2.0	4.3	4.3	3.3	3.3	3.3	3.3	3.3	3.0	2.7

#	issue	Anaerobic digestion & upgrading	Hydrotreatment (adv. feedst.)	Transesterification(adv. feedst.)	Fermentation of lignocel. feeds.)	Alcohol to Jet (ATJ/MTJ)	Gasification and methanation	Gasification and methanol synth.	Gasification and FT-synthesis	Pyrolysis	Hydrothermal liquefaction
3.2	High feedstock prices mainly an issue on mid-term, till 2030, as technology development will help to broaden the feedstock base.	1.0	2.5	2.5	3.0	3.0	3.0	3.0	3.0	3.0	2.3
3.3	Difficult to get long term contracts from biomass suppliers	2.5	3.5	3.5	4.0	4.0	3.3	3.3	3.3	3.3	3.0
4	**Feedstock logistics**										
4.1	Alternative raw materials, like primary residues scattered, high collection and transport costs.	3.0	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.3
4.2	Need for hub and spoke model										
5	**Research and technology development**										
5.1	Technology development needed to reach commercial scale installations (TRL9)	2.3	2.7	3.3	4.3	4.7	4.7	4.7	4.0	5.0	5.0
5.2	Technology development enabling technologies to use a wider range of feedstocks (gasification, pyrolysis, HTL), enabling switch from woody feedstocks to agricultural residues	1.3	3.0	3.5	3.3	3.3	3.7	3.7	3.7	4.0	4.3
5.3	Optimal utilisation of feedstock & released CO2 required	3.5	3.5	3.5	3.0	2.3	3.3	3.3	3.3	3.0	3.7
5.4	Technology development required to reduce biofuel production costs	2.0	3.3	3.7	3.0	2.7	3.3	3.3	3.3	3.3	4.3
5.5	Technology can be made fully independent from fossil resources (e.g. natural gas, coal, oil)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

Table A3 - 1 Long list of critical issues for capacity development of advanced biofuels

#	issue	Anaerobic digestion & upgrading	Hydrotreatment (adv. feedst.)	Transesterification(adv. feedst.)	Fermentation of lignocel. feeds.)	Alcohol to Jet (ATJ/MTJ)	Gasification and methanisation	Gasification and methanol synth	Gasification and FT-synthesis	Pyrolysis	Hydrothermal liquefaction
6	**Financial issues**										
6.1	Lack of price security for advanced biofuels	5.0	3.3	3.3	4.3	4.3	3.7	3.7	3.7	3.7	3.7
6.2	High investment costs (for large scale installation)	2.0	2.5	2.5	4.0	5.0	4.7	4.7	4.7	5.0	4.5
6.3	High biomass prices	3.0	3.7	3.7	4.0	4.0	5.0	5.0	5.0	4.0	5.0
7	**Subsidies/incentives**										
7.1	Price security offtake advanced biofuels for 10 years needed	4.0	3.3	3.3	3.3	4.0	3.7	3.7	3.3	3.3	3.7
7.2	Need for investment subsidies	3.3	3.7	3.7	3.3	4.0	4.0	4.0	4.0	4.0	4.0
7.3	Biofuels could be stronger promoted (e.g. Important Project of Common European Interest (IPCEI) dedicated for biofuels)	4.3	4.3	4.0	4.7	4.7	5.0	5.0	5.0	5.0	5.0
7.4	Access to low-cost capital required	3.3	3.7	3.7	4.0	4.3	4.3	4.3	4.3	4.3	4.3
7.5	Lack of incentives for bio-based chemicals, making coproduction of biofuels and biochemicals more attractive	2.0	2.0	2.0	3.0	2.0	2.7	2.7	2.0	2.7	2.7
7.6	Opt. out penalty for SAF should be high enough.		4.5			4.3					
7.7	Carbon offsetting used as alternative for real switch to advanced biofuels and renewable fuels	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
7.8	Carbon taxes should play an important role as rational price /CO2 reduction mechanism	5.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5

