TNO 2022 R11146

TNO innovation for life

CO_2 UTILIZATION IN THE ROTTERDAM HARBOR AREA AND PREPARATION FOR FLIE DEMONSTRATION PROJECTS

Final version, 15-March-2021

SCOPE OF THIS REPORT

This report is the outcome of an assignment by Provincie Zuid-Holland. Provincie Zuid-Holland asked TNO to investigate the potential of synthetic fuel production in Rotterdam Harbour Industrial Cluster (HIC), taking into account on the one hand the availability of waste CO2 streams in HIC and on the other hand the expected growth of the availability of green hydrogen. Synthetic fuels to be considered are kerosene and methanol.

The target is to deliver a substantial contribution to the national goal of 14% non-fossil kerosene use in 2030, as set in the "Ontwerp-Luchtvaartnota" by the Minister van I&W d.d. 15 mei 2020. Part of the assignment is to investigate the future value chain of synthetic fuel production, to identify possible value chain partners, and to initiate cooperation between the value chain partners and the Field Lab Industrial Electrification (FLIE) and start working towards a pilot on a relevant scale in HIC, supported by FLIE (website Field Lab). This assignment was carried out in cooperation between TNO and FLIE partners Deltalinqs and Innovation Quarter.

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ASSIGNMENT OVERVIEW

- This report offers relevant background information and forms the basis for developing a pilot project related to the development of a supply chain for CO_2 utilization.
- The deliverable merges work from separate project tasks, and is divided in the following parts:

- Part 1: Technical report describing the various options available in terms of for CO_2 utilization, with a selection of three promising options for which the corresponding value chains and infrastructure requirements are further evaluated. (p.7)
- Part 2: Public requirements report describing various aspects that are related to a supply chain for CO_2 utilization, concerning regulation, certification, safety & environment, public perception, and funding instruments. (p.31)
- Part 3: Inventory of the role of existing infrastructure (p.60)
- Part 4: Industry engagement report, summarizing the outcome of the interviews that were conducted, as well as the outcome of the workshop held on the 14th of December. (p.65)

EXECUTIVE SUMMARY
PART 1 - TECHNICAL REPORT CO_2 UTILIZATION

- There is ample CO_2 available in PoR from multiple industrial sources. However, they are primarily fossil-based and the vast majority of these streams have a low concentration of CO_2 (<12%). This increases capture costs and energy expenditure.
- Some sources (biogenic CO_2, concentrated CO_2 from process capture and streams containing CO) have a higher potential for utilization from an energy efficiency perspective.
  - The combined potential to produce synthetic kerosene from these sources is in the order of 2 Mton/y, of which only a part would be based on biogenic CO_2
- Regardless of the CO_2 concentration or presence of CO, using **fossil sources** for the production of synthetic hydrocarbon fuels results in a **limit of roughly 40% for the overall CO_2 reduction** (including indirect emissions due to processing and dependant on the carbon intensity of the energy used).
- It is expected that the upcoming EU regulation on Renewable Fuels (REDII) will set a threshold at **70% CO_2 emission reduction.** This is likely to deter investments in synfuel pilots based on fossil CO_2.
- Synthetic fuel from biogenic CO_2 has an emission reduction potential of **75-85%** and is likely to meet the REDII threshold. From this perspective, this is the preferred CO_2 source for synfuel production on the short term, but the availability is limited.
- An alternative source is CO_2 captured from the atmosphere (direct air capture, DAC). Synthetic fuels produced from DAC CO_2 can have a high overall CO_2 reduction factor, but only if low-carbon heat and power are available because the capture and conversion process are very energy intensive.

EXECUTIVE SUMMARY
PART 2 - PUBLIC REQUIREMENTS

- Current EU legislative framework (particularly REDII, ETS directive) **does not give regulatory clarity** for RFNBO (renewability + additionality of procured electricity; eligibility of carbon sources; how emission reductions are to be accounted & credited)
- Legislative updates are ongoing (as part of Green Deal follow-up), which should provide more clarity on how to secure the **challenging 70% GHG reduction target** for RFNBO (incl. e-fuels) as transport fuels
- From EU-REDII perspective, circular carbon sources (**biogenic or atmospheric**) are preferred over fossil CO_2

EXECUTIVE SUMMARY
CONCLUSIONS

- Major infrastructure changes will be necessary for the port of Rotterdam to maintain its position as a major fuels distribution hub in the context of the energy transition. One option is to produce synthetic fuels starting from H2 and CO2 that is captured locally either from industrial sources or directly from air.
- There is ample CO_2 available in PoR from multiple industrial sources, but it's mainly (>90%) fossil-based
- Regardless of the CO_2 concentration or presence of CO, using fossil sources for the production of synthetic hydrocarbon fuels results in a limit of roughly 40% for the overall CO_2 reduction (including indirect emissions due to CO_2 capture and processing, exact number dependent on the carbon intensity of the energy mix).
- Synthetic fuel from biogenic CO_2 has a higher emissions reduction potential and is likely to meet the REDII threshold. This would be a preferred CO_2 source for synfuel production but its availability is limited.
- An alternative source is CO_2 captured from the atmosphere (direct air capture, DAC). Synthetic fuels produced from DAC CO_2 can have a high overall CO_2 reduction factor, but only if low-carbon heat and power are abundantly available, because the capture and conversion processes are very energy intensive.
- Lastly, it should be noted that synthetic fuels have to be competitive with bio-based alternatives. Global capacity for the production of biofuels is rapidly expanding, as some conventional refineries are converted to bio-refineries and new facilities are built based on novel technology.

CONTENTS
PART 1 – TECHNICAL REPORT CO_2 UTILIZATION

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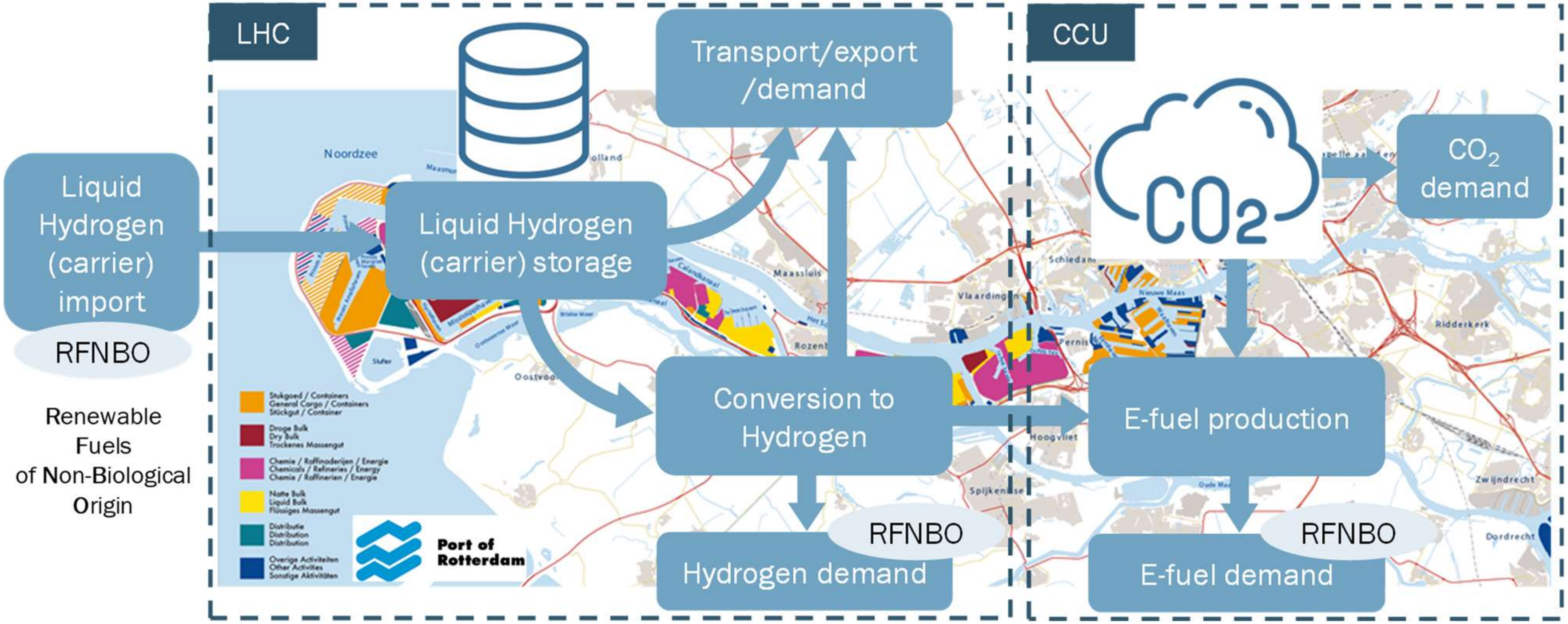
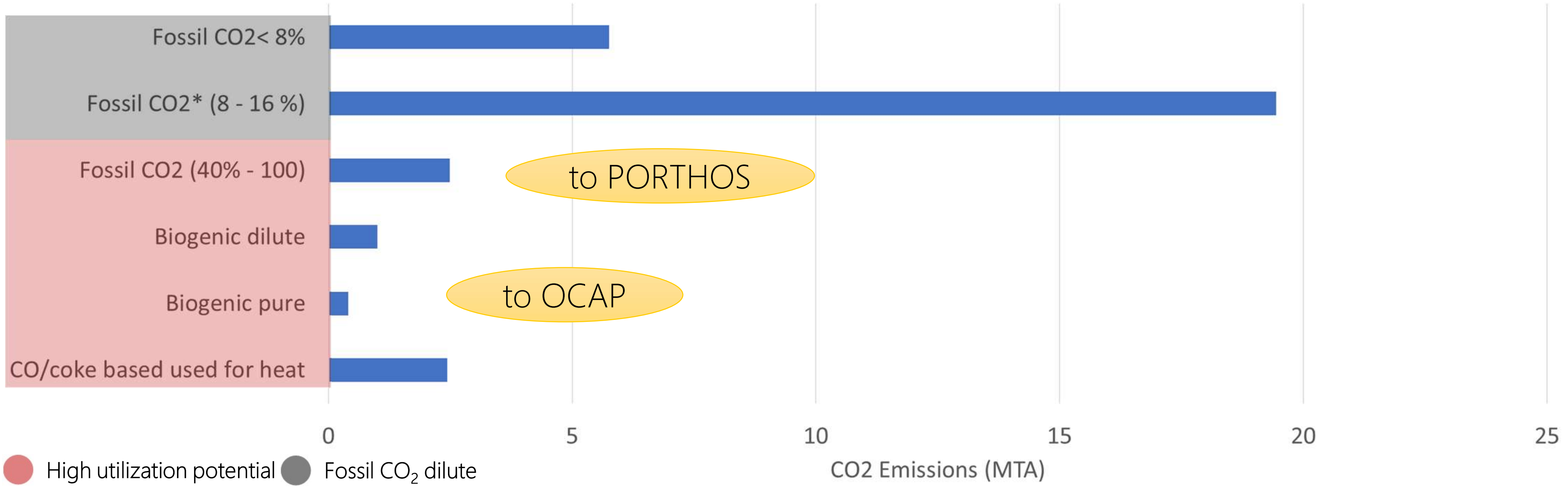
PROJECT SCOPE

The following slides explore the possible case of producing synthetic fuels in Rotterdam and how the various CO_2 sources could be used

LHC	Optimal liquid hydrogen carriers
CCU	Feasibility synthetic fuel production from CO_2 and hydrogen



CO_2 EMISSIONS DISTRIBUTION IN HIC ROTTERDAM



* Fossil CO_2 production can significantly reduce by 2030 due to changes in fossil based power production (eg. closure of coal fired power plants).

Fossil dilute CO_2 dominates (~90%) overall CO_2 emissions from POR.
CO_2 emissions with high utilization potential already have several users/takers.

Notes:

1. >0.5 Mta of high-purity CO_2 (40% - 100%) is dispersed into fuel gas system to get rid of other gases (eg. VOC's, sulphur groups etc).
2. Most of the CO / coke based CO_2 emissions have a purity between 14% and 40%.
3. Includes CO_2 going to OCAP. OCAP transports a mixture of fossil and bigenic CO2. Includes planned CO_2 for PORTHOS.
4. The CO2 emissions changes based on operational running capacity of industrial (power) plants. The absolute CO_2 emissions may vary each year.

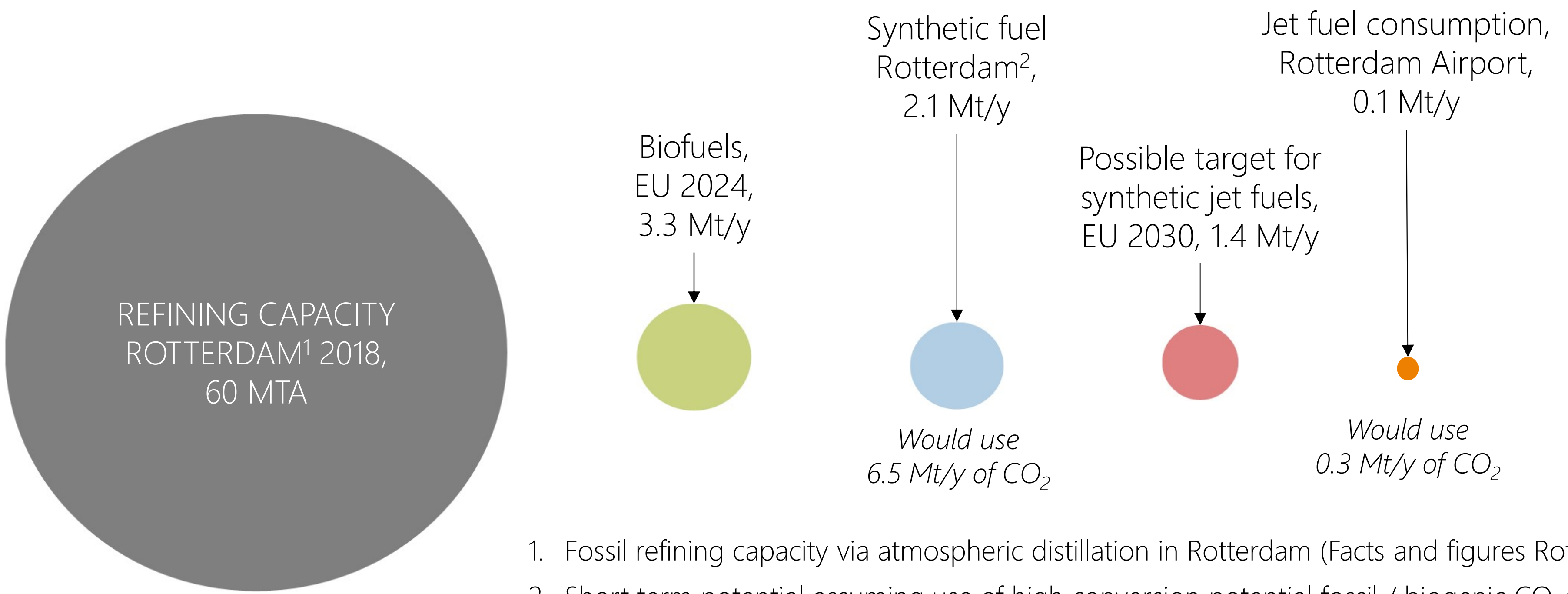
ESTIMATES FOR CO_2 CONVERSION TO FUELS

	Maximum potential (Mta)		
	CO_2	Conversion to kerosene / naphtha	Conversion to methanol
High CCU potential	6.5	2.1	4.7
Dilute fossil CO_2	25.2	8.2	18.3

- Maximum potential for conversion of high potential CO-CO_2 sources range from 2.1 Mta to 4.7 Mta.

Notes: estimates ignore conversion losses and are aimed at maximum reachable potential.

A COMPARISON OF SCALES



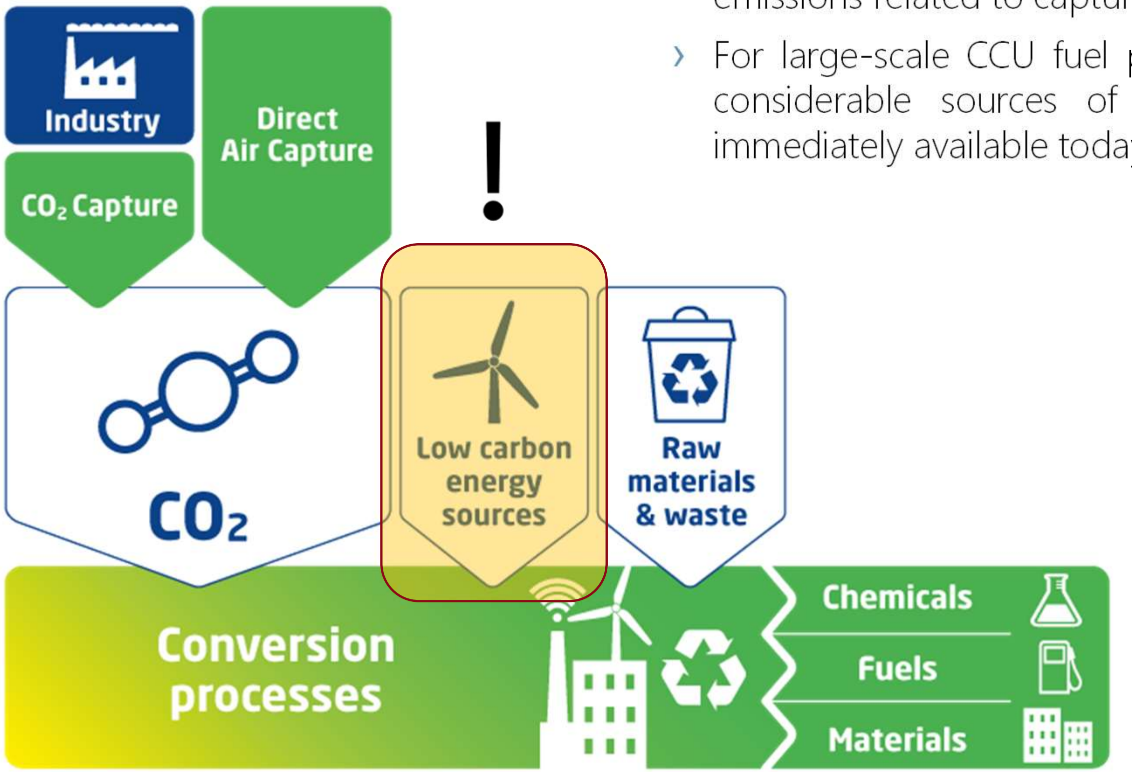
1. Fossil refining capacity via atmospheric distillation in Rotterdam (Facts and figures Rotterdam).
2. Short term potential assuming use of high conversion potential fossil / biogenic CO, CO_2 sources.

