Syngas value chain in Rotterdam HIC

Deliverable 1: Archetype value chain

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Introduction – A strategic syngas value chain assessment

As the chemical industry transitions toward circular and renewable carbon, syngas emerges as a uniquely versatile building block for what comes next. Produced from waste, biomass, or CO_2, and convertible into chemicals, fuels, and other hydrocarbon products, syngas connects diverse feedstocks to a wide range of valuable outputs — making it a natural focal point for large-scale circular carbon development.

The Rotterdam Harbor Industrial Cluster (HIC) is uniquely positioned to lead this development. Its logistical reach across roads, rails and waterways, its access to large volumes of renewable power, and its role as a hub for international trade flows of feedstocks and products give the Rotterdam HIC the foundations to develop syngas value chains at meaningful scale — supplying both chemicals and fuels to the Antwerp-Rotterdam-Rhein-Ruhr Area (ARRRA) super-cluster and the Northwest European hinterland.

This study was initiated by the Province of Zuid-Holland (PZH), team Sustainable Harbor, Industry and Maritime Industry. PZH asked itself: "What can we do to stimulate the development of circular and renewable carbon investments in the Rotterdam Harbor Industrial Cluster?" To answer this, PZH commissioned Tekenkamer van de Industrie (TvdI) and Sproule ERCE to conduct a strategic exploration of how the transition toward circular carbon can move forward — assessing what syngas value chain development in the Rotterdam HIC could look like at different scales, what it requires, and what it means for the existing industrial ecosystem, infrastructure, and investment climate.

To structure this exploration, first archetypes of syngas value chains were developed to understand value chain requirements and conversion efficiency. Based on these archetypes three versions were made of development pathways for a syngas value chain with the aim to increase scale and allow the R-HIC to continue to play its critical role. These versions are deliberately polarized to surface the impact of starting with a different approach. For all three versions, as scale increases the complexities grow: from the challenge of supporting many independent projects, to coordinating the large-scale systemic transformation of the industrial cluster itself. The nature of the assets, the infrastructure demands, and critically, the focus of leadership all shift — from individual project developers to regional and ultimately national governance. And they differ markedly in their contribution to sustainability and strategic autonomy, making scale a strategic choice.

The exploration is structured across four deliverables and summarised in a whitepaper. Together they take the reader from the fundamentals of syngas value chains, through a scaling assessment, to a stakeholder landscape and a decision-based roadmap — building a coherent picture of what it takes to go from ambition to action. At its core, the study asks which scale is needed, and what it would take for the Rotterdam HIC to supply the hinterland and achieve our goals of CO_2 neutrality, circularity and strategic autonomy — creating a diversified circular carbon portfolio that secures the region's long-term industrial position.

Introduction – What is syngas?

Syngas has historically served as a versatile intermediate in the chemical industry, connecting diverse feedstocks to a wide range of products. Syngas or synthesis gas is a gas mixture of primarily hydrogen (H_2) and carbon monoxide, with often also some carbon dioxide (CO_2). Its strategic importance stems from its flexibility: syngas can be produced from natural gas, coal, biomass, waste, or CO_2, and converted into methanol, synthetic fuels, ammonia, and other chemicals. These chemicals are an essential feedstock to produce plastic, polyurethane-based foams, and other materials. Furthermore, syngas can be utilized in co-generation of heat and electricity. Syngas is therefore a critical building block for circular industrial value chains.

The purpose of Deliverable 1 is to establish archetypes of the circular syngas value chain—standardized representations of process steps, material flows, and conversion pathways from feedstock to hydrocarbon products. They provide foundational components for strategic assessment of scaling up the value chains to match the current carbon-conversion scale of Rotterdam HIC – around 50 Mt/y, expected to reduce to 15-20 Mt/y in a future clean and circular state. By evaluating feedstock availability across municipal solid waste, biomass, plastics, and CO_2, this work establishes a reasonable bandwidth of potential input volumes for circular syngas production in the region.

The deliverable introduces syngas fundamentals and systematically examines each archetype component: gasification of waste, biomass, and plastics; syngas production from CO_2 via reverse water gas shift; and downstream conversions including Fischer-Tropsch synthesis, methanol production, and upgrading of methanol to fuels or chemicals. The final section addresses the circularity and sustainability aspects of syngas chains.

In this deliverable we focus on how syngas can be produced from alternative non-fossil sources to create routes for circular and sustainable supply of carbon from sources like waste, plastics and biomass, as well as from CO_2. Furthermore, we review syngas utilization options such as methanol production and Fischer-Tropsch synthesis. An accompanying Excel model enables quantitative value chain analysis, allowing the interested reader to explore different feedstock combinations, production scales, and product portfolios for their own assessment and strategic exploration.

Scope

The study focuses on the impact of developing syngas-based value chains on the Rotterdam Harbor Industrial Cluster (HIC). The aim is to understand how development of value chains supports industrial activity in this area. The Rotterdam HIC is the connecting hub between international trade flows of goods and material arriving in the port by ship, and the logistical network connecting these flows to the North-Western European Hinterland. Below an overview of the scope of this study.

Feedstock: Municipal Solid Waste (MSW) and Refuse Derived Fuel (RDF), plastic waste, biomass, and (biogenic) CO_2.

Utilities: Energy requirements (when known), water, hydrogen and CO_2 (emission and CCS) impacts are assessed.

Products: Primary products are Methanol and hydrocarbons (synthetic fuels and olefins such as Ethylene and Propylene).

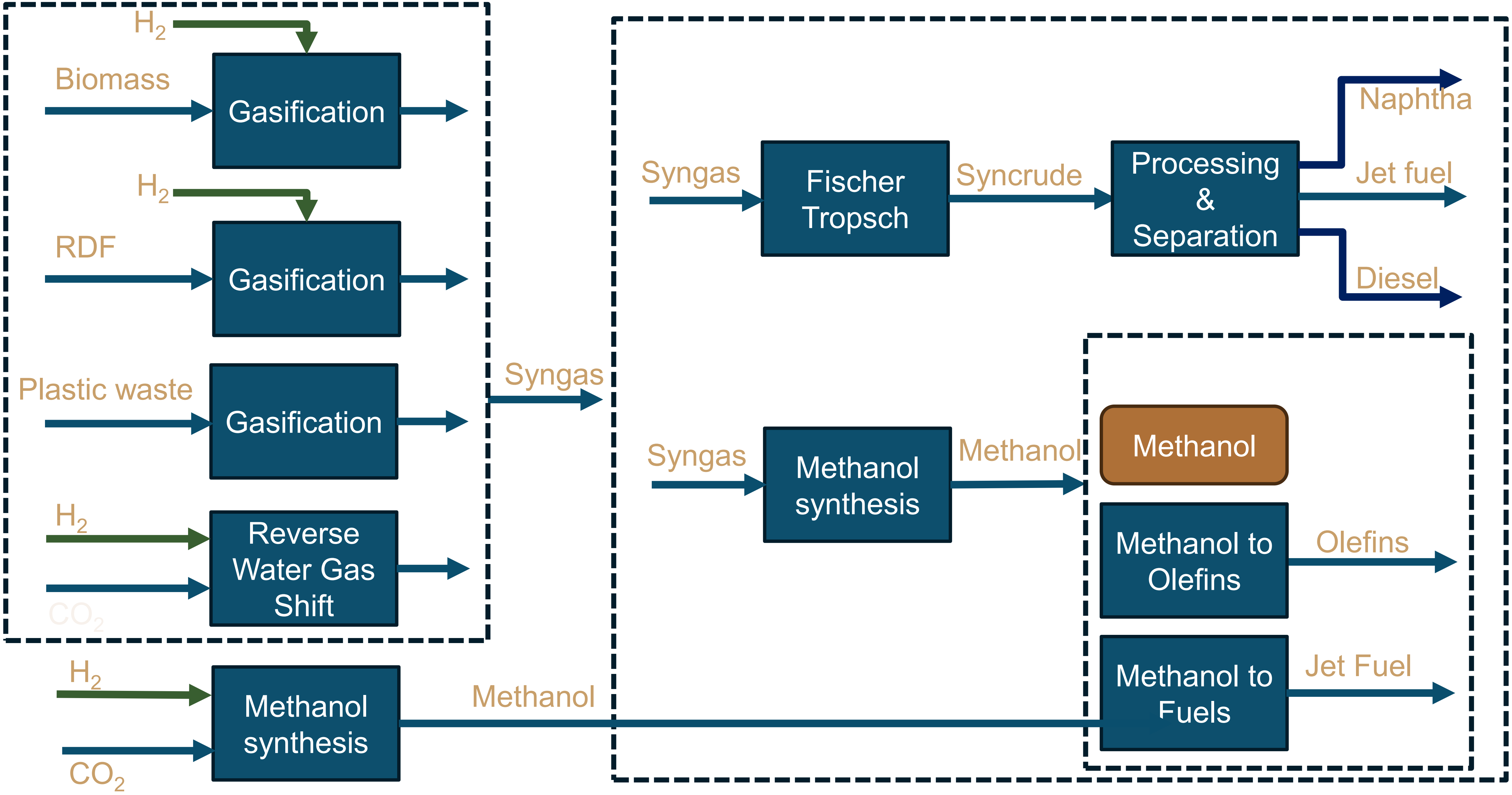
Byproducts: Heat, waste, wastewater, CO_2 produced - (when known)