#	issue	Anaerobic digestion & upgrading	Hydrotreatment (adv. feedst.)	Transesterification(adv. feedst.)	Fermentation of lignocel. feeds.)	Alcohol to Jet (ATJ/MTJ)	Gasification and methanisation	Gasification and methanol synth.	Gasification and FT-synthesis	Pyrolysis	Hydrothermal liquefaction
8	**Regulatory uncertainty**										
8.1	Policy uncertainty to ensure continued demand for advanced biofuels in hard to abate sectors (e.g. aviation and shipping)	3.5	5.0	4.3	4.7	4.7	5.0	5.0	5.0	5.0	5.0
8.2	Uncertainty on what feedstocks allowed or not (e.g. Delegated Act annex IX takes long time)	4.0	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
8.3	Long term policy certainty (e.g. during RED II implementation, RED III proposal already there, including discussion on eligibility feedstocks). Policies to be fixed and stable for long period of time.	4.0	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
9	**Regulatory/standardisation/permitting issues**										
9.1	Administrative burdens	1.3	1.3	1.3	1.3	0.0	1.3	1.3	1.3	1.3	1.3
9.2	Long permit lead times	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
9.3	Lack of united EU set of rules subsidies and incentives for advanced biofuels	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0

Table A3 - 2 Long list of critical issues for capacity development of advanced biofuels (Cont'd)

#	issue	Anaerobic digestion & upgrading	Hydrotreatment (adv. feedst.)	Transesterification(adv. feedst.)	Fermentation of lignocel. feeds.)	Alcohol to Jet (ATJ/MTJ)	Gasification and methanisation	Gasification and methanol synth.	Gasification and FT-synthesis	Pyrolysis	Hydrothermal liquefaction
10	**Suitable locations for facilities**										
10.1	Lack of customer sites where biomass logistics, permitting and off-take can be rapidly developed	2.0	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
10.2	Limited availability of suitable industrial sites	2.0	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
11	**Employment issues**										
11.1	Availability of technical skills to supply the new planned installations	1.3	1.7	1.7	2.0	2.0	2.0	2.0	2.0	2.0	2.3
11.2	Willingness of technical staff to work on remote industrial facilities (close to the feedstock, away from cities)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
11.3	Availability of personnel for biomass supply	1.7	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
12	**Cooperation between industrial sectors**										
12.1	Connection raw material sectors and industrial sectors	2.3	2.3	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
13	**Social acceptance**										
13.1	Social acceptance with local communities	2.3	2.0	2.0	2.0	2.0	2.3	2.3	2.3	2.3	2.3
13.2	Social acceptance at country level	2.3	2.3	2.7	3.0	2.7	2.7	2.7	2.7	2.7	2.7
13.3	Specific lobby against certain technologies	2.0	2.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5

Table A3 - 3 Long list of critical issues for capacity development of advanced biofuels (Cont'd)

APPENDIX 4 GHG calculation method & eligibility CO_2 for use in RFNBO

Regarding the use of CO2 for the production of RFNBOs, in principle any source can used as long as the emissions savings are at least 70% comparted to the fossil fuel comparator (of 94 gCO2-eq/MJ) is met, following the methodology as found in Delegated Regulation 2023/1185.

$E = e_i + e_p + e_{td} + e_u - e_{ccs}$

Where:

E= total emissions from the use of the fuel (gCO2eq/MJ fuel)

$e_i = e_i$ elastic + e_i rigid – e ex-use: emissions from supply of inputs (gCO2-eq/MJ fuel)

> e_i elastic = emissions from elastic inputs (gCO2-eq/MJ fuel)
>
> e_i rigid = emissions from rigid inputs (gCO2-eq/MJ fuel)
>
> e ex-use = emissions from inputs' existing use or fate (gCO2-eq/MJ fuel)

e_p = emissions from processing (gCO2-eq/MJ fuel)

e_{td} = emissions from transport and distribution (gCO2-eq/MJ fuel)

e_u = emissions from combusting the fuel in its end-use (gCO2-eq/MJ fuel)

e_{ccs}= emission savings from carbon capture and geological storage (gCO2eq/MJ fuel)