- Extrapolating German targets* to the entire EU ambitions, supplying 2% synthetic fuel (non-biogenic) for aviation in 2030 is equivalent to a market size of roughly 1.4 Mt/y
- In comparison, the overall refining (distillation) capacity in the port of Rotterdam is much higher: > 60 Mta.

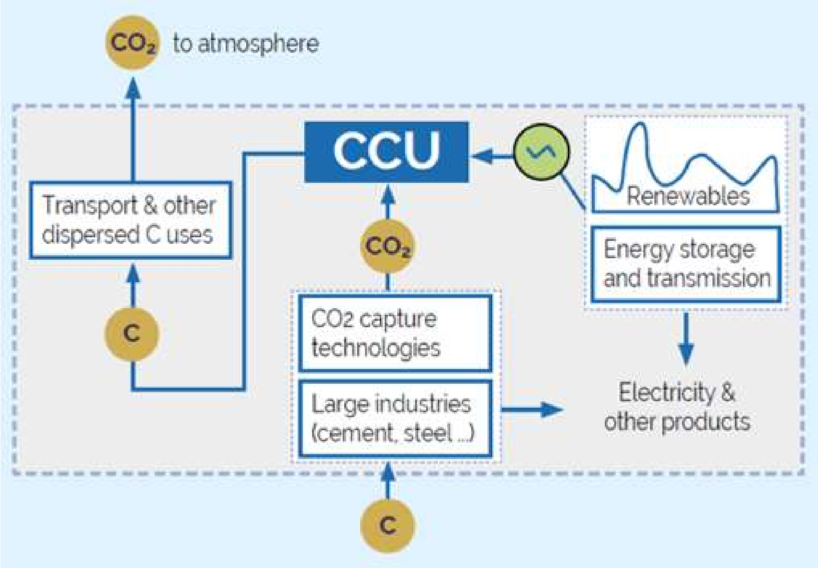
*https://www.argusmedia.com/en/news/2145902-europe-makes-legislative-push-for-aviation-transition

CARBON CAPTURE AND UTILIZATION

- For CCU fuels based on fossil carbon, the *theoretical maximum for emissions reduction is ~50%* vs current chains. The actual reduction will be lower because of emissions related to capturing, transporting and converting CO_2
- For large-scale CCU fuel production, a large amount of renewable power and considerable sources of captured CO_2 are required. Neither of these is immediately available today, although the situation could change in the future.



Source: CO$_2$Value Europe

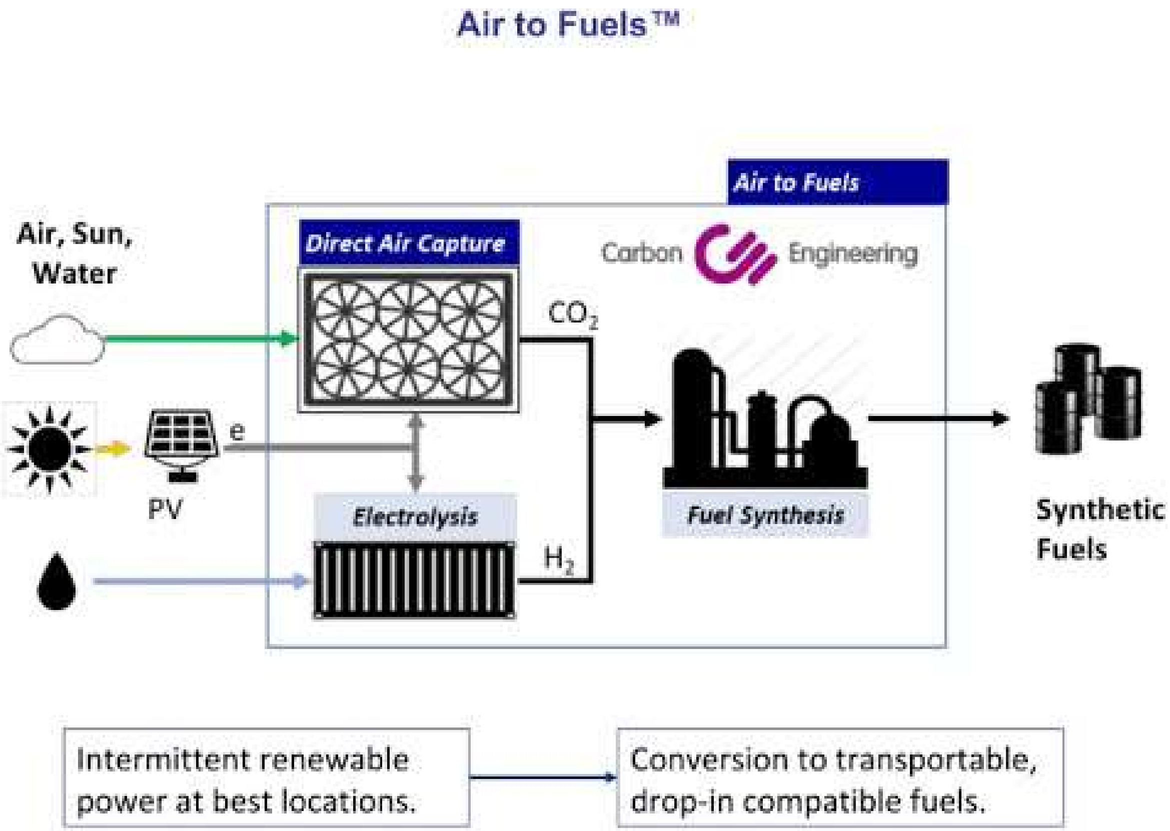


SAPEA, 2018, *Novel Carbon Capture and Utilisation Technologies*

DIRECT AIR CAPTURE

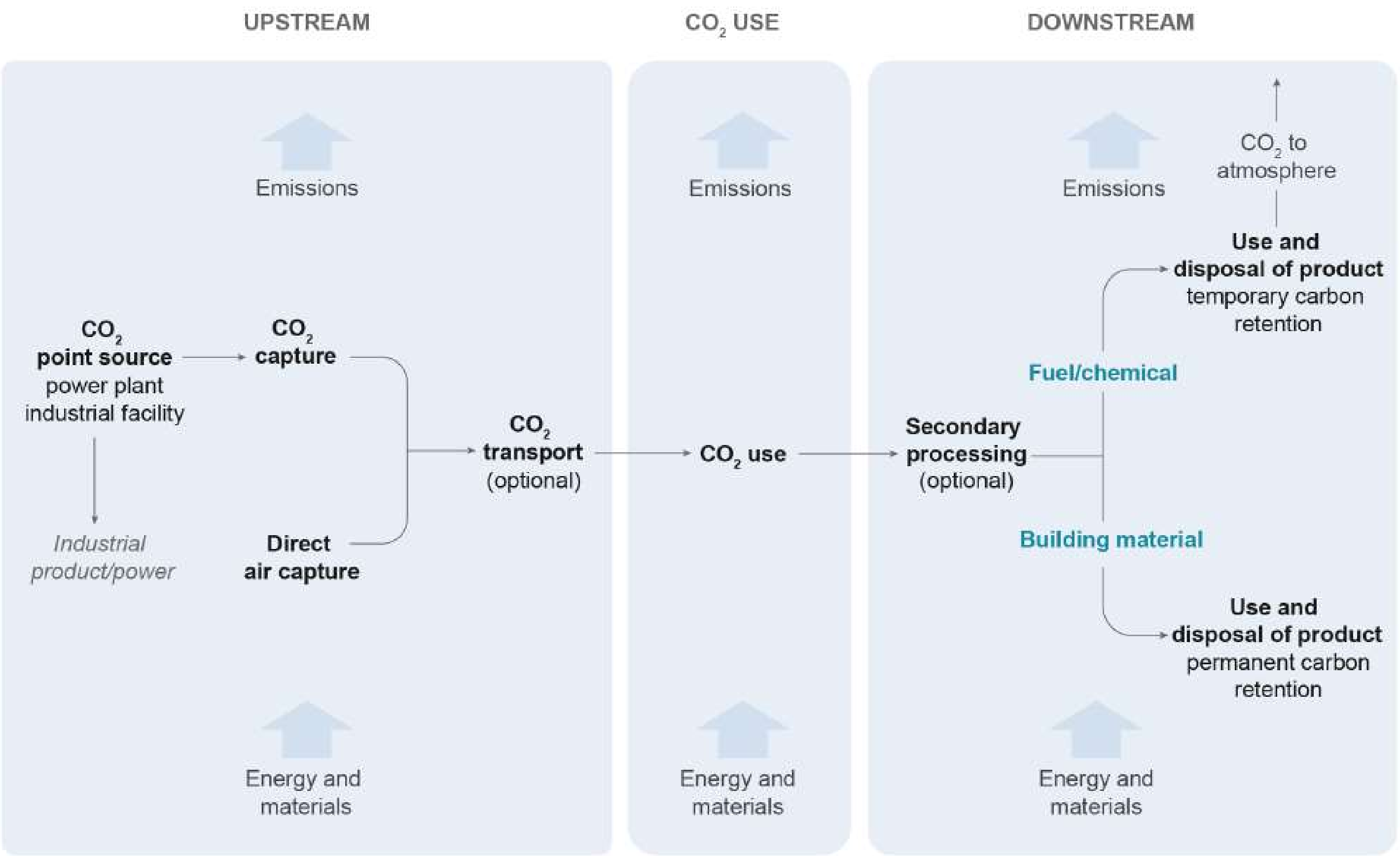
- There is one additional option, namely direct air capture of CO_2 from atmosphere and subsequent conversion to fuels/chemicals.
- Due to the very low concentration of CO_2 in atmosphere (~400ppm), capturing it at industrial scale requires large plot areas and has significant energy consumption:
  - Power: 0.9 MJ/kg CO_2
  - Heat: 5 MJ/kg CO_2
  - (TNO DAC Factsheet – 2030 estimates)

- Companies active in this area:
  - Carbon Engineering (Canada)
  - Carbon Recycling International (Iceland)
  - Climeworks (Switzerland)
  - Ineratec (Germany)



EMISSIONS FROM CO_2 CAPTURE AND UTILIZATION

Figure 18. Life cycle of CO_2-derived products and services



Source: 2019 IEA report, *Putting CO_2 to Use*

- All CO_2 capture and utilisation options require energy and may cause emissions

CO_2 REDUCTION POTENTIAL OF DIFFERENT OPTIONS

- All CO_2 capture options, as well as the conversion processes, require energy input in the form of electricity and heat
- The overall CO_2 emissions reduction depends on the availability of low-carbon energy
- In the case of biogenic CO_2 (biofuels from non-food crops, waste etc.), upstream emissions from biomass processing and transport can be very significant.

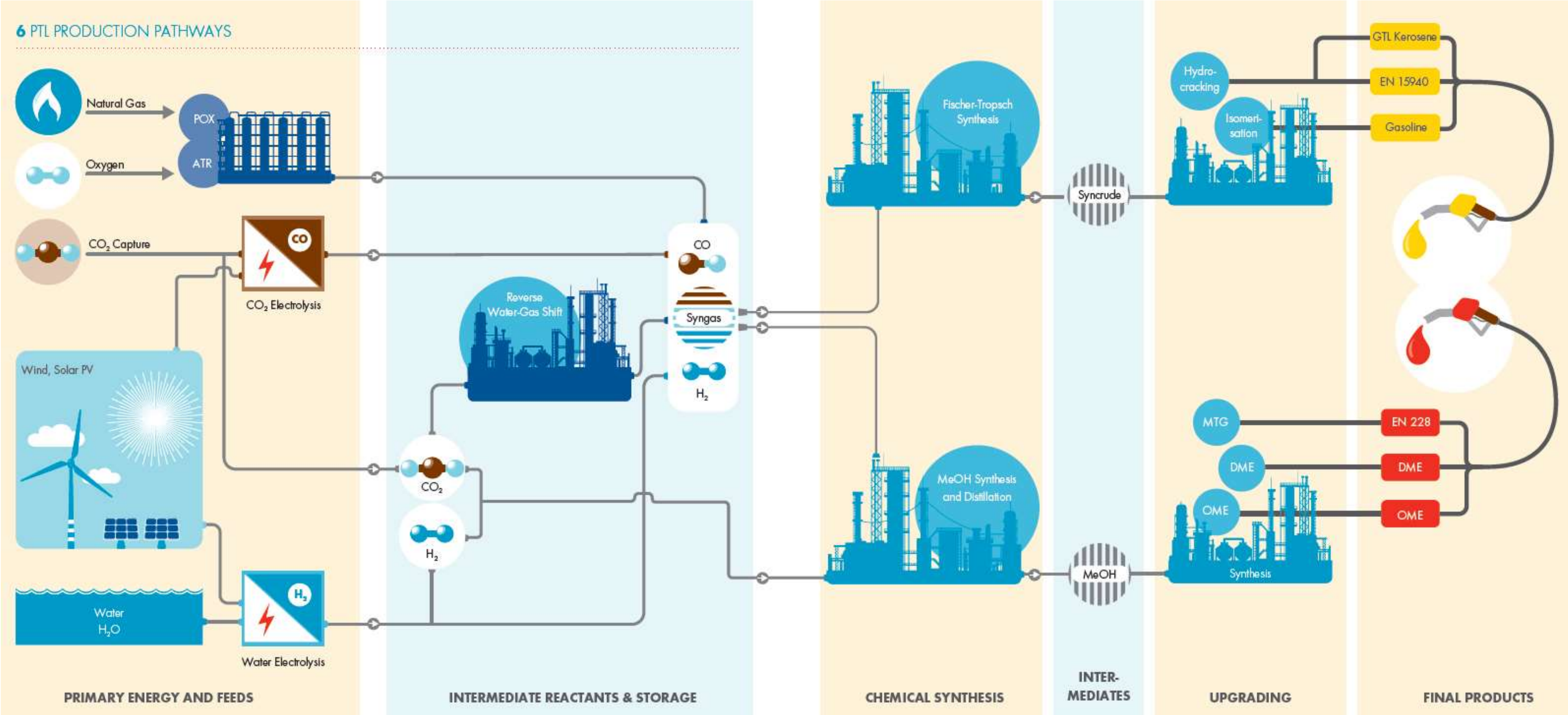
CO_2 source	CO_2 Concentration	Maturity / TRL	Energy input required (excluding CO_2 compression)	Emissions reduction potential (indicative)
Fossil diluted	< 16%	High / TRL 9	Heat (LP steam): 2.5-3 MJ/kg CO_2 Electricity: very limited	Max 50%*
Fossil concentrated	40-100%	High / TRL 9	N/A (unless CO_2 purification is required for the process)	Max 50%*
Biogenic diluted	< 12% (approx.)	High / TRL 9	Heat (LP steam): 2.5-3 MJ/kg CO_2 Electricity: very limited	Max ~80-85%*
Direct air capture	400 ppm	Medium / TRL 6-7	Heat: 5-6 MJ/kg CO_2 Electricity: 0.9 MJ/kg CO_2	Max ~70-80%*

* These are approximate values and a more detailed assessment is required to have more detailed estimates. In all cases, the CO_2 intensity of the energy source for the conversion process plays a major role in determining the net reduction of CO_2 emissions. With the carbon intensity of todays energy mix, the CO_2 emissions reduction potential when utilizing CO_2 from fossil origen is about 30-40%

- See also "CO_2 reduction potential of different options" slides in the appendix for comparison examples

OPTIONS FOR PRODUCING SYNTHETIC FUELS

- The production of e-kerosene via Fischer-Tropsch has much in common with e-methanol synthesis



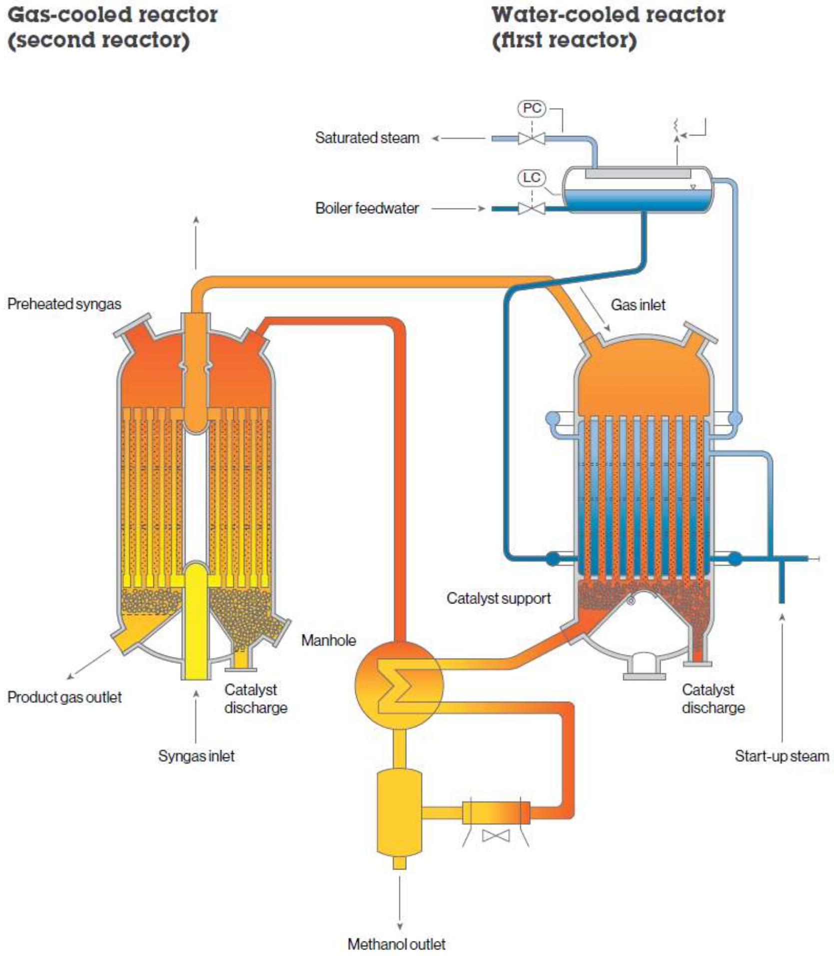
Source: Shell, 2018, *The Road to Sustainable Fuels for Zero Emissions Mobility - Status and Perspectives for Power-to-Liquids Fuels*

SYNTHETIC METHANOL (MeOH)

- Conventional methanol production technology converts either natural gas or coal to syngas, followed my methanol synthesis in multi-tubular reactors, as shown in the diagram on the right.
- It is also possible to produce methanol starting directly from green H_2 and pure CO_2, or by adding a reverse water-gas shift reactor to partially convert CO_2 to CO prior to the methanol synthesis step.
- For the methanol to be green, the carbon source needs to be either bio-based (e.g. from biomass gasification or biogas reforming) or CO_2 can be captured from air.
- Direct air capture is straightforward, and CO_2 is available anywhere on the planet, but it is costly and energy intensive.
- Unlike ammonia, when producing green methanol from CO_2, a third of the hydrogen is converted back to water:

<u>Hydrogen utilization factor:</u>

Methane	$CO_2 + 4H_2 \rightarrow CH_4 + H_2O$	50%
Ethanol	$2CO_2 + 6H_2 \rightarrow C_2H_5OH + 3H_2O$	50%
Methanol	$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$	67%
Ammonia	$N_2 + 3H_2 \rightarrow 2NH_3$	100%



Air Liquide, 2017, *Methanol and Derivatives, Proven Technologies for Optimal Production.*

› SYNTHETIC KEROSENE

- Fischer-Tropsch is well-known technology and applied commercially (e.g. Shell's Pearl GTL and Sasol's Oryx plants in Qatar)
- It's essential to note that this process doesn't only produce kerosene, but rather a full range of hydrocarbon molecules, ranging from light gases to heavy waxes (solid at >100°C). This is unavoidable, and a complex separation and upgrading section needs to be included downstream of the synthesis unit.
- On weight basis, the main product (by far) is synthetic water!
- Also, synthetic kerosene is not a drop-in aviation fuel because it doesn't contain any aromatic molecules. Currently, GTL kero can be blended up to 50% in jet fuel for civil aviation.