Geography: The focus is on (local integration of) novel value chains in the Rotterdam HIC. At the same time Rotterdam is a crucial node in the Northwestern ARRA industrial super cluster and HIC developments are explored in that context. For feedstock potential and markets the scope takes Western Europe into account. Mass imports of feedstocks and renewable products are considered to come from the Rest of the World.

Production volumes: We follow the Sustainable Industry Lab determined target of 15 to 20 Mt/yr renewable carbon demand in the Netherlands for a Net-Zero and circular future as a target ambition for clean hydrocarbon product volume.

Time: We follow standard timelines from Global and national transition target setting (2030 and 2050 targets). We explore which steps to take going forward from today (2025). As this study is a high-level strategic exploration assessing the risks and uncertainties of different developments, we do not put definitive timelines to the developments identified but do give indications where possible.

Stakeholders: As transition is a national ambition and policy agenda, stakeholders from both the Rotterdam HIC and from relevant areas across the Netherlands have been involved or interviewed as part of this project.

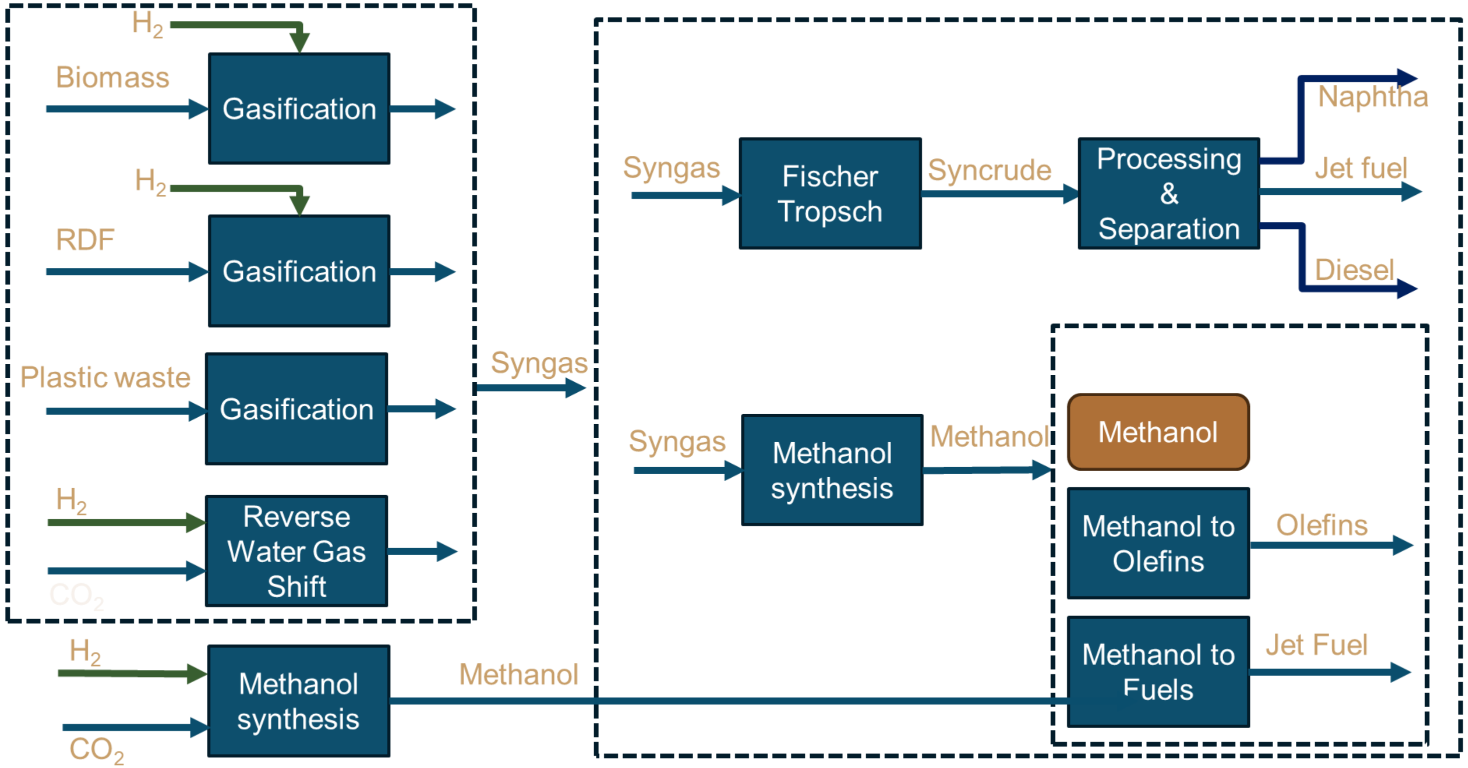

H_2
Biomass
Gasification
H_2
RDF
Gasification
Plastic waste
Gasification
H_2
Reverse Water Gas Shift
CO_2
Syngas
H_2
Methanol synthesis
CO_2
Methanol
Syngas
Fischer Tropsch
Syncrude
Processing & Separation
Naphtha
Jet fuel
Diesel
Syngas
Methanol synthesis
Methanol
Methanol
Methanol to Olefins
Olefins
Methanol to Fuels
Jet Fuel

Archetype syngas value chains from renewable feeds

An archetypal syngas value chain can be divided into a syngas production part and syngas utilization for synthesizing products. An overview of an archetypal syngas value chain is presented in Figure 1. For the syngas production, several alternative feedstocks and processing technologies are available, with each having their tradeoffs and limitations such as availability of feedstock, carbon efficiency, the production of side-products and connected markets. Syngas utilization consists of three main options, production of fuels, chemicals or utilization as a heat source. In this review, syngas utilization as a heat source is not considered.

In the next sections, each of the available processing steps for both syngas production and utilization is discussed in more detail.

Figure 1: Overview of the routes for producing syngas and the main products synthesized from syngas considered in this review.



Gasification to produce syngas – general introduction

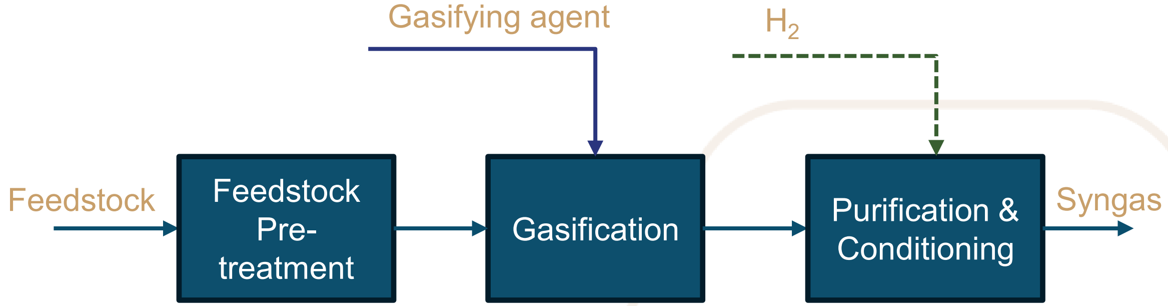
Gasification is the thermochemical process that converts carbon-rich feedstock (e.g., biomass and municipal solid waste) into syngas.