One key element in this calculation is e ex-use, which includes the CO2 equivalent of the carbon incorporated in the chemical composition of the fuel that would have otherwise been emitted as CO2 into the atmosphere. The intake of e ex-use in the RFNBO compensates for the emission of CO2 after combustion of the RFNBO as (e_u). Article 10 of Delegated Regulation 2023/1184 determines that the CO2 from the following sources count as e ex use:

a) the CO2 has been captured from an activity listed under Annex I of Directive 2003/87/EC and has been taken into account upstream in an effective carbon pricing system [i.e. EU-ETS] and is incorporated in the chemical composition of the fuel before 2036. This date shall be extended to 2041 in other cases than CO2 stemming from the combustion of fuels for electricity generation; or

b) the CO2 has been captured from the air; or

c) the captured CO2 stems from the production or the combustion of biofuels, bioliquids or biomass fuels complying with the sustainability and greenhouse gas saving criteria and the CO2 capture did not receive credits for emission savings from CO2 capture and replacement, set out in Annex V and VI of Directive (EU) 2018/2001; or

d) the captured CO2 stems from the combustion of renewable liquid and gaseous transport fuels of non-biological origin or recycled carbon fuels complying with the greenhouse gas saving criteria, set out in Article 25(2) and Article 28(5) of Directive (EU) 2018/2001 and this Regulation; or

e) the captured CO2 stems from a geological source of CO2 and the CO2 was previously released naturally.

Captured CO2 stemming from a fuel that is deliberately combusted for the specific purpose of producing the CO2 and CO2, the capture of which has received an emissions credit under other provisions of the law shall not be included.

In practice it means that CO2 from fossil energy-based electricity plants can be used until 2036, and that CO2 from other EU-ETS companies can be used until 2041. After that date CO2 from bioenergy installations and direct air capture will be the main sources of carbon for RFNBOs.

APPENDIX 5 E-hydrogen for mobility projects from IEA database

Table A5 - 1 Capacity development of E-hydrogen for mobility, retrieved from the IEA hydrogen projects database (IEA 2022).

E-hydrogen for mobility		
Company/Project	PJ/year	ktoe/year
Operational		
Alliander Oosterwolde - solar park of GroenLeven	0.03	0.68
Apex Energy, Rostock-Laage	0.04	0.97
AuxHYGen, phase 1	0.02	0.45
Cotbus	0.00	0.07
DEMO4GRID	0.08	1.94
Don Quichote	0.01	0.13
eFarm (5 production sites in North Frisia)	0.02	0.48
EnBW H2 station, Stuttgart	0.01	0.13
Energiepark Mainz	0.11	2.58
Energy observer	0.00	0.02
FaHyence	0.00	0.07
GNVert H2	0.00	0.08
H2 Logic 3 HRS with onsite electrolysis in Copenhagen	0.03	0.63
H2 Logic HRS with onsite electrolysis Aalborg	0.01	0.21
H2 Logic HRS with onsite electrolysis Holstebro	0.01	0.21

E-hydrogen for mobility		
Company/Project	PJ/year	ktoe/year
H2 Logic HRS with onsite electrolysis in Vejle	0.01	0.21
H2BER (Berlin airport)	0.01	0.22
H2Herten	0.00	0.08
H2KT - Hydrogen Energy Storage in Nuuk	0.00	0.04
H2Move, Fraunhofer ISE	0.00	0.02
H2Nodes, Parnu	0.02	0.41
H2Nodes, Riga	0.01	0.31
H2ORIZON	0.02	0.43
H2PiyR Pamiers	n.k.	n.k.
Hamburg - Schnackenburgallee	0.00	0.08
Hamburg Hafen City, CEP	0.01	0.27
HRS Aalborg	0.01	0.13
HRS CMB	0.02	0.43
HRS CMB Port of Antwerp	0.02	0.52
HRS CNH2 Puertollano	0.00	0.03
HRS TMB Barcelona	0.04	0.86
HyBALANCE	0.02	0.52
Hybrid Power Plant Enertrag, Prenzlau	0.01	0.27
Hydrogen Valley South Tyrol - Bolzano, CHIC	0.02	0.40
HYPOS (several projects)	0.03	0.62
Hystock (EnergyStock)	0.02	0.49
INGRID	0.02	0.56
Leuchtturmprojekt Power-to-Gas Baden-Württemberg	0.02	0.56
Lighthouse Project PtG Baden-Wuerttemberg	0.02	0.49
Localhy	n.k.	n.k.
Oxelösund Forklifts	n.k.	n.k.
Parnu refuelling station	0.02	0.45
Pau bus station HRS	0.01	0.21