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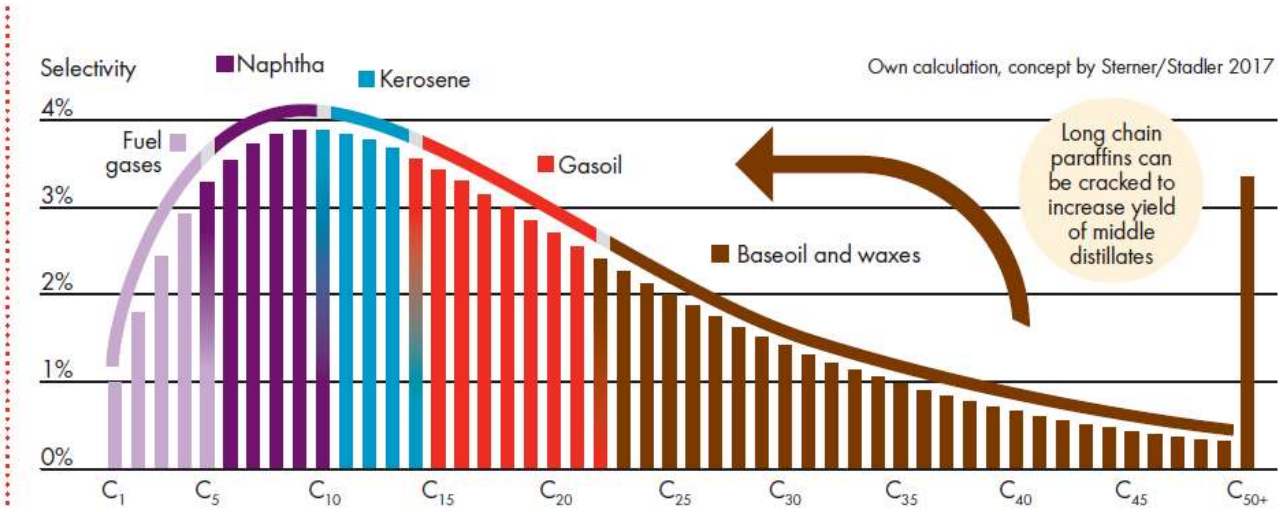
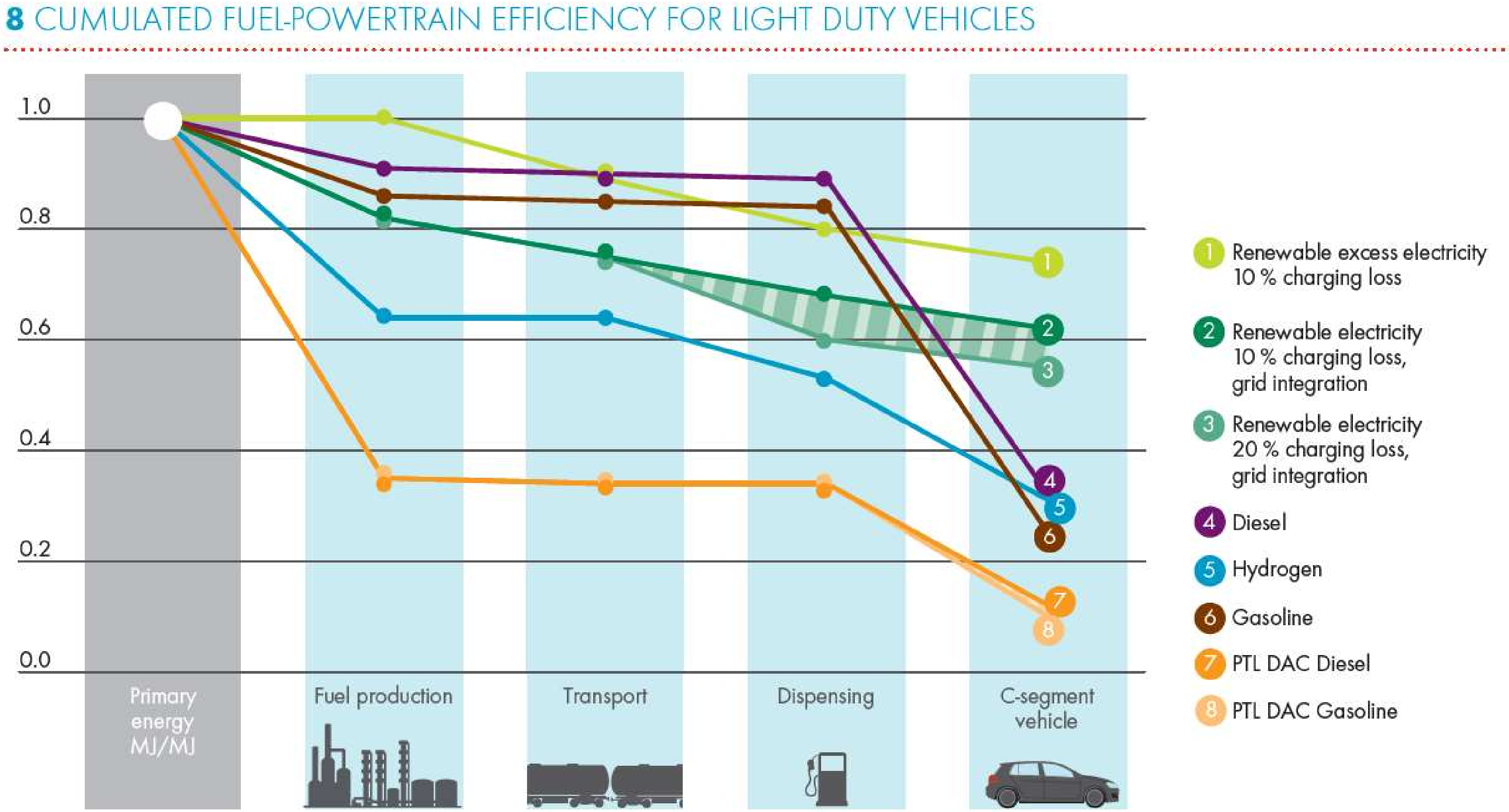
FISCHER-TROPSCH HYDROCARBON PRODUCTS
Product distribution from FT reactor for ASF distribution function with $\alpha = 0.90$



Shell, 2018, *The Road to Sustainable Fuels for Zero Emissions Mobility - Status and Perspectives for Power-to-Liquids Fuels*

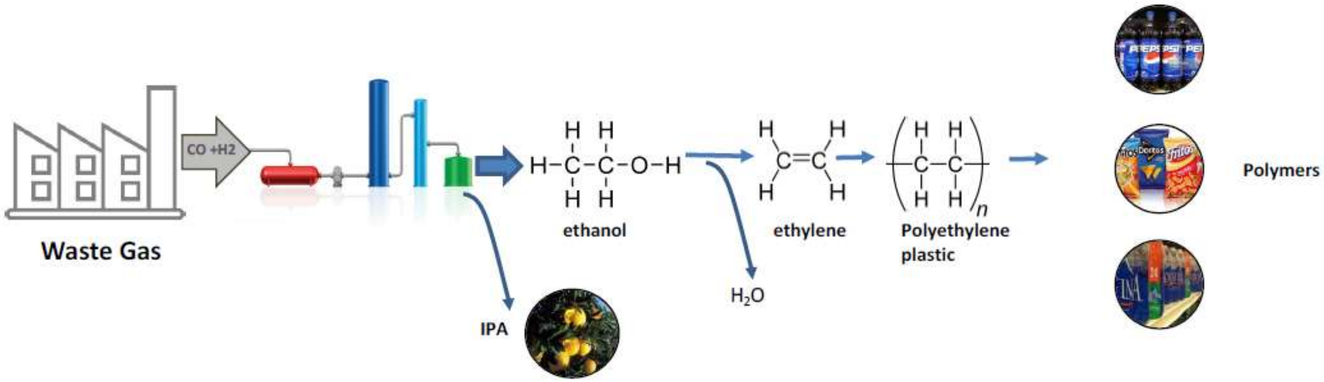
› INDICATIVE PRODUCTION EFFICIENCY OF SYN-FUELS



Shell, 2018, *The Road to Sustainable Fuels for Zero Emissions Mobility - Status and Perspectives for Power-to-Liquids Fuels*

SYNTHETIC KEROSENE

- An alternative to synthetic kerosene production via the F-T route is the conversion of ethanol to kerosene. This is being commercialized by LanzaTech, a company that has developed technology to convert various waste gas streams to ethanol:



- The production of synthetic kerosene is achieved by first dehydrating ethanol to ethylene, then by the olimerization of ethylene to kero-range paraffins. This so-called alcohol-to-jet kerosene can also only be blended up to 50% in jet fuel.

Source: LanzaTech, *No Carbon Left Behind: Alcohol-to-Jet* (2018 presentation)

BIO-BASED SUSTAINABLE FUELS

- Map of Emerging SAF-production in 2018 (Nordic Energy Research)

Treklyngen

QUANTAFUEL

BIOZIN

Silva Green Fuel

Nordic Energy Research, 2019, *Nordic perspectives on Sustainable Aviation Fuel*

BIO-BASED SUSTAINABLE FUELS

- New biorefineries & oil refinery conversion projects globally total over 12 Mtpa capacity (~520 PJ/y)

Company	Location	Process	CAPEX	Target fuels	Capacity, [ktpa]	In operation
Eni	Venice, Italy	oil refinery conversion	500 M€	80% diesel	360	2014
Eni	Venice, Italy	biorefinery expansion			200	2024
Eni	Gela, Italy	oil refinery conversion	360+ M€	diesel	750	2019
Holly Frontier Corporation	Cheyenne (WY), US	oil refinery conversion	125-175 M$	Diesel	280	2022
Marathon Oil	Martinez (CA), US	oil refinery conversion		diesel + kero	2280	2022-2023
Marathon Oil	Dickinson (ND), US	oil refinery conversion		diesel	550	2022
Neste	Porvoo, Finland	oil refinery conversion		diesel + kero	380	2007
Neste	Singapore	biorefinery		diesel/kero/naphtha	1300	2010
Neste	Singapore	biorefinery expansion	1400 M€	diesel/kero/naphtha	1300	2022
Neste	Rotterdam, NL	biorefinery	670 M€	diesel/LPG	1000	2011
Neste	Rotterdam, NL	biorefinery expansion		diesel/kero/naphtha	450	2023
Phillips66	Rodeo / San Francisco (CA), US	oil refinery conversion	700-800 M$	diesel/gasoline/kero (70/10/20)	2100	2024
Red Rock	Lakeview (OR), US	(new) Gasification + F-T		diesel + kero	50	2021
SkyNRG	Delfzijl, NL	new biorefinery		kero	100	2023
St1	Gothenburg, Sweden	new biorefinery	200 M$	diesel/kero/naphtha	200	2022
Total	Grandpuits, France	oil refinery conversion		diesel/kero/naphtha (30/40/15)	400	2024
Total	La Mede, France	oil refinery conversion	275 M$	diesel + kero	500	2019

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CONCLUSIONS

- Major infrastructure changes will be necessary for the port of Rotterdam to maintain its position as a major fuels distribution hub in the context of the energy transition. One option is to produce synthetic fuels starting from H_2 and CO_2 that is captured locally either from industrial sources or directly from air.
- There is ample CO_2 available in PoR from multiple industrial sources, but it's mainly (>90%) fossil-based
- Regardless of the CO_2 concentration or presence of CO, using fossil sources for the production of synthetic hydrocarbon fuels results in a limit of roughly 40 % for the overall CO_2 reduction (including indirect emissions due to CO_2 capture and processing).
- Synthetic fuel from biogenic CO_2 has a higher emissions reduction potential and is likely to meet the REDII threshold. This would be a preferred CO_2 source for synfuel production but its availability is limited.
- An alternative source is CO_2 captured from the atmosphere (direct air capture, DAC). Synthetic fuels produced from DAC CO_2 can have a high overall CO_2 reduction factor, but only if low-carbon heat and power are available, because the capture and conversion processes are energy intensive.
- Lastly, it should be noted that synthetic fuels have to be competitive with bio-based alternatives. Global capacity for the production of biofuels is rapidly expanding, as some conventional refineries are converted to bio-refineries and new facilities are built based on novel technology.

PART 1 – APPENDICES

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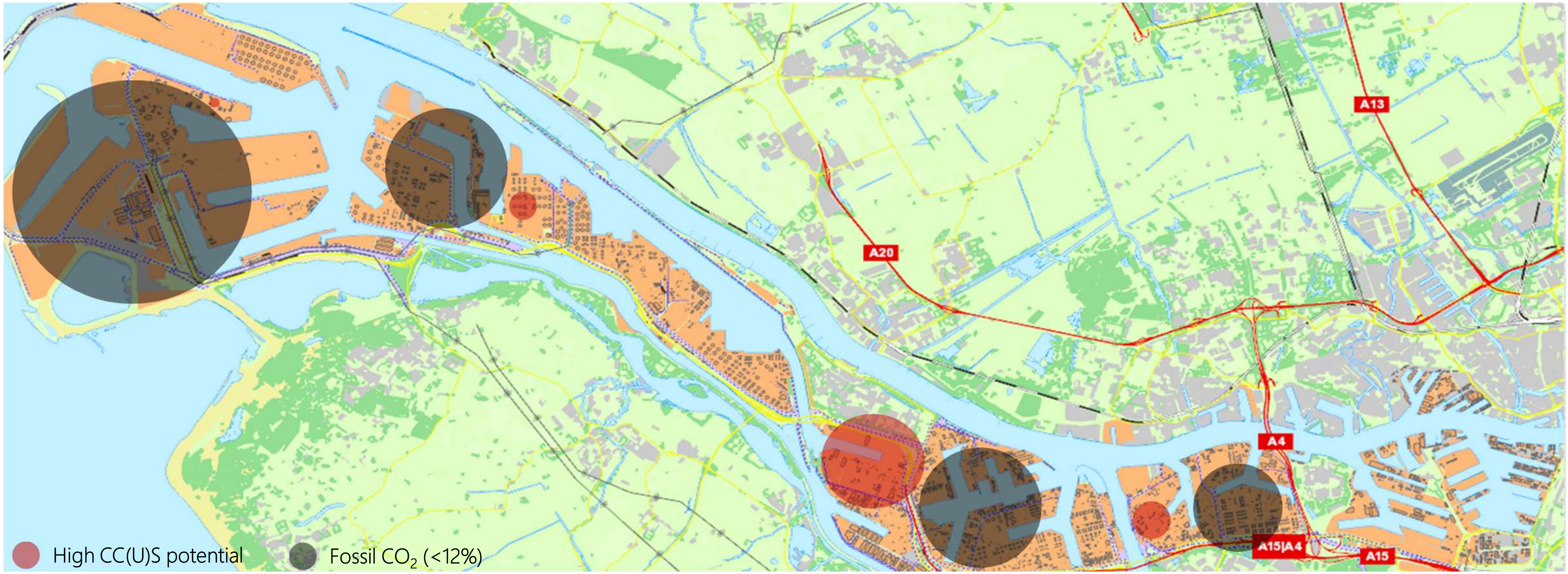
CO_2 DISTRIBUTION BY LOCATION



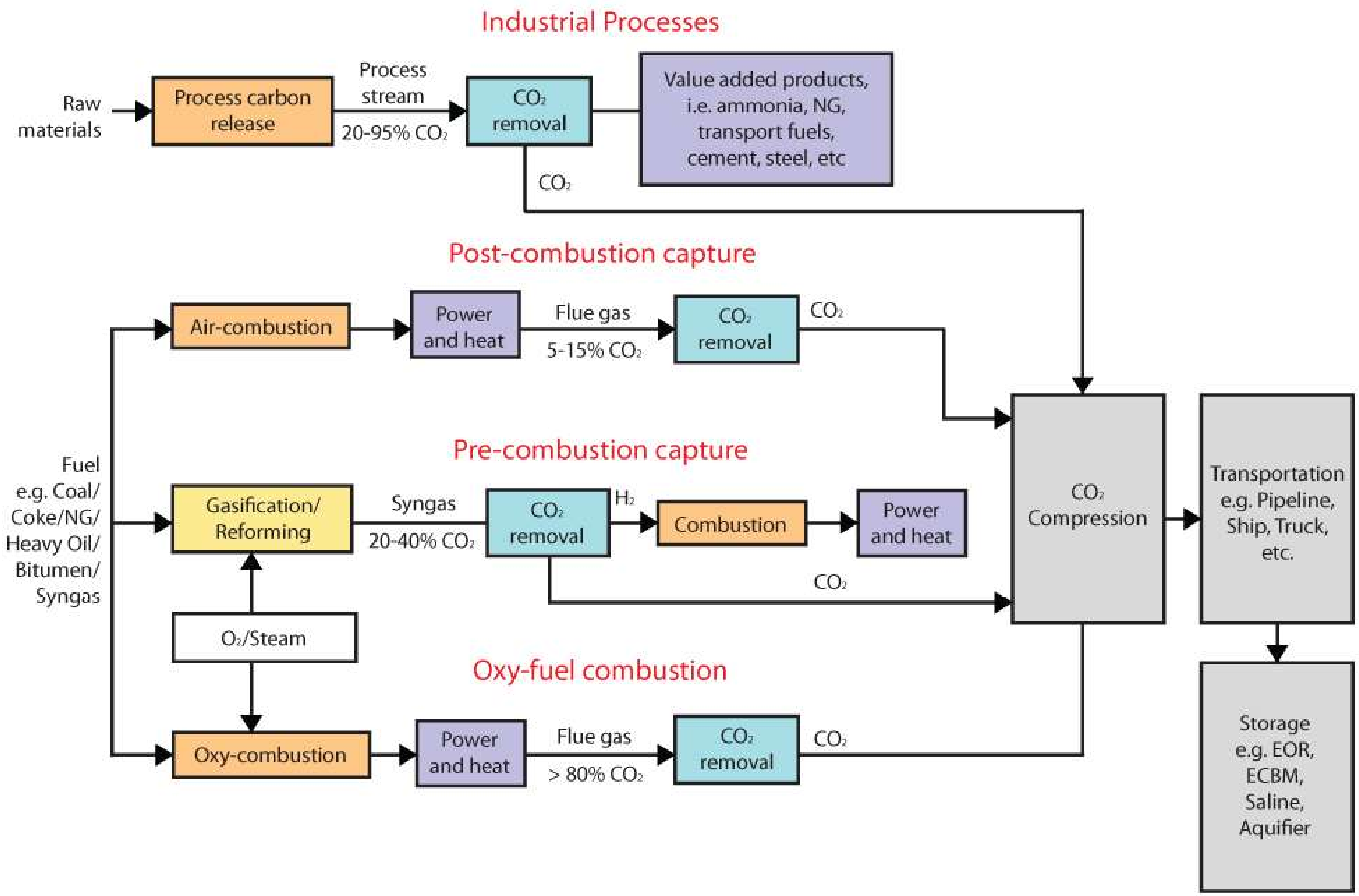
- The most promising streams for CC(U)S potential are located in the Botlek and Pernis

Note: The circles not entirely to scale.