Each gasification process consists of three main steps:
1. Feedstock pretreatment
2. Gasification
3. Purification

Feedstock pretreatment consists of the removal of components that would damage the gasifier (e.g., metals, glass), followed by reducing the size of the feedstock to adequate size fit for the gasifier. Pretreatment can also include a feedstock drying step based on the used material feedstock.

In the gasification reactor, the feedstock reacts with a controlled amount of oxygen, steam or carbon dioxide at elevated temperature to primarily breakdown the feedstock into hydrogen, carbon monoxide, and carbon dioxide. Each of these gasifying agents have their tradeoffs, for instance using steam will increase H_2 production, while pure O_2 would lower the heating requirements. The process is typically performed in the range of 800 – 1000 °C where the required heat is generated by combusting a small fraction of the feedstock or providing additional fuel such as natural gas.

Figure 2: Generic material flows of gasification for syngas production



There are multiple types of gasification technologies available, with each different type of gasifier requiring different feedstock preparation and having different operating conditions and capacity.

The gas leaving the gasifier now contains several contaminants that need to be removed. First, solid particles such as tars are removed from the syngas stream, followed by the removal of sulfur and chlorine-based compounds. Depending on the used feedstock and the syngas requirements of the downstream process, further syngas conditioning may be required. For instance, hydrogen may have to be added to the syngas stream or the CO_2 in the syngas may have to be converted into CO as the presence of CO2 in syngas would reduce the performance of downstream Fischer-Tropsch processes.

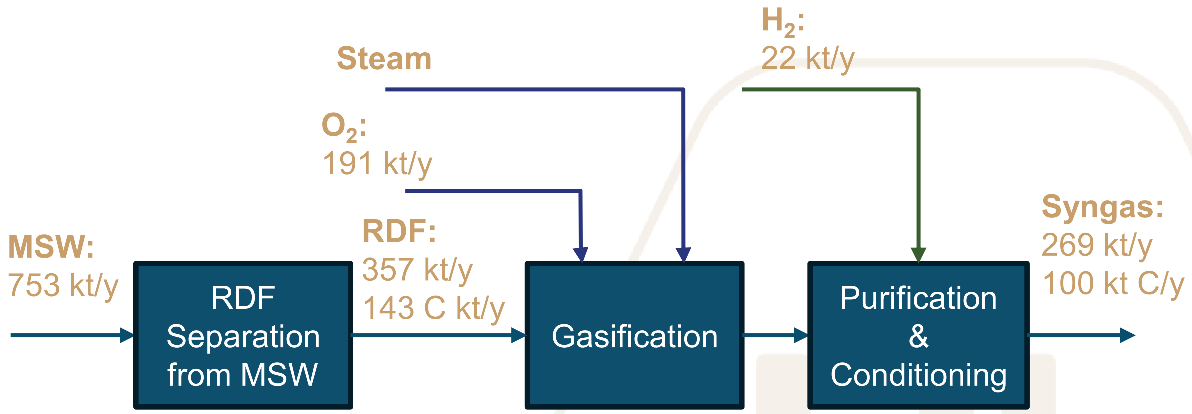
Waste gasification: RDF (1/2)

Municipal solid waste (MSW) end of life treatment currently consists of it being used as an energy source by waste incinerators to generate electricity and heat.

Refuse Derived Fuel (RDF) is the fraction separated from municipal solid waste with a relatively higher carbon content and energy density, mainly consisting of plastics, paper, textiles and wood. Traditionally, RDF has been used as an energy source by energy-intensive industries such as cement kilns to generate heat. Compared to MSW, RDF has more uniform properties and is therefore more straightforward to be used as an alternative carbon source to produce syngas via gasification.

The RDF-based syngas production would start with the separation of the RDF fraction from the MSW. This includes the removal of large pieces of glass, stone and metals. The conversion of MSW to RDF is reported from 0.29 up to 0.66 kg RDF per kg of MSW. This spread is most likely a result of the difference in MSW quality and properties among countries and seasonal variation. In this study, the average conversion factor of 0,475 kg RDF per kg of MSW is applied. The overall carbon efficiency from MSW to separation into an RDF fraction followed by gasification is estimated to be ~33%.

Figure 3: Main material flows of RDF waste gasification



Before the RDF enters the gasifier, all remaining metal is removed as they can damage the gasifier, and the remaining RDF is shredded. The resulting material enters the gasifier which is operated at 800-1000 °C and atmospheric pressure.

Waste gasification: RDF (2/2)

In addition to RDF, oxygen and steam are fed to the gasifier. The gasifier produces a gas mixture primarily containing H_2, CO, CO_2, water and contaminants such as solid particles, sulfuric acid and hydrochloric acid.

After the removal of these contaminants, the syngas can be used for Fischer-Tropsch synthesis or methanol production.

The overall gasification process has a carbon efficiency of about 70%, with 30% of the carbon not being converted to syngas. Most of the lost carbon will be in the form of CO_2 emitted by the process or captured for storage or processing (CCU, co-feed to Methanol synthesis or recycled back to gasification reactor).

Feedstock availability:

In 2022, the Netherlands incinerated 7.4 Mt/y of MSW, of which 6.2 was domestic waste and the remainder was imported from abroad[2]. Based on IEA data, the availability of MSW and therefore RDF is expected to increase across the Netherlands, Belgium and Germany by 2050.

Local generation of MSW is currently limited and is already in use as an energy source to produce heat and electricity. Depending on the allocation of the Netherlands' MSW for gasification, up to 1 Mt C/y syngas could be produced.

Table 1: Availability of MSW in 2022 and 2050 forecast based on IEA data[1]

	2022 [Mt/y]	Minimum 2050 [Mt/y]	Maximum 2050 [Mt/y]
Netherlands	7.2	7.3	10.1
Belgium	3.1	3.2	4.4
Germany	26.4	26.7	36.3
Europe	107.0	102.0	139.3

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1. IEA (2023). World Energy Outlook 2023.
2. PWC (2024). Study on the future chemical raw material value chain and the role of alternative waste processing technologies.

Waste gasification: Plastic

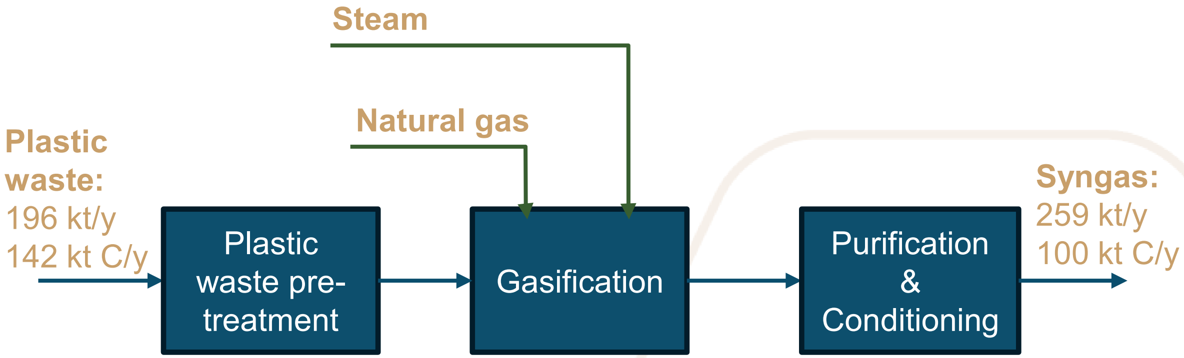
Plastic waste treatment consists of a cascade of options based on the quality of the plastic waste in which waste treatment options at the top of the cascade are preferred over the processes down the cascade. For each waste treatment step of the cascade, as much of the plastic waste will be treated with only the unsuitable waste cascading down to the next waste treatment step. Mechanical recycling is at the top of the cascade, followed by depolymerization, pyrolysis and finally gasification. In comparison to RDF, using plastic waste as feedstock has advantages, as the gasification of plastic waste has improved H_2 to carbon ratio and higher gas yield.