E-hydrogen for mobility		
Company/Project	PJ/year	ktoe/year
Power to Green H2 Mallorca - Phase 1	0.04	0.95
Sirea - Castres site	0.01	0.21
SMT-AG Artois-Gohelle	0.01	0.24
Trzebinia refinery	0.04	1.00
Veolia wastewater sludge plant	n.k.	n.k.
vHyGO - 1st Facility for H2 buses in Bouin (H2 Ouest)	0.01	0.31
WindGas Hamburg-Reitbrook	0.03	0.64
Wuppertal refuelling station	0.05	1.12
Total operational	**0.91**	**21.74**
Demo		
Aeropila	0.00	0.00
Brande Hydrogen project	0.01	0.17
CUTE and HyFLEET:CUTE, Barcelona	0.01	0.13
CUTE, Stockholm	0.01	0.13
Etzel, Salt caverns	n.k.	n.k.
GRASSHOPPER	0.00	0.04
GRHYD	0.01	0.22
HEAL - Hydrogen-based Energy Systems for Arctic Logistics	n.k.	n.k.
HRS Halle (Continued as Ref148)	0.01	0.13
Hydrogen village Burgenland	0.00	0.00
HyFLEET:CUTE, Amesterdam	0.01	0.13
HyFLEET:CUTE, Hamburg	0.01	0.13
ITHER	0.00	0.03
Porto, CUTE	0.01	0.13
Power to flex (several pilot projects)	n.k.	n.k.
RES2H2 Gran Canaria	0.00	0.03
SPHYNX, R&D	n.k.	n.k.
Stand-alone power system, Neo Olvio of Xanthi	0.00	0.00

E-hydrogen for mobility		
Company/Project	PJ/year	ktoe/year
Steinbeis Innovation Center Braunschweig	0.02	0.50
Thüga PtG plant Frankfurt/Main	0.01	0.13
Vendée hydrogène	0.07	1.69
WAviatER	n.k.	n.k.
Wind2Hydrogen, HyCentA	0.00	0.04
Total demo	**0.15**	**3.67**
Under construction		
Abanto Technology Park	0.05	1.24
Dijon Métropole Smart EnergHy	0.02	0.49
Duwaal	0.04	0.86
Esslingen District	0.01	0.24
H2GO - 1st phase	0.04	0.99
H2RES - Orsted offshore wind	0.04	0.97
HRS Bremervörde - trains	0.07	1.67
HRS Wilrijk	0.01	0.13
Hydrogen Lab Gorlitz	n.k.	n.k.
Hyoffwind Zeebrugge, 1st phase	0.02	0.50
Hyport - Toulouse-Blagnac Airport	0.02	0.42
Hysolar Green on Road - Nieuwegein	0.04	0.99
Konin Power Plant, phase 1	0.04	1.07
Konin Power Plant, phase 2	0.04	1.07
Power to Green H2 Mallorca (GREEN HYSLAND) - Phase 2	0.16	3.72
SoHyCal	0.13	3.22
WIVA P&G Hydrogen Region	0.44	10.46
Wunsiedel Energy Park (Phase 1)	0.14	3.44
Total under construction	**1.32**	**31.51**
FID		
"Waste-to-wheels" Charleroi		