CARBON CAPTURE OPTIONS

- Nearly all of the CO_2 available in the PoR industrial area falls under one of the following categories in terms of capture options:

  1. Process capture (e.g. H_2 production plants like SMRs)
  2. Pre-combustion capture (future option if blue H_2 is deployed)
  3. Oxy-combustion capture (future option if this technology is used)
  4. Post-combustion capture (existing sources and technology that is ready to be deployed – see for example the new project at the AVR plant in Duiven)



https://www.nrcan.gc.ca/energy/energy-sources-distribution/coal-and-co2-capture-storage/carbon-capture-storage/co2-capture-pathways/4289

Table 1. Selected CO_2 capture cost ranges for industrial production

CO_2 source	CO_2 concentration [%]	Capture cost [USD/tCO_2]
Natural gas processing	96 - 100	15 - 25
Coal to chemicals (gasification)	98 - 100	15 - 25
Ammonia	98 - 100	25 - 35
Bioethanol	98 - 100	25 - 35
Ethylene oxide	98 - 100	25 - 35
Hydrogen (SMR)	30 - 100	15 - 60
Iron and steel	21 - 27	60 - 100
Cement	15 - 30	60 - 120

Notes: Some cost estimates refer to chemical sector and fuel transformation processes that generate relatively pure CO_2 streams, for which emissions capture costs are lower; in these cases, capture costs are mostly related to further purification and compression of CO_2 required for transport. Depending on the product, dilute energy-related emissions, which can have substantially higher capture costs, can still make up an important share of overall direct emissions. Costs estimates are based on capture in the United States. Hydrogen refers to production via steam reforming; the broad cost range reflects varying levels of CO_2 concentration: the lower end of the CO_2 concentration range applies to CO_2 capture from the pressure swing adsorption off-gas, while the higher end applies to hydrogen manufacturing processes in which CO_2 is inherently separated as part of the production process. Iron and steel and cement capture costs are based on 'Nth of a kind' plants, reflecting projected cost reductions as technology is applied more broadly. Iron and steel and cement costs are based on capture using existing production routes – however, innovative industry sector technologies under development have the potential to allow for reduced costs in the long term. The low end of the cost range for cement production applies to CO_2 capture from precalciner emissions, while the high end refers to capture of all plant CO_2 emissions. For CO_2 capture from iron and steel manufacturing, the low end of the cost range corresponds to CO_2 capture from the blast furnace, while the high end corresponds to capture from other small point sources. Costs associated with CCUS in industry are not yet fully understood and can vary by region; ongoing analysis of practical application is needed as development continues. SMR = steam methane reforming.

Source: Analysis based on own estimates and GCCSI (2017), *Global Costs of Carbon Capture and Storage*, 2017 Update; IEAGHG (2014), *CO_2 Capture at Coal-Based Power and Hydrogen Plants*; NETL (2014), *Cost of Capturing CO_2 from Industrial Sources*.

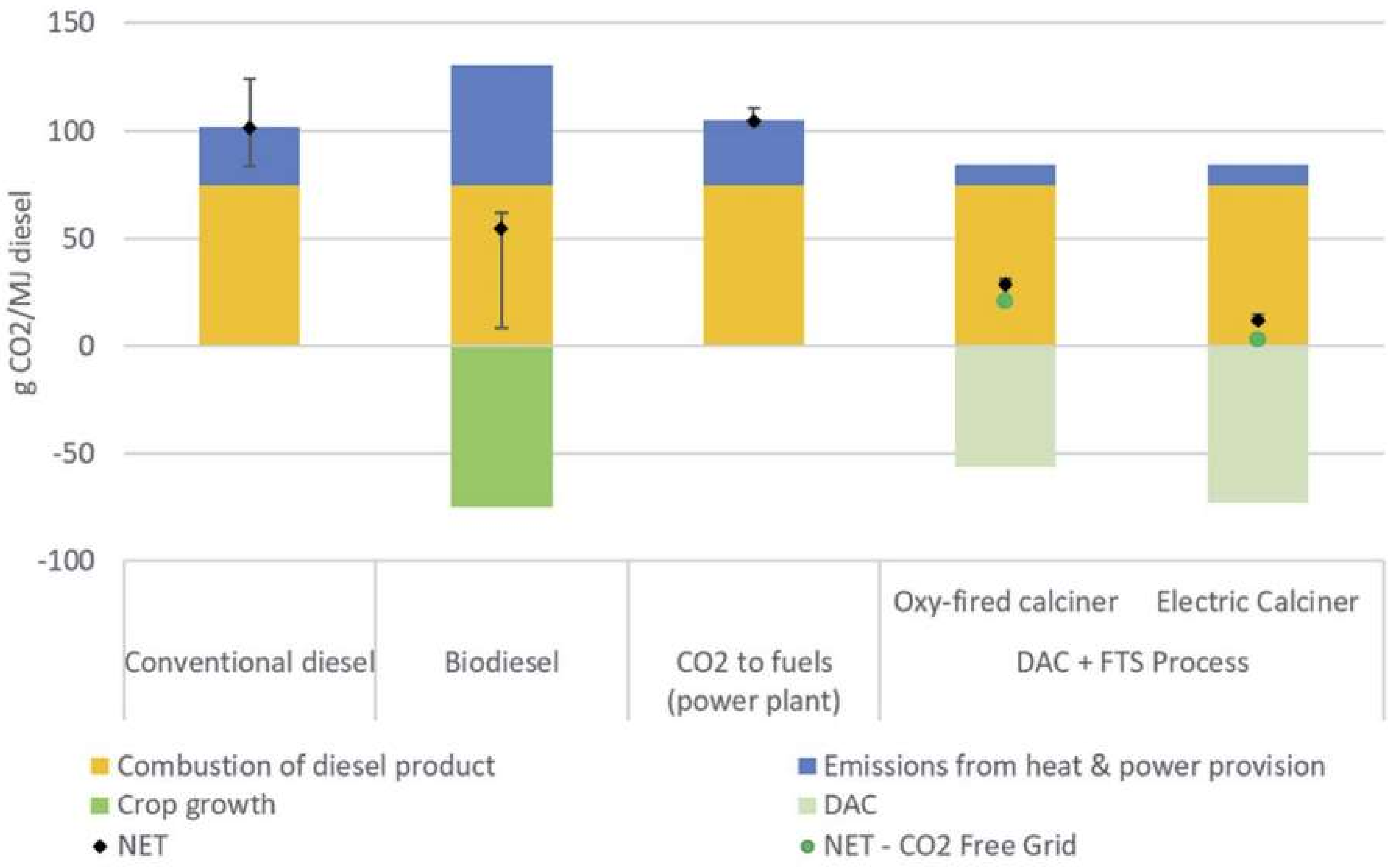
Source: 2019 IEA report, *Putting CO_2 to Use*

The cost for coal to chemicals is also representative for oil residue gasification

CO_2 REDUCTION POTENTIAL OF DIFFERENT OPTIONS

- A recent (2020) paper compares the overall CO_2 emissions of different types of diesel fuel:
  - Conventional
  - Biodiesel
  - Synthetic (FT) diesel produced from CO_2 captured from a natural gas power plant
  - Synthetic (FT) diesel produced from CO_2 captured from air

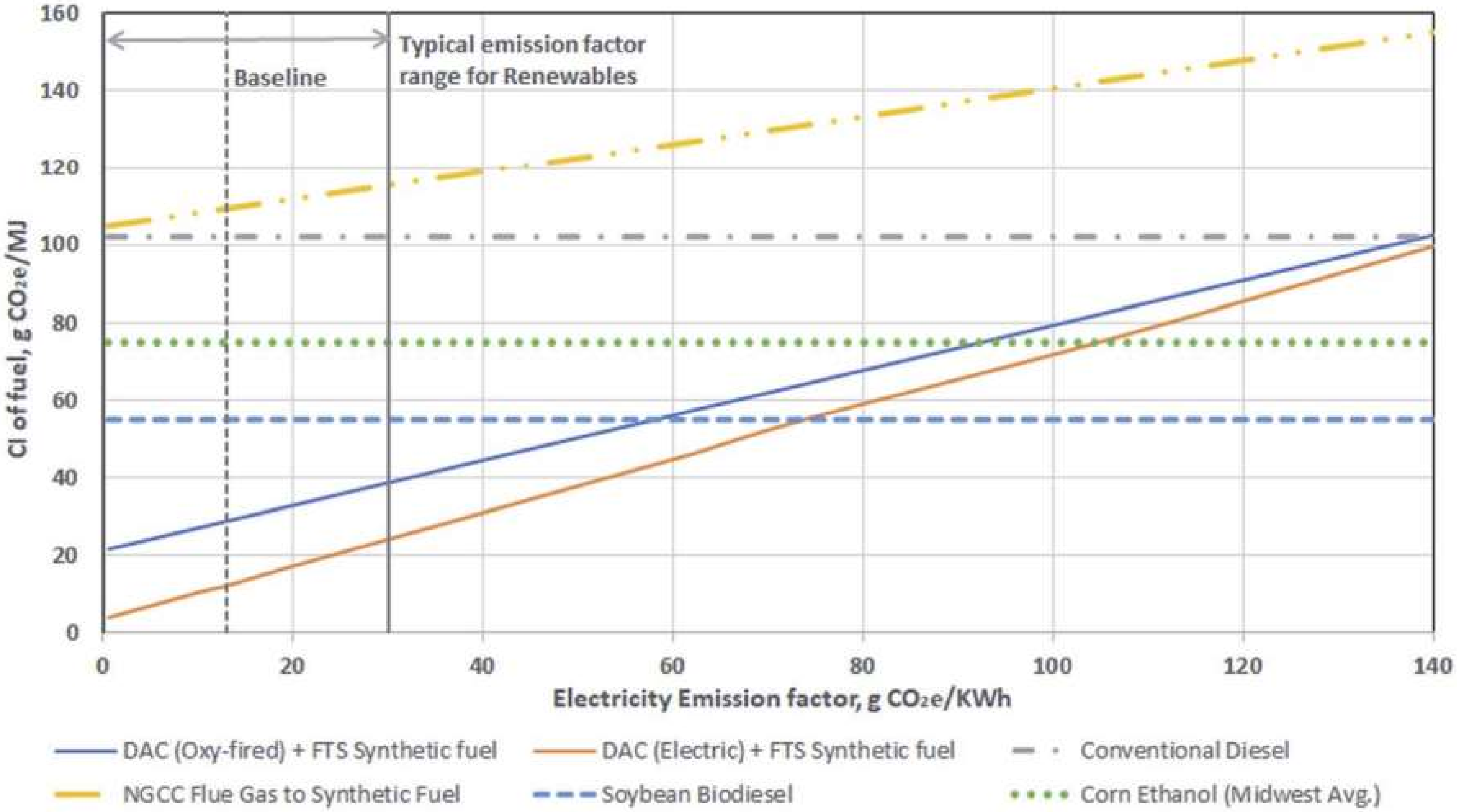
- These results are representative for kerosene as well



C. Liu et al, 2020, *A life cycle assessment of greenhouse gas emissions from DAC and Fischer–Tropsch fuel production*

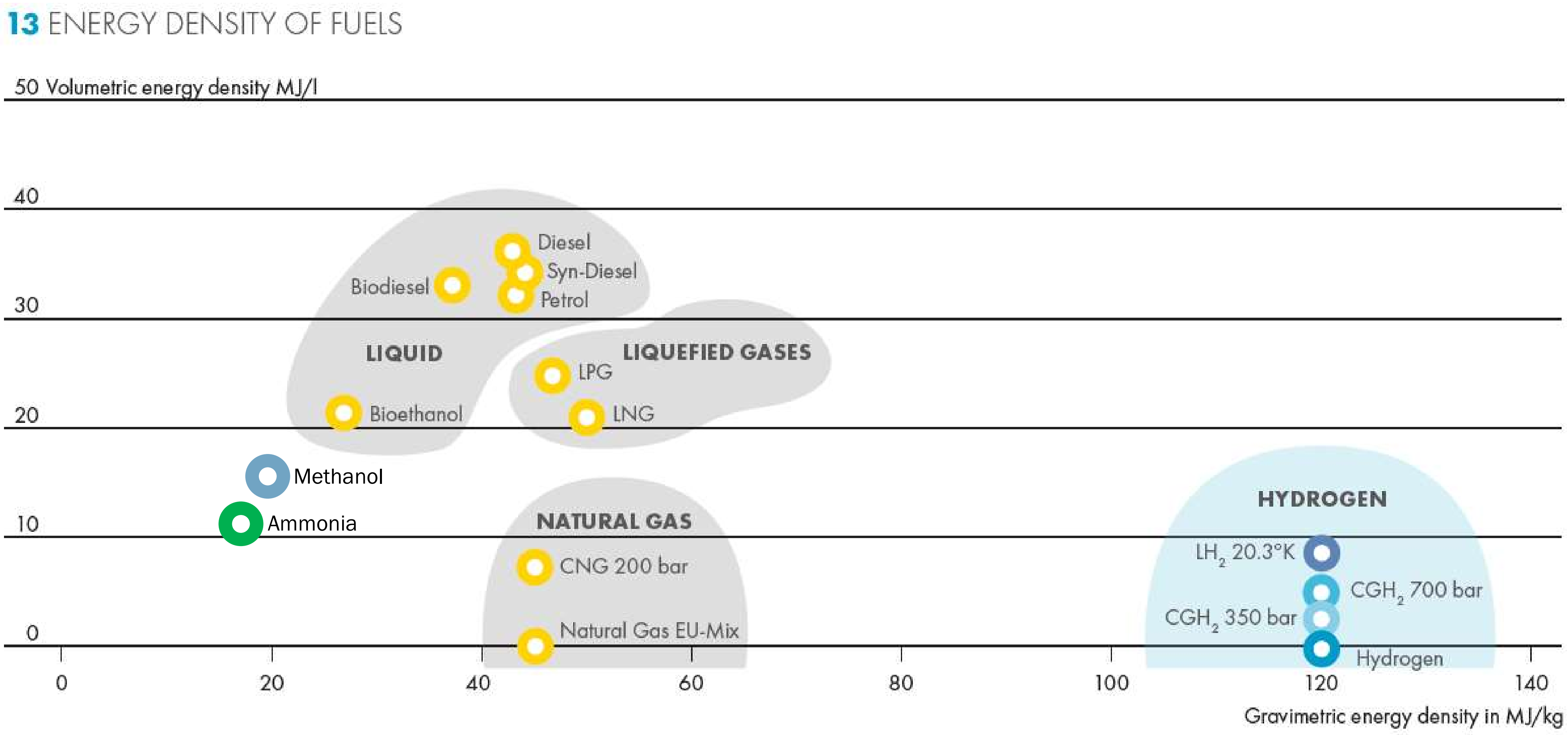
› CO_2 REDUCTION POTENTIAL OF DIFFERENT OPTIONS

› The authors highlight the importance of having abundant low-carbon electricity available: a significant (>50%) reduction of CO_2 emissions is only achieved if the electricity used by the process has a carbon footprint of roughly 60 g CO_2 / kWh or less



C. Liu et al, 2020, *A life cycle assessment of greenhouse gas emissions from DAC and Fischer–Tropsch fuel production*

ENERGY DENSITY OF EXISTING AND EMERGING FUELS



Shell, 2017, *Shell Hydrogen Study - Energy of the Future? Sustainable Mobility through Fuel Cells and* H_2

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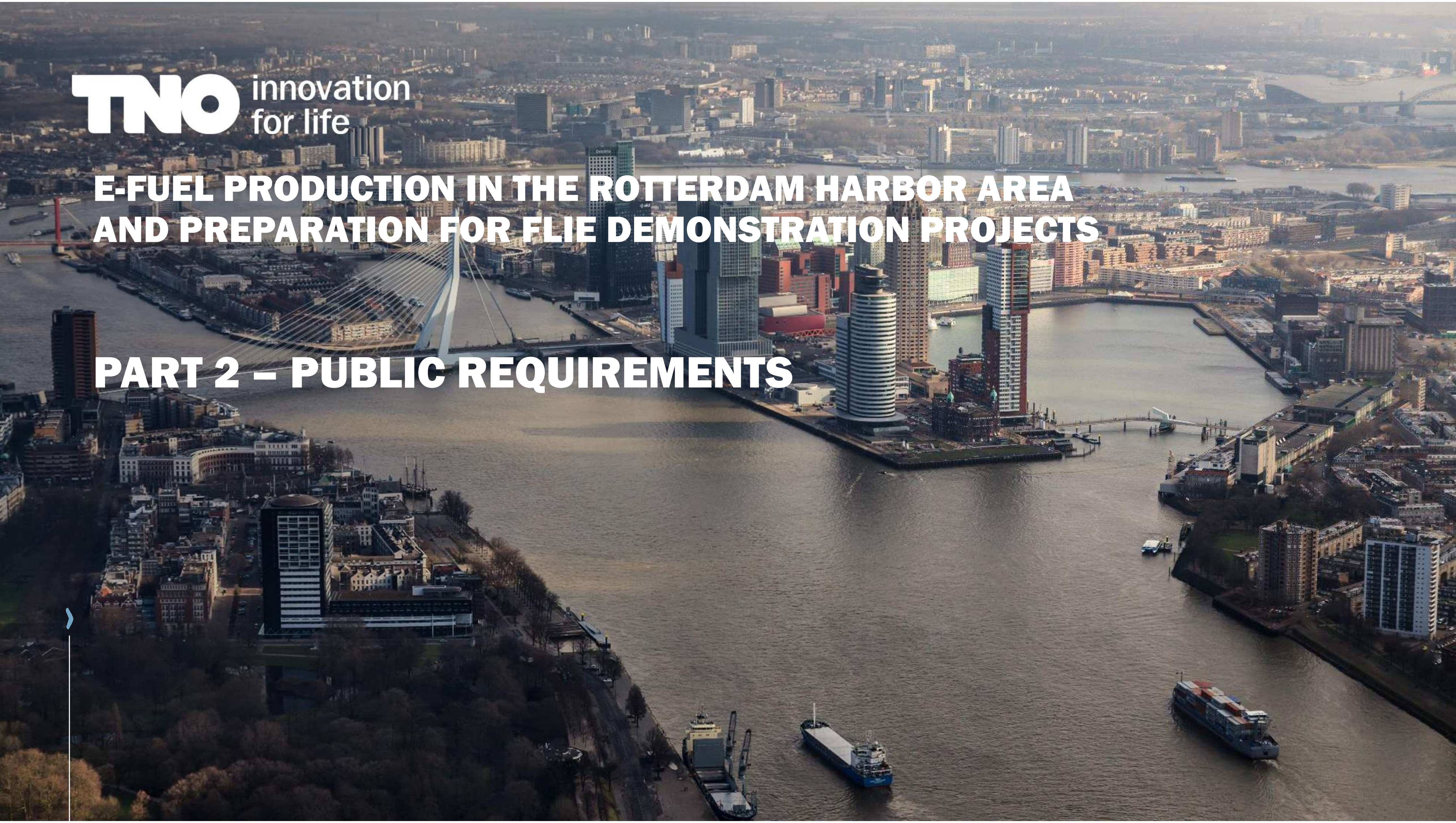
E-FUEL PRODUCTION IN THE ROTTERDAM HARBOR AREA AND PREPARATION FOR FLIE DEMONSTRATION PROJECTS