Before the plastics feedstock can enter the reactor, it requires pre-treatment. First the feedstock is rinsed to remove residual liquids and solids, followed by grinding of the plastic waste into smaller particles.

The plastic feedstock is gasified at a temperature of 800-1000 °C at atmospheric pressure. Compared to RDF, pure plastic waste gasification will produce more tar and methane. Steam is used as the gasifying agent to improve hydrogen production, resulting in the need for additional heat to be provided to the process from natural gas.

After gasification, first tars, ammonia (NH_3), and HCl are removed from the syngas stream, followed by the removal of H_2S. Depending on the quality of the plastic waste, addition of H_2 may be required to reach the desired syngas composition. The process has a carbon efficiency of ~70%.

Figure 4: Main material flows of plastic waste gasification



Feedstock availability:
In 2020, the Netherlands had 1.7 Mt/y of plastic waste. Less than 50% of the total plastic waste passes through waste sorting facilities, of this sorted plastic waste only 0.5 Mt/y was recycled in 2020. Most of the plastic waste is sent straight to incineration without waste sorting. KPMG expects that by 2030, roughly half of the plastic waste will be sorted and be available for recycling[3].

Other studies measuring plastic waste in carbon flows expect 43% of carbon in plastic waste to be recycled by 2030, with major parts of the carbon in plastic waste expected to be recycled using mechanical recycling (13%) and pyrolysis (20%), with gasification receiving the carbon (8%) that cannot be used by other recycling technologies[4]. Increased sorting of plastic waste by 2050 would increase the carbon recycling through gasification to 14%.

3. KPMG (2023). Plastic feedstock for recycling in the Netherlands.
4. Lange, J. P., et al. (2024). "Plastic recycling stripped naked - from circular product to circular industry with recycling cascade." ChemSusChem **17(12): e202301320.**

Waste gasification: Developments

Enerkem Alberta Biofuels

Enerkem had a waste to fuels plant in operation between 2014 and 2024. The plant first produced methanol using RDF as feedstock and later changed to the production of ethanol.

Waste-to-Chemicals

With the Waste-to-Chemicals project Akzo-Nobel, Air Liquide, Shell and Enerkem were planning to build an RDF gasification plant to produce methanol in Rotterdam HIC. The plant would convert up to 360 kt/y RDF into 220 kt/y methanol using the technology provided by Enerkem. It proved hard to take the FID on the project.

Ecoplanta

Repsol is planning to build an RDF gasification plant to produce methanol in Ell Morell, Spain. Using technology provided by Enerkem, the plant will convert 363 kt of RDF in up to 237 kt/y methanol with operations expected to start in 2029.

FUREC

In Limburg, the FUREC (Fuse Reuse Recycle) project is planning to use MSW to produce hydrogen to replace the fossil hydrogen used by the OCI ammonia plant in Chemelot, reducing CO_2 emissions. The project will have the MSW collected across Limburg and the Belgian border and separated at a separate site, before RDF is transported to the gasification site located on Chemelot. In total, 800 kt/y of MSW will be collected and gasified to produce 61 kt/y of H_2. Due to the larger scale, the process will use an entrained flow gasifier allowing a higher production capacity per gasifier compared to fluidized bed reactors. The process is scheduled to start operation in 2028.

Innovative gasification technologies

DOPS-Recycling Technologies is developing a novel gasification reactor capable of using municipal solid waste and biomass feedstock that is flexible and robust, even capable of handling difficult materials unsuitable for other gasifiers. In 2026, DOPS-RT aims to start operations of their 100 kt/y methanol plant based on regional agro-food industrial wastes.

SCW systems has developed supercritical water gasification technology that breaks down all organic material into methane, hydrogen and water. Their technology allows industrial waste streams and other waste streams with high water content to be converted into syngas, hydrogen, or green methane.

GIDARA Energy

Gidara has procured the high-temperature Winkler (HTW) fluidized bed gasification technology, which has a history dating back to the 1920's. They work on Advanced Methanol Amsterdam, an RDF based methanol production plant.

Biomass gasification

Wood biomass from wood and forestry residues is an alternative feedstock for producing syngas through gasification. Depending on the shape and size of the woody biomass feedstock, and the used gasification reactor, different feedstock pretreatment steps are required. Basic pretreatment includes the grinding down of biomass feedstock and drying of the biomass before sending it to the gasifier. This drying step lowers the heating requirement of the gasifier in the next step of the process. More advanced pre-treatment is torrefaction of the biomass feedstock. Torrefaction is performed at 250-320°C in an oxygen free or reduced environment, resulting in the breaking down of the biomass feedstock into a more energy dense and brittle material.

The pretreated biomass enters the gasifier which is operated around 800-1000 °C and atmospheric pressure. In this report steam is used as gasification agent for biomass gasification to increase the production of H_2. After gasification, tars and solid particles are removed followed by the removal of sulfur compounds and other contaminants. Additional H_2 is required to use the syngas in downstream processes. The overall process has a carbon efficiency of ~41%.

Biomass availability:

The availability of woody biomass produced within the Netherlands will be limited, most of the biomass will have to be obtained from outside the Netherlands. Currently, there already is an existing global market for woody biomass making availability of feedstock less risky in comparison to the other feedstocks.

Figure 5: Main material flows of biomass gasification

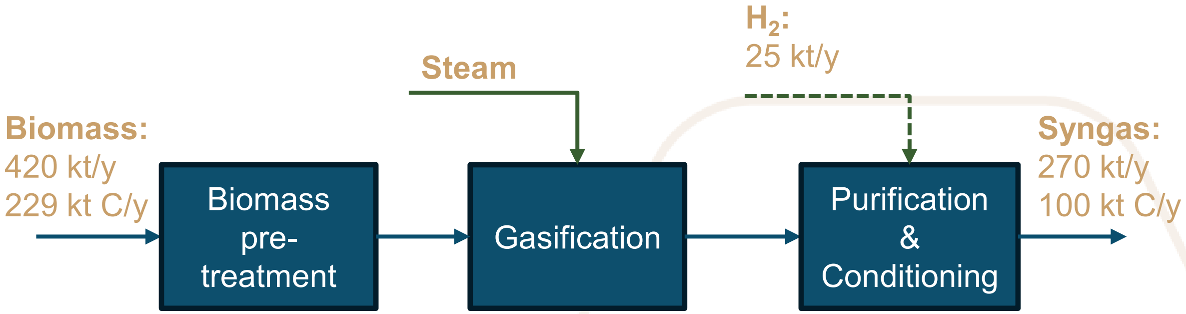


Table 2: Availability of primary solid biomass in 2022 and 2050 forecast based on IEA data.

	2022 [Mt/y]	Minimum 2050 [Mt/y]	Maximum 2050 [Mt/y]
Netherlands	6.8	7.0	9.6
Belgium	5.2	5.3	7.2
Germany	40.3	40.8	56.1
Europe	357.7	341.0	467.9

Biomass gasification: Developments

GoBiGas[5]
In Göteborg Sweden, a demonstration plant was operated from 2005 till 2018 using biomass gasification to produce biomethane. The plant had an estimated capacity of 4.8 kt/y.

Perpetual Next:
Perpetual Next uses torrefaction as pretreatment of the biomass feedstock to use entrained-flow gasification reactors that allow for higher operating capacities compared to fluidized bed reactors. The company is developing biomass-based methanol plants in Delfzijl and in Baltania, Estonia.

Torrgas[6]
Torrgas has developed a technology that combines torrefaction with a two-stage fluidization of biomass to produce syngas without tars and slag. They developed the first commercial torrefied biomass to synthetic natural gas in Delfzijl from 2015. In 2022, Torrgas sold the project to Eemsgas (Gasunie and PerpetualNext partnership).