E-hydrogen for mobility		
Company/Project	PJ/year	ktoe/year
Alcázar de San Juan - pHYnix	0.17	4.16
Belfort HRS	0.02	0.49
BENORTH2 (Amorebieta-Boroa power plant), phase 1	0.42	9.93
ENERTRAG-Sunfire (Prenzlau)	0.20	4.86
GREEN H2 Langosteira	n.k.	n.k.
H2-Login	0.00	0.01
HaYrport	0.02	0.37
Herten HRS	0.05	1.26
HyAMMED HD trucksrefuelling station	0.04	1.05
HYBAYERN	0.05	1.23
Hyoffwind Zeebrugge, 2nd phase	0.50	11.92
Hyport	1.04	24.83
Hysetco taxi project	0.04	1.07
Hyways for future, 1st hub	0.04	0.86
Linde Leuna Chemical Complex	0.43	10.31
RIC Energy Valladolid	n.k.	n.k.
Siemens-Air Liquide Oberhausen, Phase 1	0.36	8.59
UpHy	0.11	2.58
vHyGO - 2nd facility in Vannes (EffiH2)	1.21	28.81
vHyGO -3rd facility in Brest	0.03	0.73
vHyGO -4th facility in St Nazaire	0.03	0.74
vHyGO -5th facility in Dieppe	0.03	0.74
Zero Emission Valley (14 HRS)	n.k.	n.k.
Total FID	**4.80**	**114.55**
Concept and feasibility		
HYEELIWTS - terminal of Muuga	n.k.	n.k.
Saint-Brieuc Armor Agglomeration production plant	n.k.	n.k.
Algeciras Bay	4.93	117.69

E-hydrogen for mobility		
Company/Project	PJ/year	ktoe/year
Ansasol - Castilla y León	1.56	37.26
AuxHYGen, phase 2	0.04	0.97
BENORTH2 (Amorebieta-Boroa power plant), phase 2	3.74	89.38
BLUE MED	0.21	4.97
Blue Seal	1.04	24.83
BotnialänkenH2	2.08	49.66
Canary Islands Hub, phase 1	0.12	2.87
Canary Islands Hub, phase 2	n.k.	n.k.
CHESS	0.62	14.90
Clean Hydrogen Coastline, Ems	8.32	198.63
Corrhyd'Occ (Occitanie H2 Corridor)	0.42	9.93
EHYTRANSP - TS Laevad & H2	0.10	2.48
EI-H2 - Aghada (phase 1)	1.04	24.83
EI-H2 - Aghada (phase 2)	55.09	1315.91
ELYgator	4.16	99.31
Energiepark Eemshaven West (phase I)	0.21	4.97
Energiepark Eemshaven West (phase II)	2.08	49.66
Ferrolterra plant	1.66	39.73
Ferrolterra plant, pahse 1	0.42	9.93
Firlough project	n.k.	n.k.
Fronius Solhub	0.03	0.74
FUTURA	0.04	0.97
Get H2 Lingen, phase 3	1.55	36.96
Get H2 Lingen, phase 4	1.80	42.97
Get H2 Lingen, phase 5	2.08	49.66
Get H2 Lingen, phase 6	35.34	844.17
GH2 Green Hydrogen Project, phase 1	2.03	48.58
GH2 Green Hydrogen Project, phase 2	4.16	99.31