PART 2 – PUBLIC REQUIREMENTS



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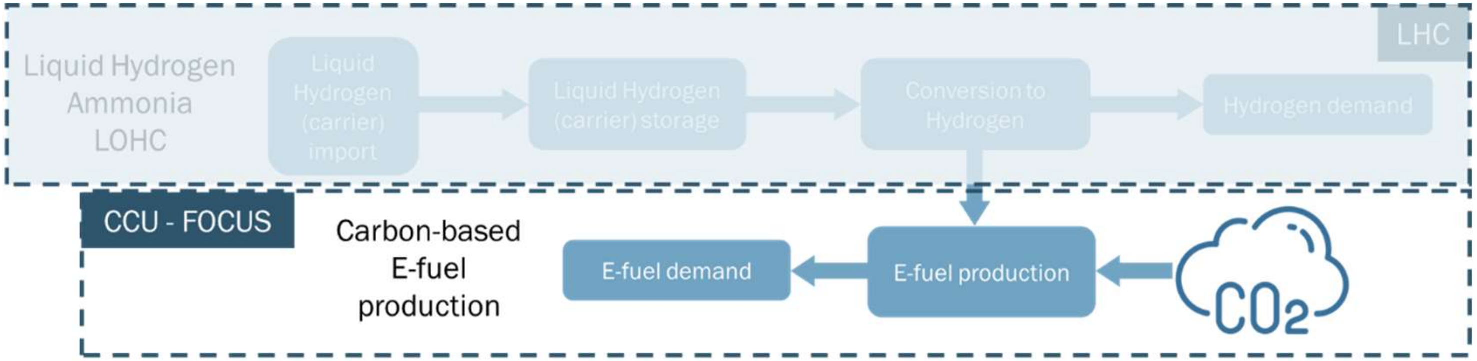
PROJECT SCOPE

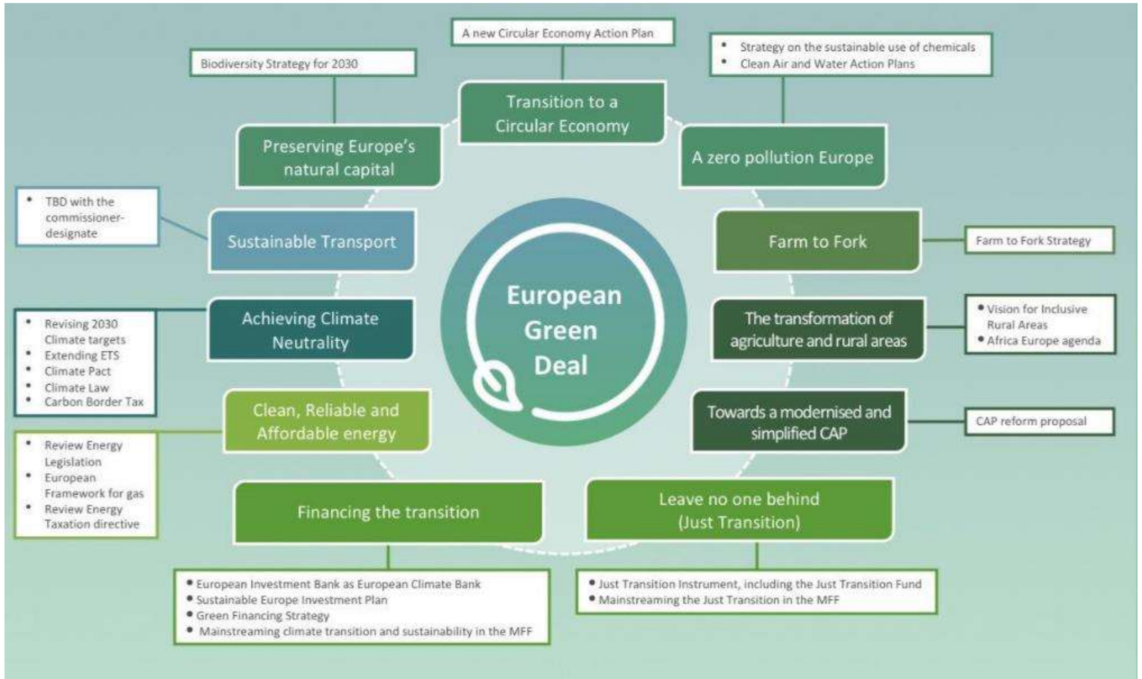


- In Part 2 of this project we focus on the public requirements associated to CO_2 capture and utilization (CCU) value chains in the Rotterdam harbor area to produce e-fuels. E-fuels (or synthetic fuels) fall under the RFNBO classification, a term that is used in the EU regulation documents. Both CO_2 and renewable energy (typically in the form of green hydrogen) are required to produce e-fuels. Hydrogen import is subject of the PZH H_2 carrier import project.
- We first offer some context of why e-fuels may play a role in the future energy system. Next, we provide information about various aspects that are related to an e-fuel supply chain concerning regulation, certification, safety & environment, public perception, and funding instruments.

Regulation	Certification/GO	Safety & Environment	Public perception	Funding instruments

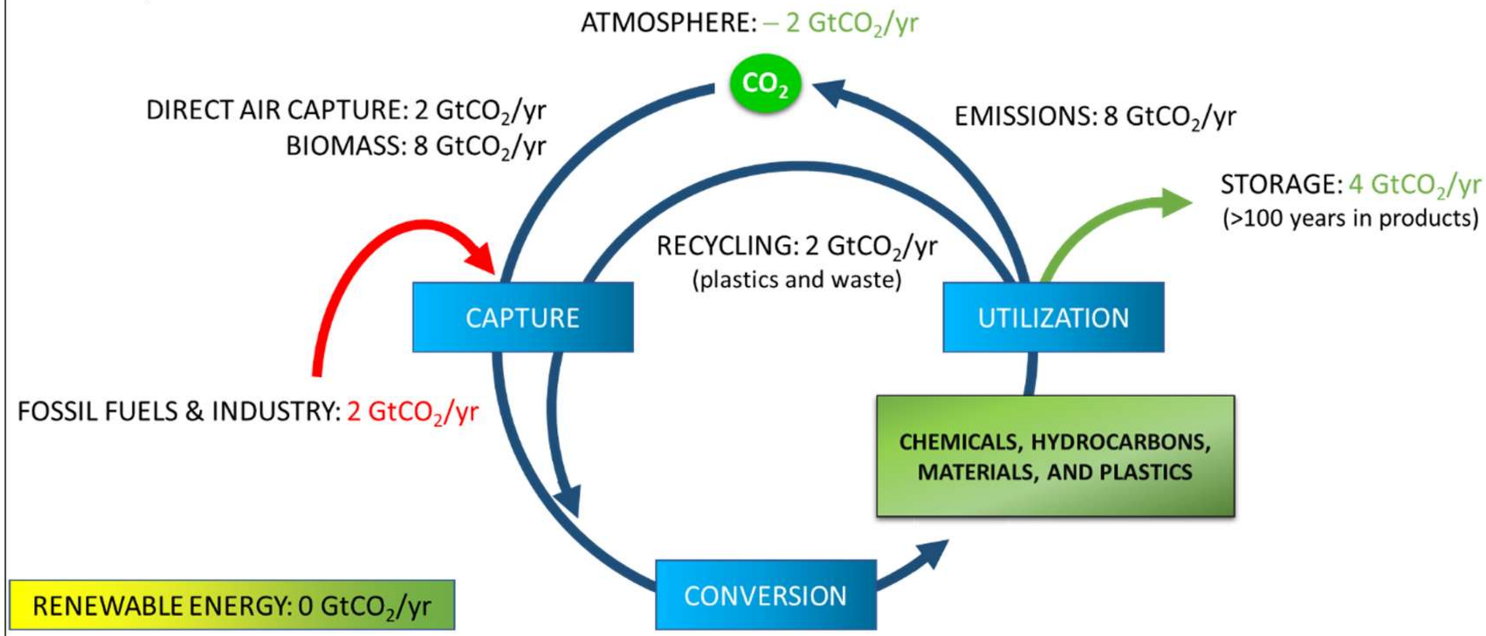
WHY E-FUELS?
EUROPEAN GREEN DEAL

- European Green Deal's decarbonisation goals:
  - Carbon-neutrality by 2050, i.e. net-zero emissions
  - increase the EU's GHG emission reductions target for 2030 to 55% compared with 1990 levels, current target is 40%
- European Commission's extensive work programme for 2020/2021 includes
  - New strategies (Hydrogen, Energy System Integration)
  - Revision/amendment legislative instruments (e.g. REDII, EU ETS, new carbon border adjustment mechanism, taxation directive)
- EU launched new funding programmes to finance the policies set out in the Green Deal, e.g.
  - ETS Innovation Fund; InvestEU; Horizon Europe (incl. Clean Hydrogen Partnership)

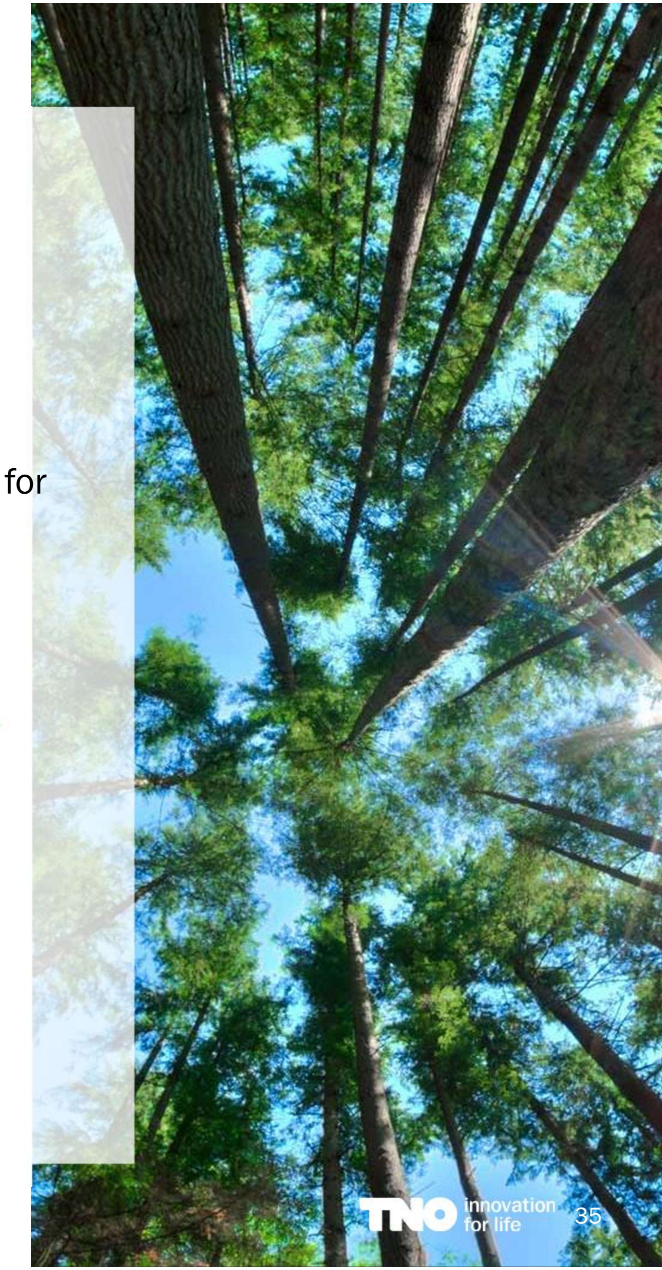


WHY E-FUELS?
CIRCULAR CARBON ECONOMY

- Renewable fuels and materials are part of a circular economy driven by renewable energy
- Without fossil-based carbon input (red arrow), such an economy ideally results in net-zero emissions or even in negative emissions if CO_2 from the atmosphere is stored in products for many decades



Source: Detz & van der Zwaan, Energy Policy, 2019

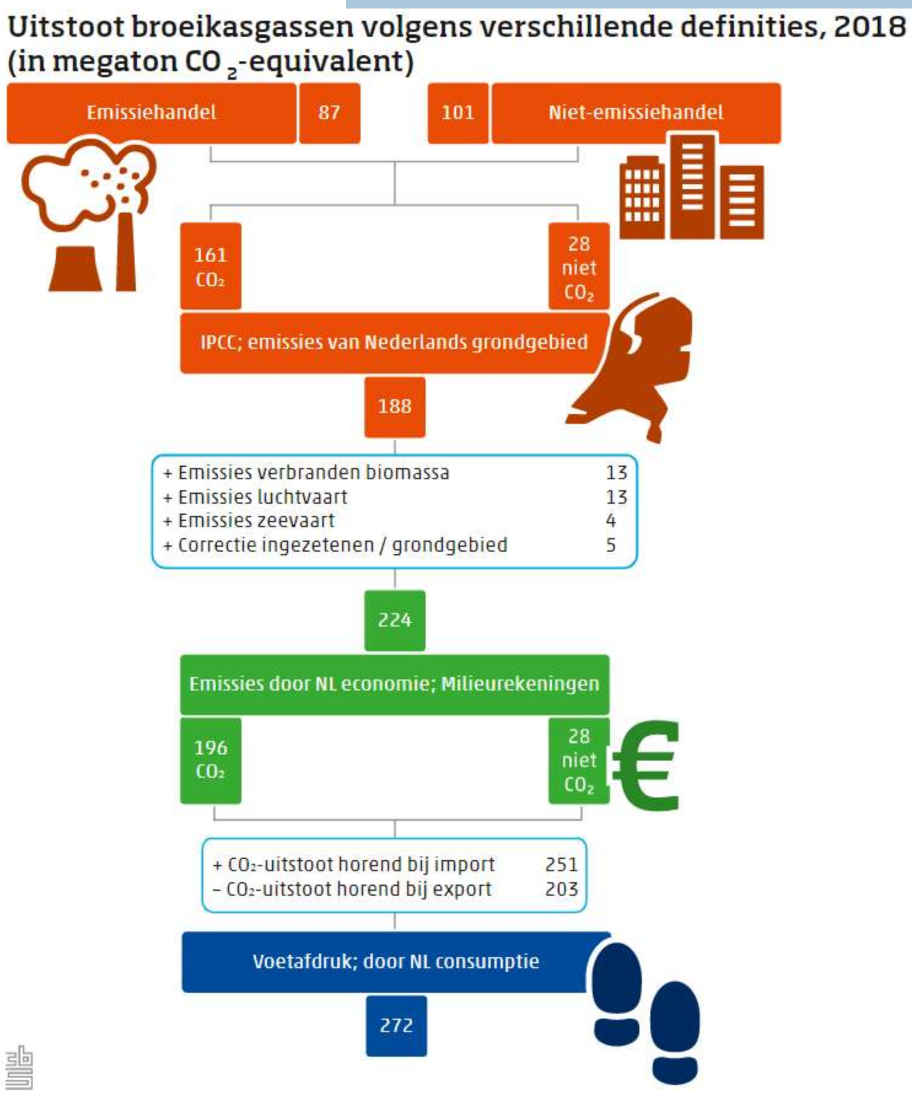


WHY E-FUELS?
EMISSIONS, ENERGY, AND POLICY

- Two beneficial aspects of using e-fuels as an energy carrier.
  - Can replace fossil fuels in various applications and, thus, avoid CO_2 emissions.
  - Allows for additional use of renewable energy (by converting renewable electricity from solar and wind into a molecular fuel).
- Policy around e-fuels is and shall be designed to in some way avoid emissions of fossil fuels and/or increase the uptake of renewable energy in society (see also previous slide). The reasoning behind policy is often determined by the (local) goals of that policy. This is also reflected by different counting rules and the extend to which overarching goals have to be realized or not (e.g. World versus EU versus NL) and how these goals are implemented in local policy.
  - Emission countings (IPCC / EU / EU-ETS / national).
  - European directives (e.g. Renewable Energy Directive - REDII).
  - Is the (renewable) energy content of e-fuels counted towards the Dutch targets and in which sector?