5. Perpetual Next. "Biomethanol at an industrial scale." Retrieved 11-12-2025, from https://perpetualnext.com/en/solutions/bio-methanol/.
6. Torrgas. "Biomass-to-bioSNG." Retrieved 11-12-2025, from https://www.torrgas.nl/projects/.

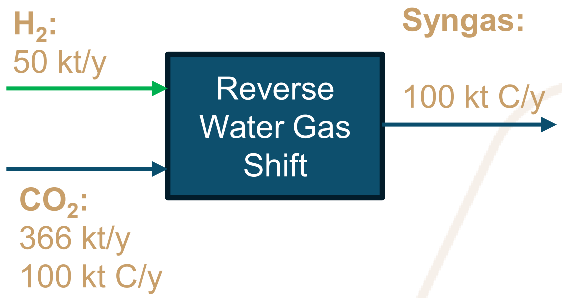
Reverse water gas shift: CO_2

The reverse water gas shift (rWGS) is an important reaction to produce syngas from CO_2 and H_2. Several process options are developed for producing syngas from CO_2, such as CO_2 co-electrolysis, with the rWGS having the highest TRL among those CO_2-based syngas routes.

CO_2 and H_2 are fed to the rWGS reactor at a molar of ratio 1:3. The rWGS reactor is generally operated at 5 bar and 800-1000°C as these conditions favor the production of CO and minimize the occurrence of undesired side reactions.[7,8] The reaction is endothermic, indicating that heat continuously needs to be provided to the reactor to keep the reaction in operation.

Not all the CO_2 is converted in the reactor, recycling this unreacted CO_2 back to the rWGS reactor would increase the yield of CO_2 to CO conversion. Furthermore, the presence of CO_2 in syngas can be problematic for processes that will use syngas further down the value chain. The assumption was made that all unreacted CO_2 was recycled back to the rWGS reactor.

Figure 6: Main material flows of the reverse water gas shift process



Reverse water gas shift reaction

$$CO_2 + H_2 \rightleftarrows CO + H_2O$$

Feedstock availability

Biogenic CO_2 sources would be the ideal CO_2 source, as the carbon in that case is considered carbon neutral, resulting in the production of sustainable chemicals or fuels. Potential sources include, paper & pulp, waste to energy, and biofuels processes.

However, CO_2-based production of chemicals and fuels requires a significant amount of hydrogen, and associated energy, in comparison to other alternative carbon sources. The availability of green hydrogen will be a major bottleneck as the demand for green hydrogen is expected to be larger than the green hydrogen production through electrolysis.

[7] Pio, D. T., et al. (2023). "Decarbonizing the aviation sector with Electro Sustainable Aviation Fuel (eSAF) from biogenic CO2 captured at pulp mills." Chemical Engineering Journal **463.**

[8] TNO, CO production via reverse water gas shift. Retrieved 11-12-2025, from https://energy.nl/wp-content/uploads/technology-factsheets-rwgs-to-co-from-co2-and-h2-1.pdf

Fischer-Tropsch synthesis (1/2)

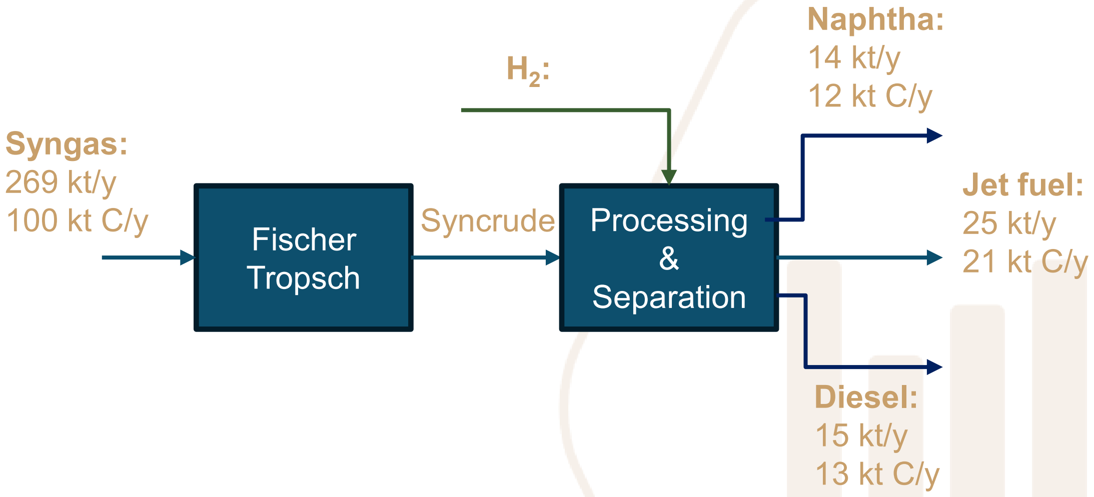
The Fischer-Tropsch process converts syngas into liquid hydrocarbons. This synthetic crude can be further upgraded to synthetic fuels, such as jet fuels, and can therefore play an essential role in the production of sustainable aviation fuels (SAF).

Low-temperature vs high-temperature

Depending on the operation temperature of the Fischer-Tropsch reactor, different product distributions are produced. The high temperature Fischer-Tropsch process (300-350°C) produces relatively short hydrocarbons such as olefins and gasoline. The low temperature Fischer-Tropsch process (200-240°C) primarily produces medium to long chain hydrocarbons that are used in diesel and aviation fuel.[9] In this study, only the low temperature Fischer-Tropsch route is considered as it produces higher-value products and greater selectivity in comparison to high temperature Fischer-Tropsch.

For the low temperature Fischer-Tropsch process, cobalt-based catalysts are preferred as they are more active and produce a higher yield of hydrocarbons for aviation fuel. This catalyst requires CO rich syngas as CO_2 is hardly converted in the reactor and lowers performance. CO_2 will therefore have to be removed or shifted back to CO via the reverse water gas shift reaction in the syngas production process before it can be used in Fischer-Tropsch process.

Figure 7: Main material flows with potential product distribution for a low temperature Fischer-Tropsch process[9].



The overall Fischer-Tropsch process consists of two sections, Fischer-Tropsch synthesis section and a processing & separation section. These sections are discussed in more detail on the next page.

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[9] Zang, G., et al. (2021). "Life Cycle Analysis of Electrofuels: Fischer-Tropsch Fuel Production from Hydrogen and Corn Ethanol Byproduct CO(2)." Environ Sci Technol 55(6): 3888-3897.

Fischer-Tropsch synthesis (2/2)

Reactor

Syngas enters the Fischer-Tropsch reactor that is operated at 200-240°C and 10-40 bar. In the reactor, syngas is converted into a distribution of long chain hydrocarbons while water is also produced as a major side product of the process. The reactions are highly exothermic, requiring constant removal of heat from the reactor to obtain the desired product distribution. After leaving the reactor, water is separated from the mixture while the unreacted syngas is recycled back to the reactor.

Product separation

The Fischer-Tropsch syncrude now requires further refining to separate the products into different fuel streams. Several refining technologies and configurations are available to refine the Fischer-Tropsch liquids into desired product categories. These will include steps such as oligomerization to create long chain hydrocarbons from the short olefins fraction in the Fischer-Tropsch liquids, hydrocracking of the heavy fraction of the Fischer-Tropsch liquids and hydrogenation. In combination with the temperature and pressure of the Fischer-Tropsch reactor, the process can be designed to maximize the production of a certain product category.

Alternatively, Fischer-Tropsch could be integrated with the existing product blending or even product refining steps in refineries.

Simplified Fischer-Tropsch reaction where for each mole of CO converted into a hydrocarbon also one mole of water is produced.

$$nCO + (2n+1)H_2 \rightleftarrows C_nH_{(2n+2)} + H_2O$$

Figure 8: SASOL Secunda[10]

Current operation

Several Fischer-Tropsch processes are in operation across the world. The largest plant, Secunda in South Africa,[10] uses coal gasification followed by Fischer-Tropsch to produce fuels and chemicals (~150,000 barrels/day, or ~7-8 Mt/y). Pearl GTL in Qatar, is another large-scale Fischer-Tropsch-based plant converting natural gas into naphtha and transport fuels.