E-hydrogen for mobility		
Company/Project	PJ/year	ktoe/year
Green Crane - La Robla, Phase 1	1.25	29.79
Green Crane, Murcia (part of Green Crane Gigafactory)	3.00	71.65
Green Fuels for Denmark - Phase 1	0.21	4.97
GreenH2UB (10 hubs of 3-10MW, the first one Ref786)	1.98	47.17
GreenH2UB (1st hub, Noord Brabant)	0.10	2.48
GreenMotionSteel	2.49	59.59
GZI Next	0.18	4.30
H_2 Air Base Leeuwarden	0.10	2.48
H2 Emden Electrolyzer	1.04	24.83
H2 Energy Europe Esbjerg green hydrogen	17.99	429.72
H2 in the Ketzin energy transition laborator	0.04	0.99
H2 Valcamonica	0.10	2.38
H2Agrar	0.04	0.99
H2GO - 2nd phase	0.49	11.67
H2HUB		
H2morrow	30.69	732.94
H2UDF, phase I	0.10	2.48
H2UDF, phase II	0.10	2.48
H2UDF, phase III	0.52	12.41
H2V IDF, final phase	6.24	148.97
H2V IDF, phase 1	2.08	49.66
H2V WN Warndt Naborien, final phase	6.24	148.97
H2V WN Warndt Naborien, phase 1	2.08	49.66
HH2E - Met Northeast Germany, phase 1	2.03	48.58
HH2E - Met Northeast Germany, phase 2	20.79	496.57
HRS Alicante	0.10	2.48
HRS Charleroi	n.k.	n.k.
HRS Murcia	0.10	2.48

E-hydrogen for mobility		
Company/Project	PJ/year	ktoe/year
HRS Plataforma Logística PLAZA	0.21	4.97
HRS Valecnia	0.10	2.48
Hydrogen Eagle (Litvínov)	0.54	12.91
Hydrogen Eagle (Spolana)	1.12	26.81
Hydrogen Eagle (Spolana), phase 2	0.62	14.90
Hydrogen Eagle (various hubs)	5.33	127.41
Hygreen Provence 1st phase	0.35	8.44
Hygreen Provence 2nd phase	2.35	56.11
Hygreen Provence 3rd phase	6.34	151.45
HyMAT SH	0.83	19.86
Hyoffwind Zeebrugge, 3rd phase	20.27	484.16
Hyport, phase 2	5.20	124.14
Hysencia, Phase I	0.83	19.86
Hysencia, Phase II	3.33	79.45
HySynergy, phase 2	6.24	148.97
HYVALUE	0.19	4.59
Hyways for future	0.13	3.14
Inspira Madrid	0.21	4.97
IPCEI SilverFrog	17.99	429.72
KEME Energy Sines	0.03	0.74
Konin Power Plant, phase 3	0.81	19.34
La Spezia Green Hydrogen	0.04	0.99
Lhyfe-Enerparc Luckau project	0.10	2.43
Norddeutsches Reallabor - Living Lab Northern Germany	0.44	10.46
Port of Gothenburg - Statkraft	0.08	1.99
Power2AX	0.03	0.64
PRIO ENERGY	0.02	0.40
Rabbalshede Krafts	1.04	24.83

E-hydrogen for mobility		
Company/Project	PJ/year	ktoe/year
Referenzkraftwerk Lausitz	0.18	4.30
Rossello paper factory	n.k.	n.k.
Ruse project	n.k.	n.k.
Siemens-Air Liquide Oberhausen, Phase 1	0.18	4.30
Speicherstadt Kerpen	n.k.	n.k.
Sunrhyse	0.62	14.90
Tarragona Green Chenical complex, phase 1	0.10	2.48
Tarragona Green Chenical complex, phase 2	0.94	22.35
Tarragona Green Chenical complex, phase 3	0.42	9.93
Val d'Hygo (Occitanie H2 Corridor)	0.10	2.48
Vätgas Ljungby	0.04	0.99
Wenger Engineering Bremerhaven	0.03	0.65
Wunsiedel Energy Park (Phase 2)	0.24	5.73
ZEHUS	0.08	1.94
Zero Emission Mobility Corridor	0.71	16.88
Total concept and feasibility	**313**	**7,483**
Grand total	**320**	**7,654**

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A substantial effort is needed to enhance the production capacity of advanced biofuels and to mobilize the required sustainable biomass feedstock, particularly lignocellulosic biomass. This escalation is essential to bridge the gap between the anticipated demand for advanced biofuels, crucial for meeting the EU's climate targets for 2030 and 2050, and the current production capacities, as well as those forecasted by experts. The present production capacity for advanced biofuels and biogas is projected to potentially increase sixfold by 2030.

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