WHY E-FUELS?
EMISSION COUNTINGS

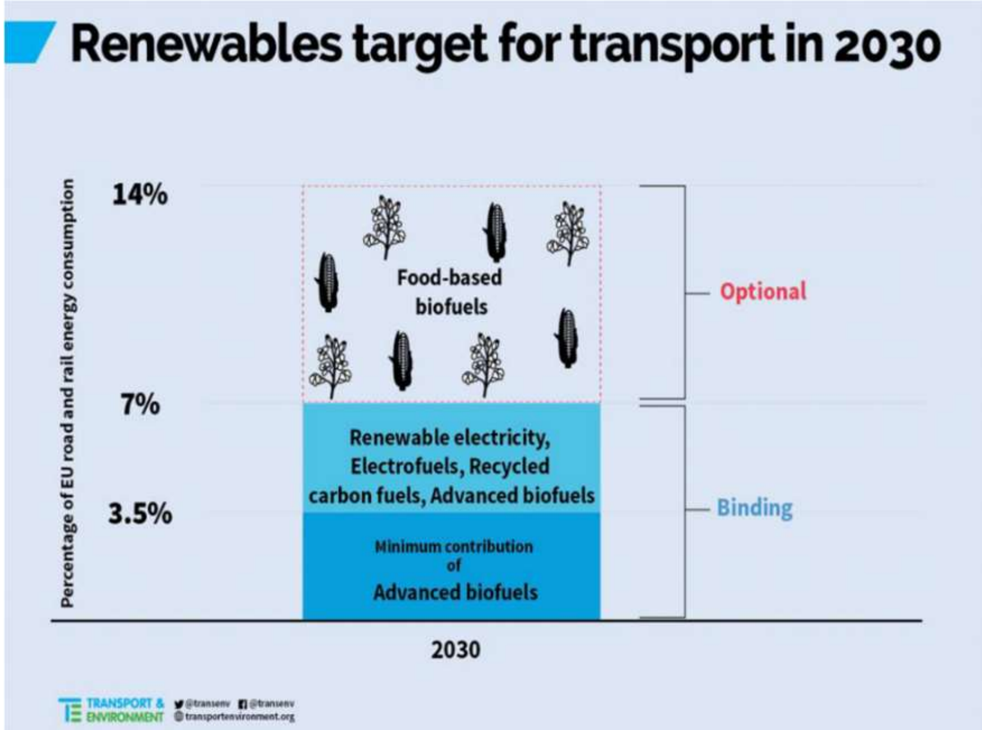
- The goals of the Paris Agreement are clear, we should limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels. How to reach these goals is less clear and relies mainly on the efforts of all countries together.
- This also means that there consist different types of emission countings (IPCC (global) / EU / national targets)
- Allocation of emissions and emission reduction targets also differ among sectors (e.g. under Emission Trading Scheme (ETS) or not).
- In this context, the allocation of the (avoided) emissions involved when using e-fuels depend on several aspects, which should be taken into account, e.g.:
  - Avoided emissions of production process (rely mainly on emission factor of the electricity used)
  - Fugitive and background emissions due to leakage, decomposition, and the emissions associated to drive the processes throughout the entire value chain
  - Final end-use sector



REGULATION

REDII & RENEWABLE FUELS OF NON-BIOLOGICAL ORIGIN (RFNBO)

- REDII opens the door for accounting e-fuels (as part of RFNBO) towards the 14% renewable energy transport target, via obligations on fuel suppliers
- REDII includes multipliers; i.e. RFNBO may count 1.2 times their energy content (for EU aviation and marine sectors); renewable electricity can count 4 times its energy content (for road transport) and 1.5 times (for rail)
- REDII requires RFNBO to meet requirements when procuring electricity, i.e. 'renewability', 'additionality', 'temporal & geographical correlation' (Art. 27)
- REDII mandates RFNBO to achieve min. 70% GHG emissions savings compared to fossil fuel baseline from 01.01.2021 (Art.27)
- Delegated Acts for methodologies to determine due 31.12.2021 : renewability of RFNBO and GHG emissions savings delivered by RFNBO (Art. 28)
- REDII does not specify source of CO_2 for RFNBO, but Commission documents indicate that Direct Air Capture (DAC) is preferred
  - Using industrial source of CO_2 could create a decarbonization disincentive for heavy industry, and could lead to double-counting of credits (under EU ETS and REDII).

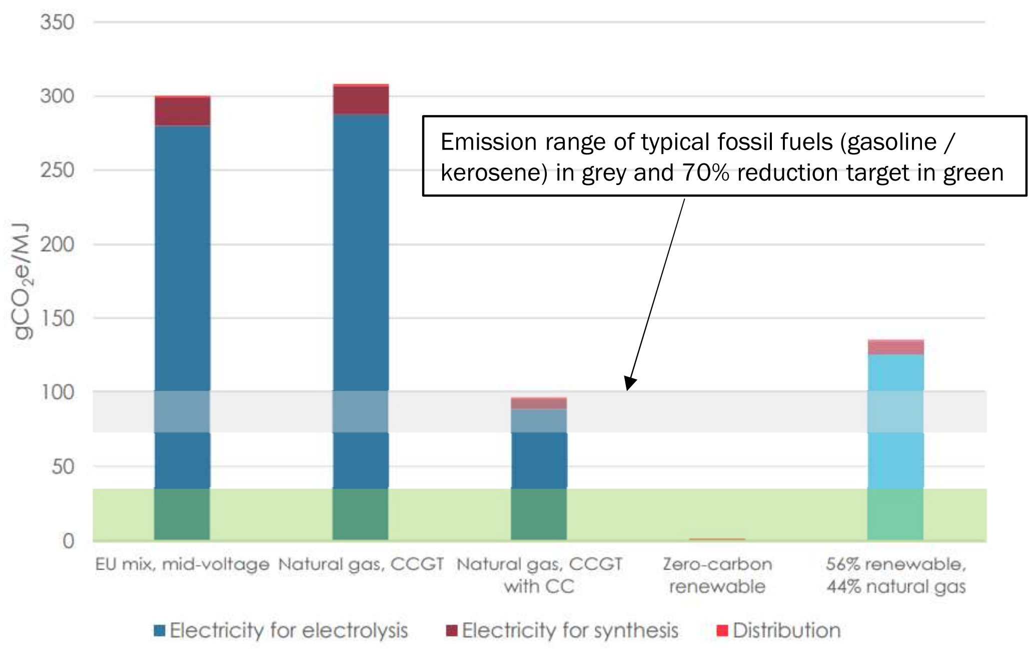


In this figure e-fuels are part of the category "Electrofuels". The overall target for renewable fuels is 14% of which food-based biofuels may cover 7% at maximum. At least 7% (binding target, but preferably more) should be covered by advanced renewable fuels such as e-fuels.

Source: https://www.transportenvironment.org/sites/te/files/publications/2020_01_REDII_general_implementation_briefing.docx_.pdf

REGULATION

- REDII mandates **RFNBO to achieve min. 70% GHG emissions savings compared to fossil fuel baseline** from 01.01.2021 (Art.27)
- Source of electricity is the largest determinant of realizable GHG emission reductions during e-fuel production.
- The share of renewable electricity used for the production process should be very high to deliver a 70% GHG emission reduction.
- An e-fuel chain with 50% energy conversion efficiency would require electricity with a maximum emission factor of approximately 15 gCO_2e/MJ. Such a low emission factor is only achievable by nearly 100% renewables (or nuclear).
- Meeting the GHG reduction requirement with average national grid electricity is only feasible in a few countries (e.g. Norway and Iceland) for a foreseeable period of time.
- Source of CO_2 will, depending on the forthcoming delegated act, play an important role in achieving the 70% reduction target and might exclude CO_2 from fossil origin (only biogenic and atmospheric CO_2 allowed).



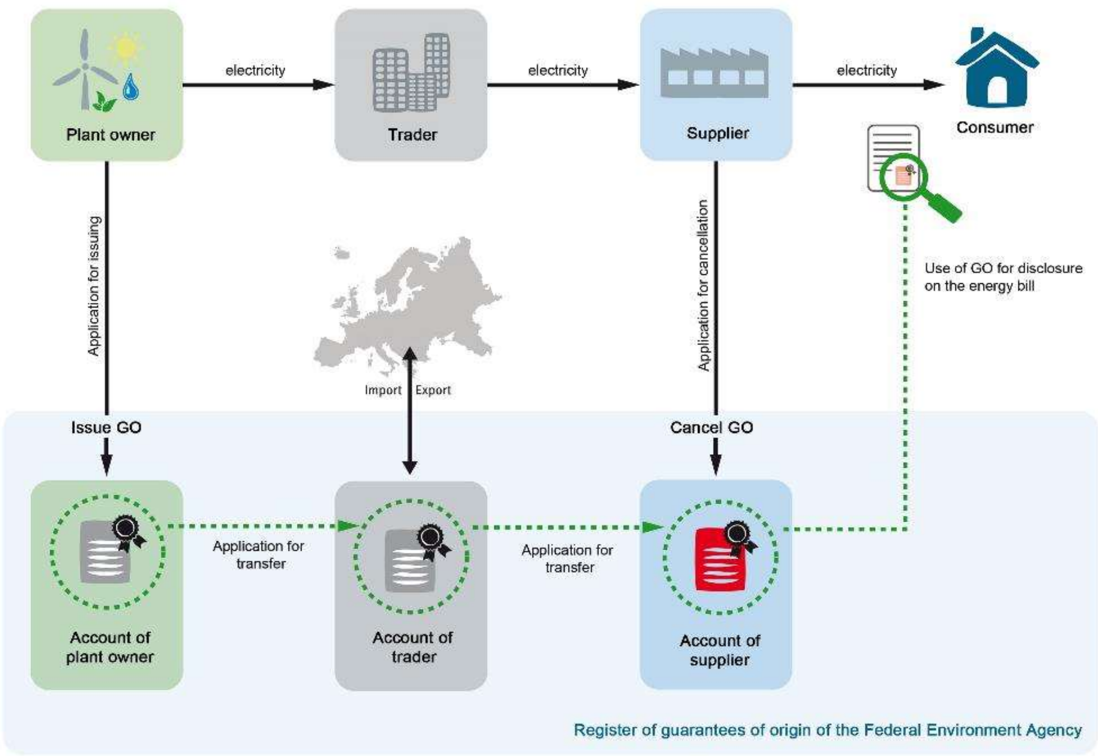
GHG intensity of fuel synthesis (40% energy efficiency) based on different electricity mixes.

Source: Malins (2017)

CERTIFICATION/GUARANTEES OF ORIGIN

- **Imported RFNBO (incl. e-fuels)** from non-EU/EEA countries **must comply with REDII requirements** (in order to count towards RES transport targets/obligations)
- REDII, Art. 30 requires:
  - MS shall take measures to ensure reliable information regarding the compliance with the GHG emissions savings
  - Regardless of whether the RFNBO are produced within the Union or are imported (REDII, Art. 30).
  - Necessary to ensure that such imports can be tracked and accounted for in a reliable way.
- Questionable if non-EU/EEA countries have **reliable data collection, monitoring and verification procedures** to document that renewability of procure electricity for RFNBO production as well as 70% GHG emission reduction compared to fossil comparator.

Illustrating certification/Guarantee of Origin



Source: Michael Marty, Magdalena Weimeister / UBA

CERTIFICATION/GUARANTEES OF ORIGIN

- To avoid double counting of renewable energy supply and emissions, several schemes exist to document and verify the origin of these sources (guarantees of origin) and their counting towards a single target (in one sector/country).
- Several schemes are already (or under negotiation to be) recognized by the European Commission
- Some of these schemes track the sustainability of specific sources, such as biomass, renewable gas, and biofuels.
- CertifHy 3 will build a certification system for RED II compliant renewable transport fuels ("RFNBOs") and will follow-up closely the development of the RED II delegated acts in this regard. CertifHy collaborates with the European Renewable Gas Registry (ERGaR) whose mass balancing scheme for cross border transfer of biomethane as a transport fuel is in the process of being approved by the European Commission.

ELECTRICITY	IN PLACE
BIOMASS	IN PLACE
RENEWABLE GAS	UNDER NEGOTIATION
HYDROGEN	UNDER DEVELOPMENT (new or integrated in other schemes?)
HYDROGEN CARRIERS AND OTHER E-FUELS?	

SAFETY & ENVIRONMENT

- Safety and environmental concerns vary among the different e-fuels (e.g. in terms of flammability and toxicity for both humans and aquatic life).
- Different precautionary measures required to ensure safe usage
- Some compounds are severely toxic, which may hamper use in the public domain
- The most important characteristics of methanol and kerosene are listed below (from Material Safety Data Sheets)

Compound		
Methanol		**Highly flammable** liquid and vapor. **Toxic** if swallowed, in contact with skin or if inhaled. Causes **damage to organs** (liver, kidneys, central nervous system, optic nerve) (Dermal, oral).
Jet fuel (kerosene)		**Flammable liquid** and vapor. Causes Skin irritation. **May be fatal** if swallowed and enters airways. May cause drowsiness or dizziness. **Toxic to aquatic life** with long lasting effects.

PUBLIC PERCEPTION

- Narrative and long term goals important. Build awareness, avoid emergence of negative perception and evaluate public acceptance.
- CCU is about circularity and different from CCS (requires clear explanations)
- Explain about the necessity, safety, sustainability, efficiency, and costs of these novel value chains
- Avoid a similar uncertainty around sustainability of biomass (for power production).
- CO_2 (fossil/biogenic/atmospheric) good or bad? Can we use it or should it be avoided at all?
- Will there be a preferred market for e-fuels and what will be the impact for society?
  - Fuel for transport (REDII) - higher premium? (willingness to pay by the costumer)
  - Industrial use (EU-ETS) – experience in sector with RFNBO chemicals

FUNDING INSTRUMENTS

Different type of funding possibilities:

- Small scale demo phase mainly focuses on validating a new technology → support instruments focus on R&D funding (investments required for demo projects)
- With large scale demonstrations, financial risks increase → necessitates additional support measures (e.g. de-risking instruments, e.g. guarantees, concessional loans, etc.)
- Early market phase, focus includes providing stable and predictable remuneration schemes (production support) and tax benefits to ensure continued innovation and cost reductions
- Commercialisation phase, once the technology has gained a strong foothold in the market → plan for (gradual) phase out of remuneration schemes and tax benefits

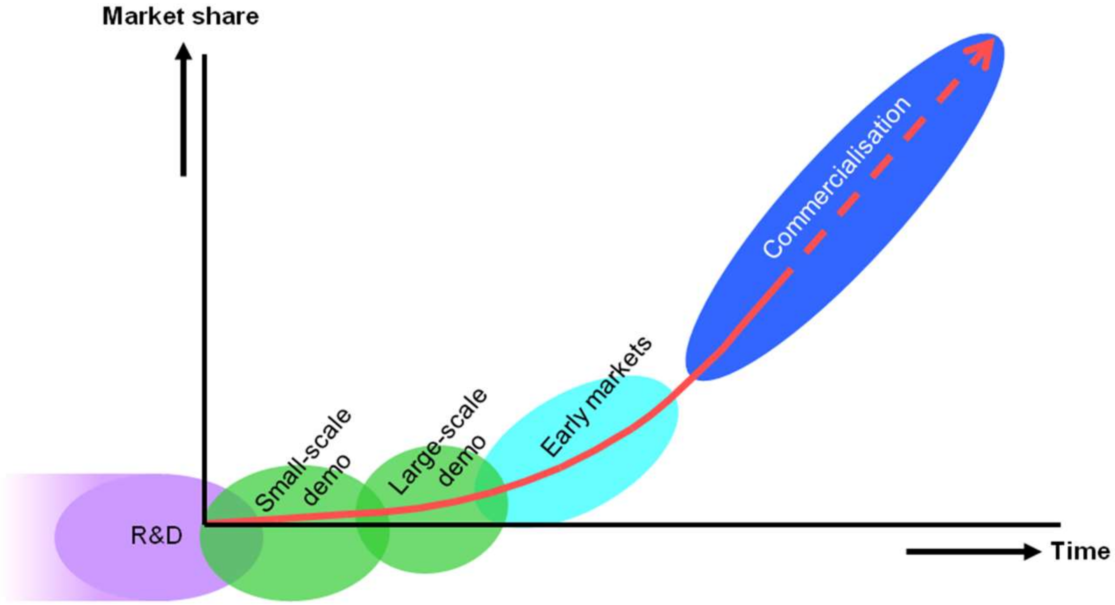


Figure: Technology development phases

See slides 55/56 in the appendix for some EU funding opportunities

CONCLUSIONS

- RFNBO incl. CCU/e-fuel technologies are the 'new kid on the block'
- Final application of the RFNBO plays key role to determine relevant regulations
- Current EU legislative framework (particularly REDII, ETS directive) does not give regulatory clarity for RFNBO (renewability + additionality of procured electricity; eligibility of carbon sources; how emission reductions are to be accounted & credited)
- Legislative updates ongoing (as part of Green Deal follow-up), which should provide more clarity on how to secure the challenging 70% GHG reduction target for RFNBO (incl. e-fuels) as transport fuels
- Monitoring and verification procedures to document the renewability of (imported) RFNBO is very important (in progress via CertifHy).
- Circular carbon source (biogenic or atmospheric) likely preferred over fossil CO_2
- Explain these new type of value chains well to society (after proper analysis) to avoid unclarity and uncertainty around its safety and sustainability
- CCU/e-fuel value chains are a research priority in new funding programmes, selection criteria for demo projects include high degree of innovation & GHG emission avoidance

PART 2 – APPENDICES

PILOT RECOMMENDATIONS

- Focus on small-scale R&D demonstration, with start-up as soon as possible
- Look for opportunities within EU's funds for demonstrating CCU technologies
- Focus on innovative aspects and opportunity for scalability
- Possibly couple a hydrogen value chain to a CCU pilot for the production of e-fuels
- Methanol and kerosene seem attractive as e-fuel products because both are likely needed for several decades (no good alternative) as chemical feedstock and jet fuel
- Think of using the small-scale demo to explore ways to meet the (forthcoming) REDII requirements
- Important to discuss with Dutch policy makers what derogations from REDII criteria are feasible from a small-scale pilot perspective.
- Focus on scaling up to large-scale demo once there is more clarity on the regulatory framework for RFNBO, and on the basis of lessons learned from the small-scale demo

ABBREVIATIONS

- REDII: Recast Renewable Energy Directive (Directive (EU) 2018/2001)
- EU ETS: EU Emission Trading Scheme
- EGD: European Green Deal
- RFNBO: Renewable Fuels from Non-Biological Origin
- CCU: Carbon Capture and Utilization
- GO: Guarantee of Origin
- PPA: Power purchase agreement
- MS: Member States
- COM: European Commission
- SAF: Sustainable Aviation Fuels
- RES-T: renewable energy in transport
- RES-E: electricity from renewable energy sources

REDII REQUIREMENTS
RENEWABILITY

REDII requirements (direct connection):

- Art. 27(..): *electricity consumed must be: "**produced exclusively from renewable sources**"*
- Art. 27(3) "*installation generating renewable electricity [...] is not connected to the grid or is connected to the grid but evidence can be provided that the electricity concerned has been supplied* ***without taking electricity from the grid***."

Questions arising from REDII requirements:

- Electrolysis-based RFNBO and synfuels requires "baseload" electricity, how to ensure this, and at what cost
- Direct connection to a single renewable electricity facility would impose significant costs by preventing maximum utilisation of electrolysers for production of RFNBO

REDII requirements (average grid electricity), relates to Recital (90):

- "*... there should be an element of* ***additionality****, ... the fuel producer is adding to the renewable deployment or to the financing of renewable energy.*"
- "*...**temporal...correlation** between the electricity production unit with which the producer has a bilateral renewables power purchase agreement and the fuel production".*
- '*geographical correlation* *between the electricity production unit with which the producer has a bilateral renewables PPA and the fuel production*".

Questions arising from REDII requirements (to be addressed):

- Not yet clear what is meant by "additionality". New renewable assets, subsidized/unsubsidized? Ca;dlja;ldfja;ldfja;ldjfaldj;aldjfadjadj
- Temporal correlation: contracted assets? Intraday matching, full/partial/system level? ....
- Same bidding zone? Same side of grid congestion within bidding zone? Different bidding zones (with approved coupling capacities)

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REDII

RELEVANT RECITALS & ARTICLES CONCERNING RFNBO & TRANSPORT TARGET

Renewability

Recital (90): […] To ensure that RFNBO contribute to GHG reduction, the electricity used for the fuel production should be of renewable origin. … For example, RFNBO cannot be counted as fully renewable if they are produced when the contracted renewable generation unit is not generating electricity.