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[10] Wikimedia Commons contributors. Sasol Secunda 19.jpg, Wikimedia Commons. https://commons.wikimedia.org/w/index.php?title=File:Sasol_Secunda_19.jpg&oldid=722812128

Methanol synthesis from syngas (1/2)

The conversion of syngas into methanol is the industrial standard for producing methanol and is therefore very well understood and optimized for efficiency. The overall methanol production process consists of a syngas upgrading step, a methanol synthesis section, and finally a separation section.

For the methanol process, a syngas upgrading step may be required depending on the quality of the syngas entering the process. This syngas upgrading step consists of adding additional H_2 to offset the presence of any CO_2 or, alternatively, the removal of such CO_2 from the syngas. To maximize the carbon yield, only the addition of H_2 is considered. The methanol process requires syngas with a stoichiometric number of 2 to enter the reactor to maximize process performance. The quality of the syngas produced by the different feedstocks will determine the demand for H_2 for syngas upgrading.

Syngas enters the methanol reactor which is operated at a pressure of 50-100 bar and 200-300°C. In the reactor, syngas primarily converts into methanol with also some water being produced from the CO_2 conversion. The overall reaction is exothermic, and the excess reaction heat is used to generate steam. Unreacted syngas is recycled back to the methanol reactor to further increase the methanol yield.

Stoichiometric number for methanol production, it shows that if CO_2 is present in the syngas, additional H_2 is required to offset the CO_2.

$$SN = \frac{[H_2] + [CO_2]}{[CO] + [CO_2]}$$

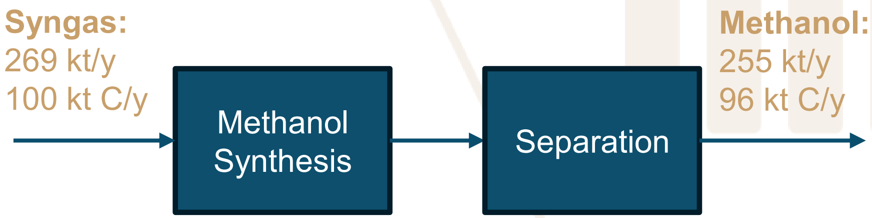
Reactions occurring in the methanol reactor.

$$CO + 2H_2 \rightleftarrows CH_3OH$$

$$CO_2 + H_2 \rightleftarrows CO + H_2O$$

$$CO_2 + 3H_2 \rightleftarrows CH_3OH + H_2O$$

Figure 9: Material flows for methanol synthesis from syngas.



Methanol synthesis from syngas (2/2)

The crude methanol now contains some remnants of the syngas, and water. These contaminants are removed by distillation, where first the light components are removed, followed by the removal of water.

The overall methanol production process from syngas has a high carbon yield of more than 95% and the process is estimated to have net heat production after considering heat consumption within the methanol separation.

Current industrial methanol production operating capacities scale from small-scale circular or renewable carbon sources (around 100 kt/y methanol) to large scale fossil-based production plants. For instance, the largest single train methanol production plants are under construction in China, where Ningxia Baofeng Energy is constructing 5 single train methanol plants with each producing around 2400 kt/y of methanol[11].

11. Johnson Matthey (2020). Retrieved 11-12-2025, from https://matthey.com/news/2020/worlds-largest-single-train-methanol-plants-to-use-johnson-matthey-technology.

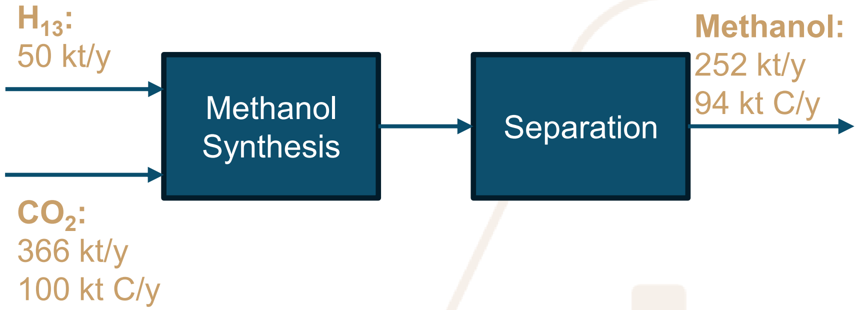
Methanol synthesis from CO_2

There are two routes to produce methanol from CO_2. The indirect route first produces syngas via a process such as the reverse water gas shift, which has been covered in this assessment. The second route is the direct route where CO_2 is directly hydrogenated to methanol in a single step, thereby avoiding the production of syngas altogether.

The overall process consists of two sections, methanol synthesis section and separation section. Both sections are nearly identical to their counterpart in the methanol production from syngas. The process uses identical conditions for the gas entering the reactor (SN = 2), identical reactor conditions (200-300°C and 50-100 bar) to the syngas route, and a similar separation for the removal of light components and water. Compared to the syngas route, direct synthesis of methanol from CO_2 will produce significantly more water. The process is also exothermic but will generate less heat compared to the syngas-based methanol production, with studies suggesting that the hydrogenation route will require additional steam for the methanol separation[12].

In comparison to the conventional methanol production from syngas, the technology is less developed with only a few industrial scale processes in operation. Carbon Recycling International has two commercial scale plants in operation (both 100 kt/y range) in China since 2023, where a carbon efficiency of about 94% is reported[13)]. Studies suggest a potential yield over 99% is possible[12)].

Figure 10: Material flows for methanol synthesis from syngas.



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12. Carbon Recycling International (2022). Retrieved 11-12-2025, from https://carbonrecycling.com/projects/shunli.
13. Kiss, A. A., et al. (2016). "Novel efficient process for methanol synthesis by CO2 hydrogenation." Chemical Engineering Journal 284: 260-269.

Methanol to olefins

The methanol to olefins (MTO) process is an important route for producing ethylene and propylene. Ethylene and propylene are essential chemical building blocks used in the petrochemical industry for products such as plastics and polyurethanes.

The MTO process consists of two sections, the reaction section and a separation section. The MTO reactor is operated at a pressure of 1-3 bar and 450°C, where methanol is primarily converted to ethylene, propylene, and water. The reaction is highly exothermic and requires continuous removal of heat. After the reactor, the product stream is cooled, and water is removed from the product stream. The product stream is further purified by distillation into separate ethylene, propylene, butenes and heavier olefins product streams.

Overall, the MTO process has a very high methanol conversion and produces more propylene than ethylene. In comparison, naphtha cracking produces a larger ethylene fraction.

Blue Circle Olefins is planning to build a MTO plant in the Port of Rotterdam producing 80 kt/y of ethylene and 120 kt/y of propylene. The facility is planned to be in operation by 2030. China has several MTO plants in operation, such as the MTO plant of Jiangsu Sailboat Petrochemicals having a combined ethylene and propylene production of 833 kt/y[15].

Figure 11: Methanol to olefins main material flows

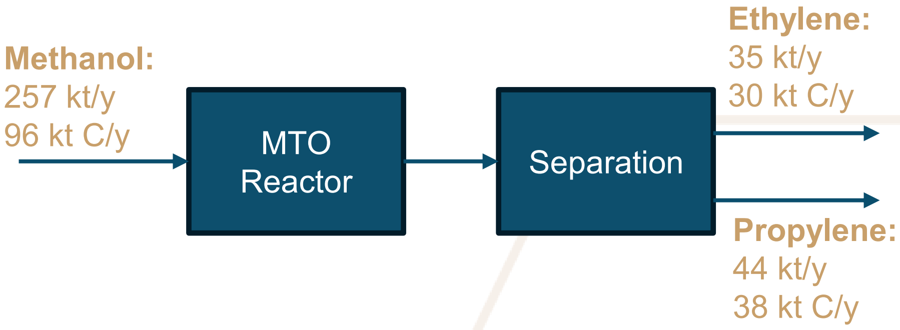

Table 3: Selectivity and conversion factors for methanol to olefins

	Selectivity	kg / kg methanol
Ethylene yield	31.29%	0.14
Propylene yield	39.55%	0.17

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[14] Manalal, J. T., et al. (2025). ACS-based MO1. MTO production (314kt/y Ethylene). Zenodo. https://doi.org/10.5281/zenodo.14894523

[15] Honeywell (2017). Retrieved 11-12-2025, from https://www.honeywell.com/us/en/press/2017/02/jiangsu-sailboat-petrochemicals-company-starts-honeywell-uop-methanol-to-olefins-unit.