Art. 27 (3): Calculation rules with regard to the minimum shares of renewable energy in the transport sector
[…], where electricity is used for the production of RFNBO, either directly or for the production of intermediate products, 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 renewable energy. … However, 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 RFNBO, […]

Transparency and traceability of renewable fuels

TRACEABILITY

Recital (84): A Union database should be put in place to ensure transparency and traceability of renewable fuels.

Art. 28 (2): Other provisions on renewable energy in the transport sector
The Commission shall ensure that a Union database is put in place to enable the tracing of liquid and gaseous transport fuels that are eligible for being counted towards the numerator referred to in point (b) of Article 27(1) or that are taken into account for the purposes [..] of Article 29(1).

Additionality

Recital (90): […]. Furthermore, there should be an element of additionality, meaning that the fuel producer is adding to the renewable deployment or to the financing of renewable energy.

Art. 27 (3): Calculation rules with regard to the minimum shares of renewable energy in the transport sector
In order to ensure that the expected increase in demand for electricity in the transport sector beyond the current baseline is met with additional renewable energy generation capacity, the Commission shall develop a framework on additionality in the transport sector and shall develop different options with a view to determining the baseline of MS and measuring additionality.

Mass balance

Art. 30 (1): Verification of compliance with the sustainability and greenhouse gas emissions saving criteria
Where biofuels, bioliquids and biomass fuels, or other fuels that are eligible for counting towards the numerator […], MS shall require economic operators to show that the sustainability and GHG emissions saving criteria […] have been fulfilled. For those purposes, they shall require economic operators to use a mass balance system […].

→ allows physical mix of (non-)sustainable products as well as the mix of consignments with different sustainability characteristics at every stage of the value chain BUT prevents blending of different batches from changing the sustainability characteristics of an original consignment or renewable fuel batch

Guarantee of origin

Recital (55): A guarantee of origin can be transferred, independently of the energy to which it relates, from one holder to another.

Recital (59): Guarantees of origin which are currently in place for renewable electricity should be extended to cover renewable gas.

Art. 2 (3) Definitions
[…] an electronic document which has the sole function of providing evidence to a final customer that a given share or quantity of energy was produced from renewable sources

Art. 19: Guarantees of origin for energy from renewable sources
MS shall ensure that when a producer receives financial support from a support scheme, the market value of the guarantee of origin for the same production is taken into account appropriately in the relevant support scheme. … The guarantee of origin shall have no function in terms of a Member State's compliance with Article 3 (Binding overall Union target for 2030)

GHG emission reduction

Art. 25 (2): Mainstreaming renewable energy in the transport sector
The GHG emissions savings from the use of RFNBO shall be at least 70 % from 1 January 2021.

EU LEGISLATIVE DEVELOPMENTS IN THE PIPELINE

- Legislative revisions/amendments (non-exhaustive list) that will have to align with European Green Deal's (EGD)'s climate neutrality by 2050 and deliver on increased GHG emission reduction 2030 ambitions

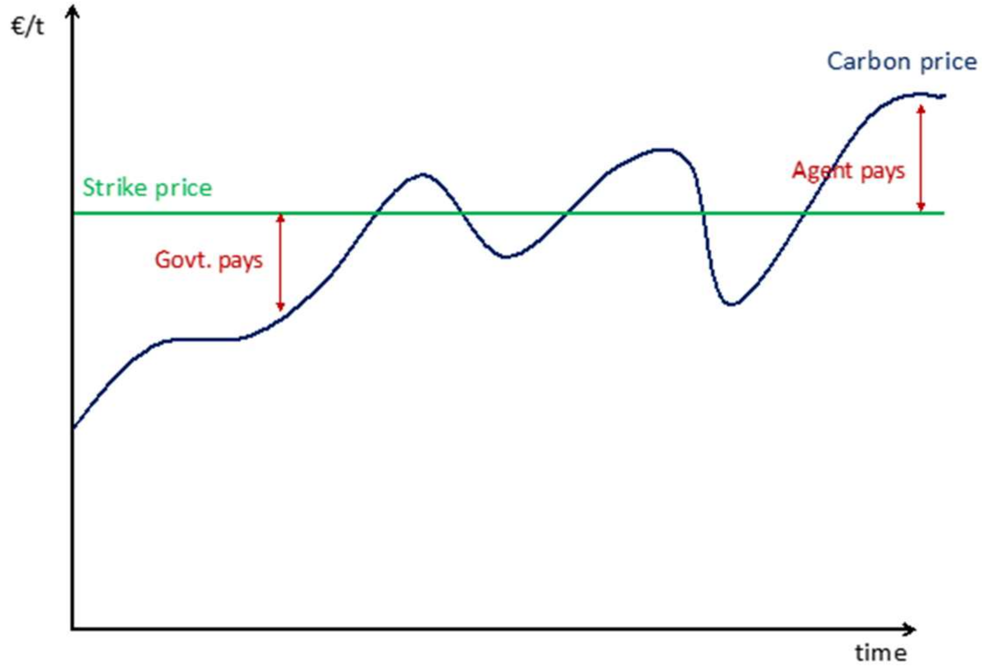
REDII amendments	• Possible upward review of min. EU-wide 32% RES target • More measures to promote renewable energy • Consider inclusion of elements from the recent European energy System Integration and Hydrogen strategies, e.g. comprehensive terminology and robust certification system
EU ETS revision (Q2, 2021)	• Concerning aviation, review subject to the international developments related to the operationalization of CORSIA • Revision will serve to implement the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) by the EU consistent with EU's 2030 climate objectives • Increase the share of allowances auctioned under the system for aircraft operators to further contribute to reducing GHG emissions • Will likely introduce carbon contract for difference (CCfD)
ReFuelEU Aviation initiative	• New legislative instrument for the uptake of alternative fuels in the aviation sector • Work began on this legislative instrument with an inception impact assessment consultation launched in April 2020
FuelEU Maritime – Green European Maritime Space	• New legislative initiative announced in the context of the 2020 Commission Work Programme • Public consultation on the is initiative launched in August 2020 • Will focus on ramping-up the production, deployment and uptake of sustainable alternative marine fuels, incl. decarbonised hydrogen-derived fuels
Revision of Third Gas Package to regulate competitive decarbonised gas markets (Q4, 2021)	• Revision will include sector coupling and low carbon gases

OTHER RELEVANT EU POLICY INSTRUMENTS IN THE PIPELINE

- Carbon Border Adjustment Mechanism and a review of the Energy Taxation Directive.
- Carbon Border Adjustment Mechanism (CBAM) aims to address carbon leakage as a result of companies relocating production to countries with less stringent carbon policies and replacing EU production with imports. CBAM could impact the import of hydrogen, or other 'products', e.g. ammonia, synthetic methane, etc. from overseas if these are not deemed sufficiently "green."
- Protection of carbon/energy intensive industries in the EU, e.g. steel, cement, etc., would enable them to stay in Europe and consume hydrogen or natural gas with CCS.
- Revision of the Taxation Directive aims to align taxation of energy products and electricity with EU energy and climate policies, to contribute to the EU 2030 energy targets and climate neutrality by 2050.
- These two initiatives, which are included in the European Commission's Work Programme for 2021, are still at an early stage.

CARBON CONTRACTS FOR DIFFERENCE (CCfD)

- Contract by which a government or institution agrees with an agent on a fixed carbon price over a given time period.
- During the contractually agreed period this agent can then sell any carbon emission reductions (or allowances) at that given price.
- If formulated as a strike price over a carbon market price (a two-sided option) then they become Carbon Contracts for Differences (CCfDs).
- If the market price is lower than the strike price, the agent receives the difference. If the market price is higher, the agent has to return the additional revenue to the government.
- CCfDs have been specifically mentioned in the national German hydrogen strategy (BMWi, 2020), and in the Green Deal Recovery Package, as tools to bridge the cost gap between conventional and decarbonized hydrogen



Source: https://climatestrategies.wordpress.com/2020/09/09/carbon-contracts-for-differences/

EU'S CHANGING POLICY/LEGISLATIVE LANDSCAPE

EU's STRATEGY ON ENERGY SYSTEM INTEGRATION (ADOPTED JULY 2020)

Highlights from the strategy:

- Priority for EU to **develop hydrogen production from RES-E**. In a transitional phase, acknowledges that **other forms of low-carbon hydrogen are also needed** to replace existing hydrogen and kick-start an economy of scale.
- Introduce a **comprehensive terminology** and a **European certification system** covering all renewable and low carbon fuels. Such a system, based notably on full life cycle GHG emissions savings, will allow for more informed choices when deciding on policy options at the EU or national level.
- Develop a regulatory framework for the **certification of carbon removals** based on robust and transparent carbon accounting to monitor and verify the authenticity of carbon removals (by 2023)
- **Demonstrate and scale-up the capture of carbon** for its use in the production of synthetic fuels, possibly **through the Innovation Fund** (from 2021)
- Promote the **financing of flagship projects** of integrated, carbon-neutral industrial clusters producing and consuming renewable and low-carbon fuels, through **Horizon Europe**, **InvestEU** and **LIFE programmes** and the **European Regional Development Fund** (from 2021)
- Consider **additional measures to support renewable and low-carbon fuels**, possibly through minimum shares or quotas in specific end-use sectors (incl. aviation and maritime), through the revision of REDII and building on its sectoral targets (June 2021), complemented, where appropriate, by additional measures assessed under the REFUEL Aviation and FUEL Maritime initiatives (2020).

EU'S CHANGING POLICY/LEGISLATIVE LANDSCAPE

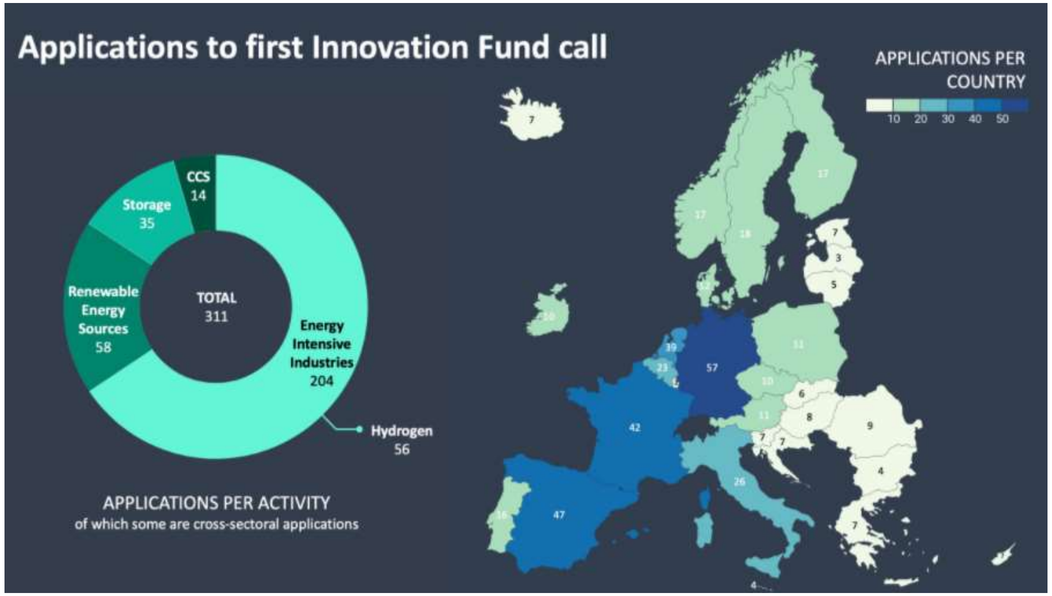
EU's STRATEGY ON HYDROGEN (ADOPTED JULY 2020)

Highlights from the strategy (bullets partially summarized from https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/07/EU-Hydrogen-Strategy.pdf):

- Proposes target of 6GW of electrolysers by 2024, and 40GW of electrolyser capacity by 2030.
- Recognises renewable hydrogen as 'end game', but acknowledges that "in the short and medium term" other forms of low carbon hydrogen (presumably mainly fossil-based hydrogen with CCS, i.e. "blue" hydrogen") will play a role.
- Recognises that, initially at least, priority uses of hydrogen will be close to the point of production in existing carbon-intensive industrial applications, e.g. refineries, ammonia and methanol production. Envisages hydrogen use to grow in local clusters (which could then expand into "valleys") around those industrial hubs.
- Recognises hydrogen's role in transport applications where electrification is more difficult, and potentially to manufacture synthetic fuels for aviation and maritime transport. Notes, however, that further work is required for this, and the EU intends to publish its Sustainable and Smart Mobility Strategy later in 2020.
- Introduce a comprehensive terminology and European-wide criteria for renewable and low-carbon certification (by June 2021).
- Explore additional support measures, including demand-side policies in end-use sectors, for renewable hydrogen building on the existing provisions of Renewable Energy Directive (by June 2021). Develop a pilot scheme (preferably at EU level) for a Carbon Contracts for Difference programme (CCfD), in particular to support the production of low carbon and circular steel, and basic chemicals.

FUNDING INSTRUMENTS
EU R&D FUNDING OPPORTUNITIES

- Support demonstration of innovative technologies and breakthrough innovation in sectors covered by the EU ETS
- Includes breakthrough innovations in renewables, hydrogen, carbon capture and utilisation, and energy storage.
- 1st call which closed in October 2020, received 311 applications (39 applications from NL and 56 applications for hydrogen, see slide).
- Tentative launch of 2nd call is December 2020
- Allows for cross-sectoral projects and/or project combining innovative technologies
- Award criteria include: GHG emission avoidance, degree of innovation, project maturity, scalability and cost efficiency



Source: https://ec.europa.eu/clima/news/first-innovation-fund-call-large-scale-projects-311-applications-eur-1-billion-eu-funding-clean_en

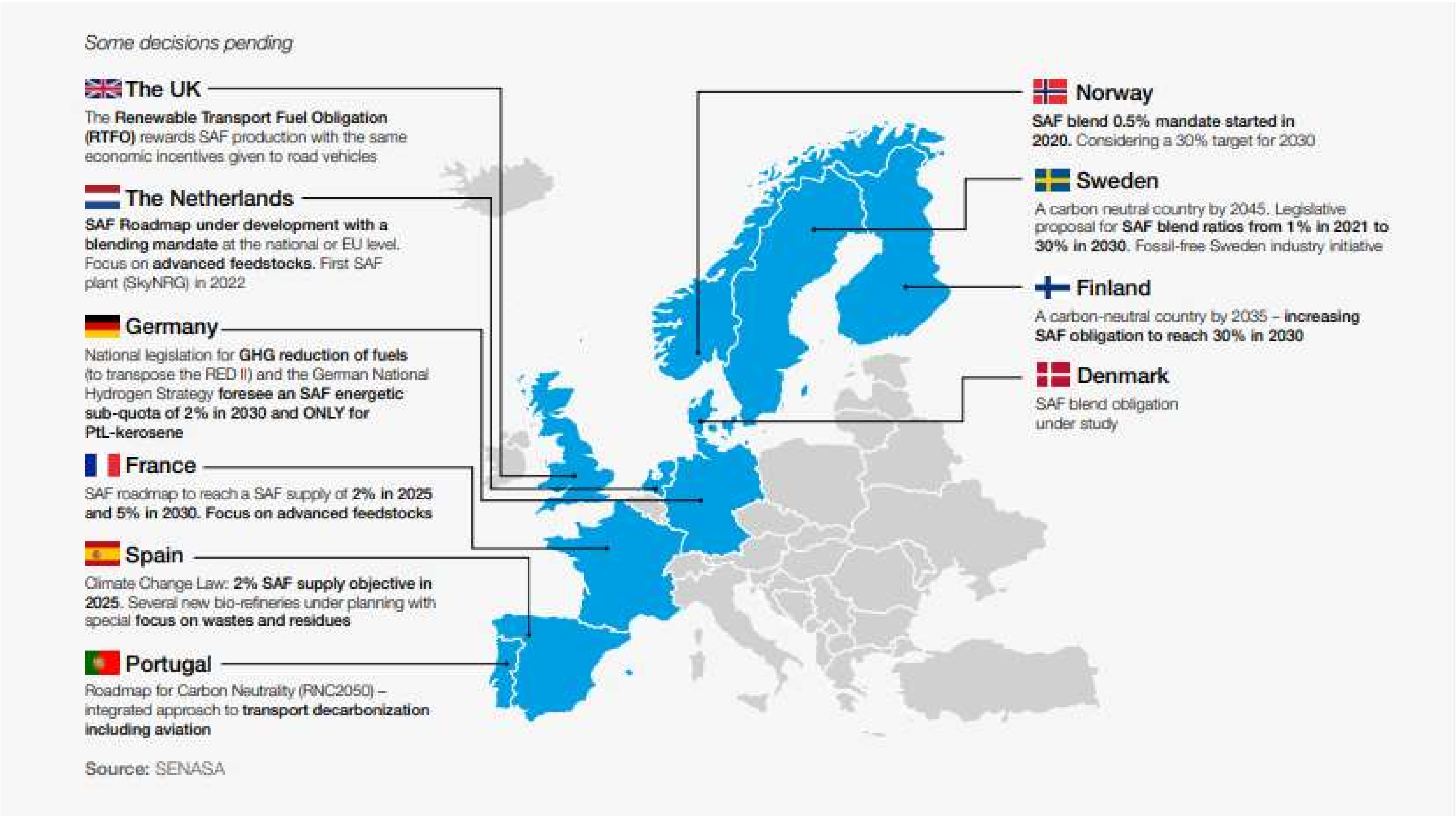
- If projects are promising but not yet mature for start-up (e.g. due to permitting procedures, financing/due diligence, feasibility studies lacking), projects can then receive project development assistance, offered by the European Investment Bank (EIB), with tentative subsidy (grant) in order of 500.000 EUR.

EU R&D FUNDING OPPORTUNITIES
BRIEF OVERVIEW OF R&D FUNDING WINDOWS

- Hydrogen is featured as a key 'sector' to receive support under the recovery plans (as it can contribute to EU's Green Deal targets, climate neutrality and EU's strategic autonomy
- Several funding windows within InvestEU programme:
  - InvestEU's first window: Sustainable infrastructure ((production of renewable energies and of alternative and clean synthetic fuels)
  - InvestEU's fifth window: Strategic Investment Facility will invest in technologies key for the clean energy transition, e.g. clean hydrogen
- Recovery and Resilience Facility (mostly grants), hydrogen eligible to benefit from this scheme, provided that hydrogen projects are included in MSs' RRPs and that these get the Commission's approval. Countries with hydrogen-ambitious NECPs, such as the Netherlands, Austria, Czechia, or Portugal, are expected to better highlight hydrogen in their Recovery and Resilience Plans (RRPs).
- Just Transition Mechanism (additional investment scheme under InvestEU, grants & loans), targeted towards carbon intensive regions
- REACT-EU scheme, funds via EBRD for green energy and transport projects, hydrogen fits eligibility criteria, available financial instruments are diverse ranging from guarantees to direct loans. Countries and regions ambitious on hydrogen development (via their national hydrogen strategy or their NECPs, such as Germany, the Netherlands, Austria, France and Czechia, for instance) could be priority investment targets. This strategy aspect should be thought of in consistency with the aim of Cohesion Policy to support least developed and most vulnerable EU regions.