Methanol to fuels

The methanol to fuels process provides an alternative aviation fuel production route for the fossil-based and Fischer-Tropsch based routes.

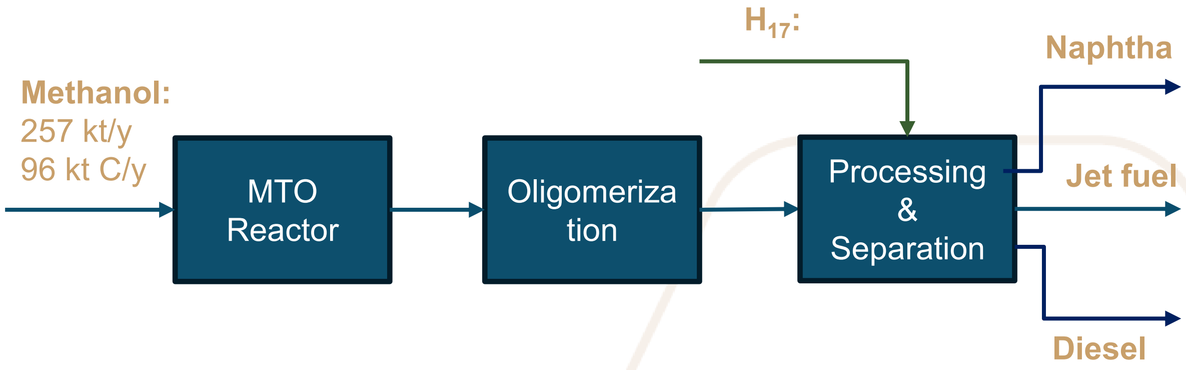
The process starts the same as the methanol to olefins process, with a MTO reactor operating at pressure of 30 bar and 450°C converting methanol into olefins[16]. After the removal of the paraffin fraction (ethane, propane) by distillation, the olefins are sent to the olefin oligomerization reactor. This reactor is operated at 50-70 bar and 200-300°C and converts the olefins into a distribution of long chain hydrocarbon products.

After oligomerization, the product stream is hydrogenated to reduce the reactivity of the hydrocarbons. Finally, the stream is separated into different product categories such as jet fuel, diesel and naphtha. According to a study[17], the process has a carbon efficiency of ~85%.

Haru Oni

Haru Oni is an e-fuels project in Chile producing fuels from CO_2 and hydrogen. Direct air capture is performed as CO_2 source, while the electricity for water electrolysis is generated by wind turbines. The process performs direct hydrogenation of CO_2 to methanol and converts the methanol primarily into gasoline[18].

Figure 12: Methanol to fuels main material flows



H_{17}:

Methanol:
257 kt/y
96 kt C/y

MTO Reactor

Oligomerization

Processing & Separation

Naphtha

Jet fuel

Diesel

Power2X

Power2X is planning to develop a production facility producing 250 kt/y of e-SAF from methanol. Locally produced green methanol from biogenic CO_2 and green H_2, and imported green methanol will be used as feedstock[19].

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16. Elwalily, A., et al. (2025). "Sustainable aviation fuel production via the methanol pathway: a technical review." Sustainable Energy & Fuels 9(19): 5151-5180.
17. Bube S, Bullerdiek N, Voß S, Kaltschmitt M (2024) Kerosene production from power-based syngas – A technical comparison of the Fischer-Tropsch and methanol pathway. Fuel 366:131269. https://doi.org/10.1016/j.fuel.2024.131269
18. MAN Energy Solutions. 'The e-fuels revolution at the "End of the World".' Retrieved 11-12-2025, from https://www.man-es.com/discover/haru-oni-e-fuels.
19. Power2X (2024). Power2X and Advario to develop world-scale e-SAF hub in the Port of Rotterdam. Retrieved 11-12-2025, from https://www.portofrotterdam.com/en/news-and-press-releases/power2x-and-advario-develop-world-scale-e-saf-hub-port-rotterdam

Overview: Feedstock and process data

Table 4: Overview of relevant feedstocks

Feedstock type	Feedstock / C [Mt/yr]			Alternative use
	NL	NL/B/D	Europe	
MSW	7 / 2.9	37 / 4.9	107 / 14.3	Heat/power
Plastic	2 / 1.0	8 / 4.0	43 / 21.5	Partial recycling, heat/power
Biomass	7 / 1.3	52 / 10.0	358 / 68.8	Building material, heat/power
CO2 (rWGS / hydrogenation)	-	-	-	CCUS, green houses

Table 5: Overview of syngas production processes

	Feedstock [Mt/y]	Carbon efficiency	H2 [Mt/y]	H2 Elec. [PJ/y]	TRL
MSW gasification	7.5	33%	0.2	43.6	~7-9
Biomass gasification	5.2	41%	0.3	50	~8-9
Plastic gasification	2.0	70%	~0	~0	~7-9
CO2 (rWGS)	3.7	99%	0.5	100.6	~6-7
CO2 direct hydrogenation	3.7	94.4%	0.5	103.6	~7-9

Table 6: Overview of processes consuming syngas

	Products [Mt/y]	[Mt C/y]	Side prod. [Mt/y]	Waste [Mt/y]	C efficiency	TRL
Methanol	2.6	1.0	-	~0	96%	9
Methanol to olefins	0.9	0.8	0.3	1.4	98%	~8-9
Fischer-Tropsch	1.0	0.9	-	1.2	88%	9

Syngas value chain in HIC (1/3)

Syngas value chains offer significant integration options with the existing processes within the HIC for both the syngas production feedstocks and the syngas-based products. However, the level of integration depends on the scale of implementation of syngas-based value chains within the HIC.

Feedstocks

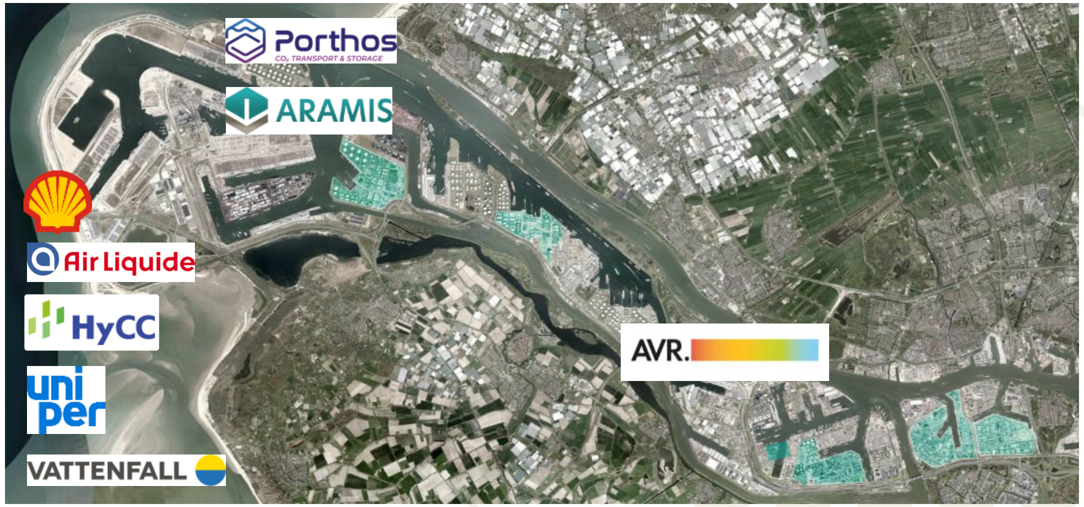
Biomass and waste

Syngas-based value chains have several options to integrate with existing industries and port services within the HIC. The utilization of RDF as gasification feedstock requires the collection of MSW and separation into an RDF fraction. This collection and separation could be done at a modified existing facility such as AVR or newly constructed facility.
Biomass will have to be imported to the HIC. Excellent port connectivity to inland and overseas international supply offer good opportunities to establish supply. This will require allocation to harbor services and space for the unloading of biomass from ships.