SAF COMPETITIVENESS AND SCALE-UP

THE EUROPEAN LANDSCAPE



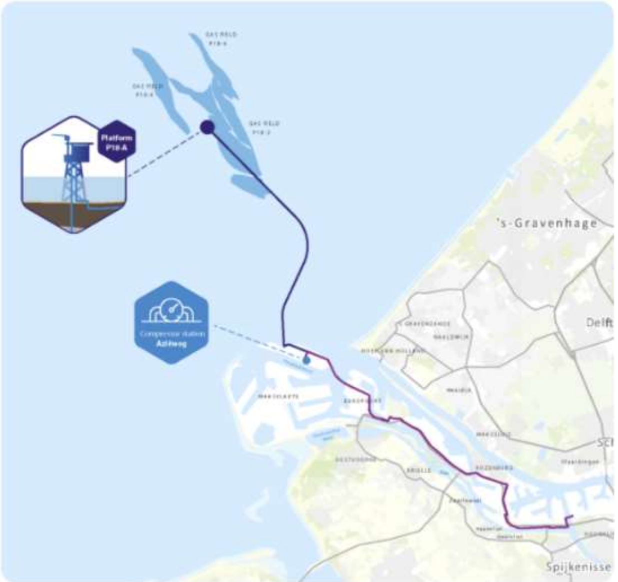
Accessed from: World Economic Forum & McKinsey report on Clean Skies for Tomorrow Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation. November 2020.

PART 3 OCAP AND PORTHOS INFRASTRUCTURE

CCS/CCU NETWORKS IN OPERATION AND PLANNED

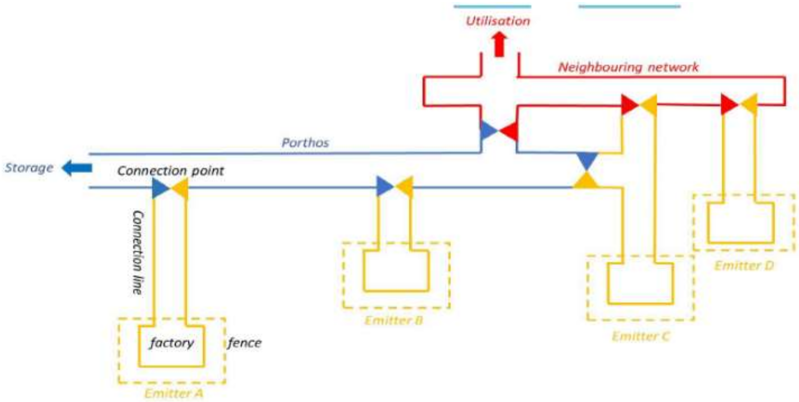
- OCAP currently has a capacity of about 0.6 Mtpa CO_2 (from Shell Pernis and Alco), with several add-on options
- There are proposals to integrate the Porthos CCS project with the OCAP pure CO_2 distribution network for greenhouses

Port of Rotterdam | gasunie crossing borders in energy | ebn



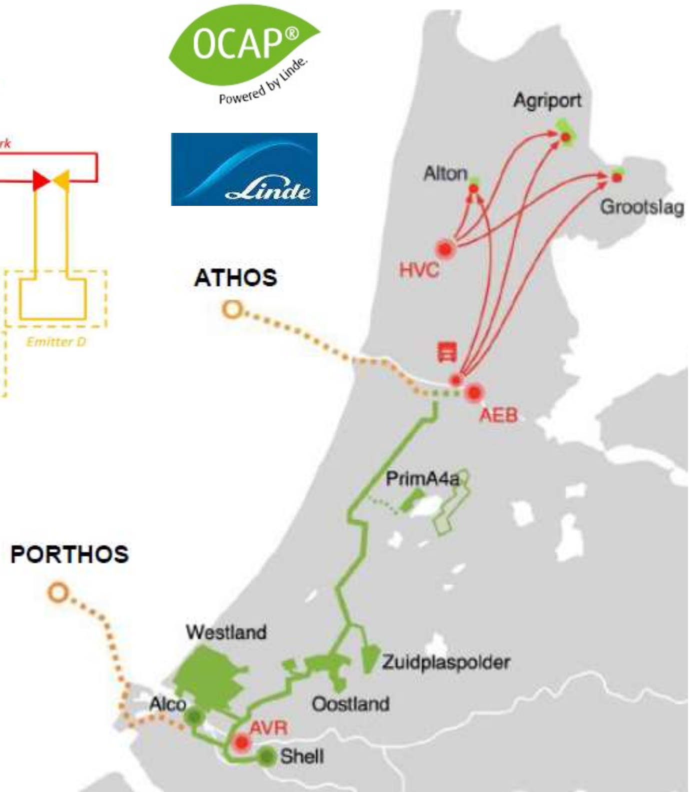
Air Liquide | Air Products | ExxonMobil | Shell

Simplified CO_2 network diagram:



Partners and CO_2 suppliers:

aeb amsterdam | alco | AVR. | HVC | Shell



PORTHOS AND OCAP RELATIONSHIP
JULY 2020 KAMERBRIEF

HTTPS://WWW.OMGEVINGSWEB.NL/BELEID/KAMERBRIEF-OVER-CO2-LEVERING-AAN-GLASTUINBOUW/

Ministers Wiebes and Schouten described the actions that will be used to increase the supply of CO_2 to greenhouse horticulture towards 2030. Supply of CO_2 by industry, for example, must ensure that greenhouse horticulture no longer has to produce CO_2 itself through burning natural gas itself.

CURRENT THINKING:

- Incentives not optimized for CO_2 supply to greenhouse horticulture.
- The Climate Agreement states that greenhouse horticulture will need approximately 2 Mt per year of externally supplied CO_2 in 2030 to achieve the reduction target.
- Therefore not only maintaining current supply but also expanding is important.
- Government will be looking at the extent to which there are possibilities via the SDE ++ to facilitate the supply of CO_2 to greenhouse horticulture.
- PBL is currently conducting research and market consultation on this for decision-making on the categories that can be included in the SDE ++ in 2021.
- This is not only about how externally supplied CO_2 can become a more attractive alternative to the use of natural gas but also how alternative heat options and energy efficiency can be effectively promoted in parallel.

PORTHOS AND OCAP RELATIONSHIP

JULY 2020 KAMERBRIEF

HTTPS://WWW.OMGEVINGSWEB.NL/BELEID/KAMERBRIEF-OVER-CO2-LEVERING-AAN-GLASTUINBOUW/

PROPOSED INNOVATION PILOT ON CO_2 DELIVERY

Therefore 3 elements for future innovation have been proposed:

- The innovation pilot will use a combination of CO_2 from fossil sources and biogenic sources. In the summer months, both fossil and biogenic CO_2 are supplied to greenhouse horticulture, while in the winter months both fossil and biogenic CO_2 are stored.
- The aim is to ensure that only biogenic CO_2 is supplied to greenhouse horticulture by means of an annual administrative settlement. Surplus biogenic CO_2 will be delivered to Porthos during winter, balancing the fossil CO_2 taken in by OCAP to meet higher summer demand. Infrastructure for OCAP and Porthos will be separate. This means that during summer OCAP extracts from the Porthos network and delivers to the network during winter.
- Together with Porthos, it will be worked out how the winter peaks in CO_2 storage will occur with this approach, and how integrated into the Porthos system this could be. Where necessary, resources from central government can be deployed to realize this innovation pilot.

This is envisaged for maintaining current supply but could also be a basis for expansion.

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TNO innovation for life

PART 4: INTERVIEW RESULTS

PROVINCIE ZUID-HOLLAND

CCU / E-FUELS

KARIN VAN KRANENBURG & SARA WIECLAWSKA, DECEMBER 2020

INTERVIEW RESULTS
CONTENTS

TNO innovation for life

INTERVIEW RESULTS
INTRODUCTION

This part of the report for the Provincie Zuid-Holland presents the results of interviews with industrial stakeholders. Goal of the interview was to get insight in activities of industrial stakeholders throughout the value chain in hydrogen (carrier) production and transport, as well as their activities and interests in CCU and e-fuel production and piloting. These slides reflect the opinions and thoughts of interviewees of these two projects.

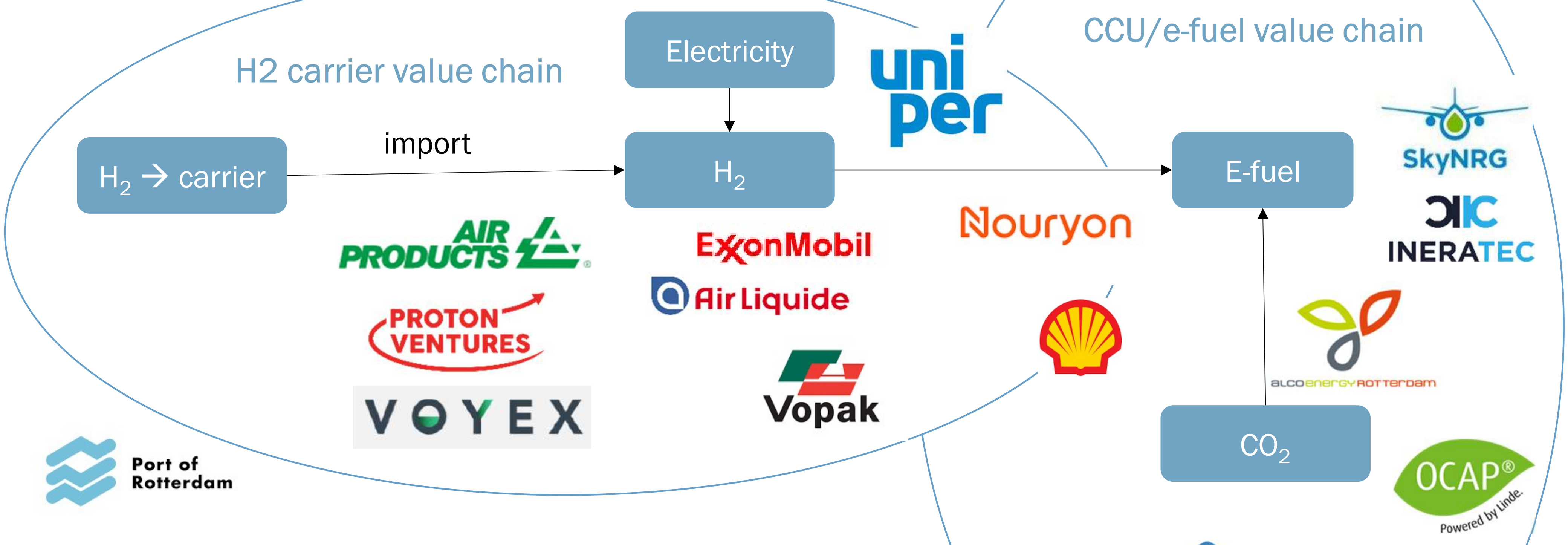
The following topics were covered during the interviews:

- Current activities with respect to hydrogen (carrier) production and transport and/or CCU and e-fuel production and piloting
- Selection of hydrogen carriers and e-fuels, KPIs and infrastructure needed
- Drivers and barriers
- Interest in pilots within FLIE context
- Role of Provincie Zuid-Holland

A list of interviewees and the questionnaire can be found in Annex A. Minutes of the interviews are available as a separate Annex in Word and an overview of interview results as an Annex in Excel.

During a workshop, held on the 14th of December, an analysis of the interview results was presented and four companies presented their ideas on a pilots. More information on the workshop can be found in Annex B.

INTERVIEW RESULTS
OVERVIEW OF INTERVIEWEES AND ACTIVITIES ON H2 AND E-FUELS



All stakeholders have different roles (users, producers, infrastructure/tech suppliers). Together they form the value chains.
In total, 17 interviews with 16 stakeholders were held.
The full interviews are summarised in interviewformats (see Annex A)

INTERVIEW RESULTS
CCU / E-FUELS

Most interviewed companies focus on CCS at this moment; CCU is seen as a more long-term innovation.

CO2 is mainly used for agriculture, but in future the interviewees see CO2 and CO as feedstock for e-kerosine and CH_3OH. There seems to be no preferred route towards e-fuels yet.

The biggest barriers for CCU mentioned by interviewees:

CO2 being too expensive for e-fuel production because of the current ETS regulations (CCS is cheaper than CCU)

CO2 not being available: Direct Air Capture technology is still expensive and not available on a large scale. Green CO2 will be mostly used for agriculture.

For the selection of a e-fuel pilot project, the following KPIs are important to interviewees:

- Stable, trusting consortium
- Embedding in the ecosystem
- Proven technology
- Insight in volume of e-fuel offtake in future
- Offtaker included
- Tech integration
- Serious scale

INTERVIEW RESULTS
DRIVERS AND BARRIERS

Business case

- Energy: costs and additionality
- Offtaker needed
- Regulation is of vital importance for the business case and currently makes mobility to a focus market for both green hydrogen and e-fuels
- Subsidies/incentives for offtakers needed
- Import may be less expensive (H2)

Regulation

- RED II as a driver for green mobility
- Investors need mandates and continuity
- Under ETS, room for CCU is limited
- Import of green hydrogen from outside EU is not covered in EU regulations

Organisation

- Ecosystem development, cooperation and trust is crucial
- Many partners, knowledge and infrastructure in Rotterdam area

Technology

- Proven technology available, but not for all routes
- Integration is a challenge
- Large scale production in many cases not yet proven
- DAC is still low in TRL

INTERVIEW RESULTS
PILOTS

Many pilots ongoing or planned. Non-extensive list of initiatives mentioned in interviews in the table (some loosely mentioned ideas are not included).

Mostly in start-up phase or demonstration phase.

An offtaker is often mentioned as a requirement for larger scale pilots.

Some companies have indicated interest in working together with other interviewed companies on pilots (Shell, Uniper, Ineratec, Air Liquide amongst others).

The FLIE has proposed to compare the outcome of the pilots (e.g. NH3 vs. LOHC) in the future, in order to maximise cross-pilot learning.

For more info: see Annex B (workshop details). The pilots from Proton Ventures, Vopak, Uniper and Alco Biofuels were pitched during the workshop..

Pilot	
NH3 as H2 carrier	PROTON VENTURES
LOHC as H2 carrier ("Puffin")	Vopak
NH3 import from Saudi Arabia ("NEOM")	AIR PRODUCTS
Various H2-related topics within 'H-vision'	Air Liquide, BP, Exxon, Gasunie, HbR, Shell, Uniper, Vopak a.o.
Jet fuel synthesis	uniper
Jet fuel synthesis (route tbd)	alco energy rotterdam
Jet fuel synthesis with DAC ("Zenid")	SkyNRG, Climeworks, Sunfire, Ineratec, HbR, Nouryon a.o.
Jet fuel synthesis from waste-oils ("HEFA")	SkyNRG, Nouryon, Gasunie a.o.
Jet fuel synthesis from syngas	Nouryon a.o.

INTERVIEW RESULTS
ROLE OF PROVINCIE ZUID-HOLLAND

The following items were named (with frequency) as possible roles for provincie Zuid-Holland:

- Permits (9)
- Driving force for innovation, create a support base, connect stakeholders (8)
- Financial support (6)
- Enabler, facilitator (5)
- Lobby at national level (3)
- Vision for the region (2)

INTERVIEW RESULTS
CONCLUSIONS

1. Cooperation from stakeholders throughout the value chain is needed to bring green hydrogen, CCU and e-fuels further. ‘Trust’ and strong consortia are often mentioned as being valuable.
2. Ammonia and LOHC are named most frequently as hydrogen carrier candidates and kerosene (and methanol) as e-fuel.
3. Many (plans for) pilots. For large scale pilots a customer/market is required, and a contract with an offtaker for many years.
4. Focus is currently at the transport market, due to a price premium for green fuels.
   - Green hydrogen and e-fuels are much more costly than fossil (and biogenic) alternatives.
   - Regulation is a driving force for green fuels in mobility (RED II, blending requirements, aviation targets).
   - Scale is important to reduce costs, but the market is not yet large.
   - Electricity costs are dominant in hydrogen and e-fuel costs, which makes importing from countries with low cost electricity an interesting option.
5. Rotterdam area is very well equipped to build a new ecosystem around green hydrogen, CCU and e-fuels.
6. Provincie Zuid-Holland can be a driving force for innovation by creating a support base and fulfulling an enabling role.

INTERVIEW RESULTS
ANNEX : WORKSHOP

1. Description of the workshop

The workshop was held on the 14th of December and had three goals:

1) To present the results of the H2-carrier and CCU/e-fuels projects from the FLIE side and get feedback. This was done by let the projectteam present three short summarising presentations: one on the technical aspects and potency, one on legislation & policy and one on the interviews

2) To look into potential pilot possibilities. This was done by 2 companies (Uniper and Alco Biofuels) present their pilot ideas and plans on alternative fuel production in pitches (with a short discussion)

3) To provoke a discussion on what pilots should encompass.

INTERVIEW RESULTS
ANNEX : WORKSHOP

2. Attendee list

Company name	Workshop attendee
Voyex	Wiard Leenders
Air Products	Vince White Ian Brass
Gemeente Rotterdam	Lieuwe Brouwer
Proton Ventures	Jacco Mooijer
HbR	Niels Verkaik
Uniper	Yolande Verbeek, Harald Hecking
Vopak	Emma Zomers, Daan de Groot
SkyNRG	Oskar Meijerink
OCAP	Jacob Limbeek
Alco Biofuels	Pablo Vercruysse Alain Steels
Lyondell	Robert Tieman
&Flux	Mark Zuyderwijk
Provincie Zuid-Holland	Wouter Groenen, G Priester
On behalf of FLIE	Willem Frens, Wiebe Buist, Allister Slingenberg, Jeroen van Woerden
On behalf of TNO	Octavian Partenie, Karin Kranenburg, Remko Detz, Karina Veum (presenters), Arie Kalkman (PL), Sara Wieclawska (facilitator)

WORKSHOP RESULTS
RECOMMENDATIONS

- Elaborate possibilities for pilots within FLIE context further with most probable candidates:

Alco Biofuels
Jet fuels

Uniper
Jet fuels

- Enable these pilots in a facilitating role, through permitting, bringing parties together and subsidies (for producer or offtaker).
- Help stakeholders with finding an offtaker that can participate in the pilot.