CO_2

Circular or carbon neutral CO_2 from other processes within the port can be used to produce syngas via the reverse water gas shift or direct methanol production. This CO_2 could be obtained from biomass gasification plants, or other biogenic CO_2 sources in the vicinity. However, this will require the presence of CO_2 pipelines and the availability of sufficient green H_2.

Figure 13: Potential feedstock integration options within HIC



Industrial waste streams

Industrial waste streams have a potential to serve as feedstock. Existing industrial sites, such as refineries, commonly incinerate lighter hydrocarbons to heat their processes. These streams can be used to produce syngas for products or for hydrogen. Furthermore, supercritical water gasification would allow the recycling of carbon in liquid waste streams that are difficult to be cleaned. These waste streams could be converted into syngas or hydrogen using supercritical water gasification. These streams can provide a basis for a cross-port syngas ecosystem.

Syngas value chain in HIC (2/3)

Products

Syngas-based value chains can be used to produce methanol, chemicals, and fuels. Each of these products has different integration options within the HIC.

Methanol

Methanol is currently used for producing formaldehyde by Bakelite, however, demand is expected to increase in the future with the construction of methanol to olefins plants such as Blue Circle Olefins and the Power2X methanol to jet fuel plant. Methanol can also be used directly as a shipping fuel, further increasing demand in the future.

Chemical industry

For the chemical industry, syngas value chains can provide chemical building blocks. It is important to have access to biogenic or circular feedstocks to reduce scope-3 emissions and maintain long-term sustainability. Olefins (e.g. ethylene and propylene) are important base chemicals used in the Botlek area to produce various plastics. For instance, ShinEtsu uses ethylene to produce polyvinyl chloride (PVC), while Lyondell Basell uses propylene to make propylene oxide, used in turn by Huntsman to produce polyurethane. In addition, there are existing ethylene pipelines connecting HIC to Chemelot, Moerdijk, Antwerpen and several industrial clusters within Germany. Other options are the direct use of CO, or production of other base chemicals as important feedstocks.

Figure 14: Potential integration options for syngas-based chemicals

Figure 15: Potential integration options for syngas-based fuels

Syngas value chain in HIC (3/3)

Fuels

Fuels can be made indirectly from syngas through methanol, like the Power2X route for SAF, or directly, through Fischer-Tropsch synthesis. The Fischer-Tropsch process can be tuned for different categories of products and has different implementation strategies. It is typically implemented at high capacity to create economies of scale, and offers good opportunities to integrate within existing refineries, using the existing processing and separation section of a refinery to tune the product mix to markets.

System impacts

The level of integration, and therefore impact on the current system depends on the level of integration within the HIC.

The first signs of transition are based on the import of green or renewable methanol. There is no significant syngas production and conversion yet, but the methanol commodity can scale significantly and feed as shipping fuel and secondary processes to SAF and olefins. It impacts local terminal capacity, bunkering, and olefin and fuels markets.

Small scale implementation of gasification such as a single value chain from feed to product can use the port infrastructure systems but will have limited impact. It needs feedstock and product logistics, utilities, water and water treatment, H_2 supply and CO_2 handling. This can be handled within a single industrial site or co-locate on a refinery site for a slightly larger scale syngas value chain and can tie into existing infrastructure.

Larger scale implementation of syngas-based value chains will offer many integration opportunities. Large sites (Mt/y scale) will require significant power and hydrogen supply, generate substantial amounts of heat, may generate power and have a substantial footprint. This size will also require multiple feedstocks. Downstream product integration will be significant and probably require dedicated partnering with existing value chains. This scale of operations will heavily use infrastructure and logistics for power, H_2, gas, CO_2, water, (multi-)feedstock, heat, side streams, waste and products.

Systemic shift to a Renewable Carbon hub

When the size of operations grows further and deeply integrates with the Rotterdam HIC, opportunities appear for a full system paradigm shift in the port. Deep integration has the potential to transform the cluster into a future-proof, robust and competitive carbon conversion cluster. Options arise to provide flexible balancing services through generation of heat and power, use of hydrogen, providing pre-combustion CCS and H_2 generation services and much more. This enables deep integration with existing assets from refineries and chemical industries, supporting them in their transition towards a circular and sustainable system, and creating flexibility throughout the syngas system making it more robust in terms of operation and addressable market. It offers opportunity for substantial flexible and reliable offtake of renewable power and green hydrogen, and can integrate with conventional power supply, either by providing blue hydrogen for backup power, or using biogenic CO_2 from bio-energy services as a feedstock.

Circularity and Sustainability (1/3)

Circular syngas value chains offer significant potential for reducing dependency on fossil feedstocks by utilizing waste streams, biomass, and captured CO_2. Syngas value chains are easily scalable and are also very flexible in terms of different feedstocks and products. However, circularity and sustainability enablers do not always perfectly align, and scaling these value chains requires careful consideration of trade-offs across environmental, resource, and energy areas.

Feedstock circularity and carbon accounting

Municipal solid waste (MSW), refuse-derived fuel (RDF), plastic waste, woody biomass, and biogenic CO_2 – each feedstock contributes to circularity but carries different sustainability profiles. MSW and RDF contain both biogenic and fossil carbon fractions, with the biogenic portion typically accounting for 50-60% of the carbon content. This mixed composition means that while these feedstocks prevent waste going to landfill or incineration, they do not eliminate fossil carbon emissions entirely even with an increased biogenic fraction by 2050.

Plastic waste gasification offers carbon recycling for those fractions that are unsuitable for mechanical or chemical recycling but remains fossil-based unless derived from bio-based plastics.

Woody biomass is considered renewable and can be carbon-neutral when sourced sustainably, but faces ecological concerns related to land use, biodiversity impacts and competition with food production or nature restoration, while also the harvesting and logistics have their own carbon footprint, negatively impacting overall sustainability and climate impact.

Biogenic CO_2 from industrial sources or bio-energy with carbon capture (BECCS) represents a circular carbon source, but its utilization via reverse water gas shift or direct hydrogenation requires substantial quantities of renewable hydrogen, leading to high energy demands that must be met through green electricity to maintain sustainability credentials.

Energy, water, and residual streams

Syngas production and conversion processes are energy-intensive. Gasification requires high temperatures (800-1000°C) and often relies on partial oxidation of the feedstock itself or supplementary fuel to provide process heat. Fischer-Tropsch synthesis and methanol production operate at elevated temperatures and pressures, though they are exothermic and can export heat. The overall energy balance depends heavily on process integration, heat recovery, and the availability of renewable electricity for hydrogen production.

Water is consumed both as a gasifying agent (steam gasification) and cooling medium, with wastewater treatment required to manage contaminants from gas cleaning processes and produced water from methanol synthesis or Fischer-Tropsch. Residual streams include ash, slag, and tar from gasification, as well as separated sulfur and chlorine compounds, which require appropriate disposal or valorization routes. Effective management of these residual streams is essential to avoid burden-shifting from one environmental challenge to another.

Circularity and Sustainability (2/3)

Scaling challenges and trade-offs

Scaling circular syngas value chains to volumes comparable to Rotterdam HIC's current fossil-based operations (50 Mt C/y, reducing to 15-20 Mt C/y in a circular and carbon-neutral scenario) presents key challenges. Feedstock availability imposes practical limits: European MSW generation is projected at 102-139 Mt/y by 2050, while plastic waste suitable for gasification represents only a small fraction of the total plastic waste after mechanical recycling and pyrolysis have rightfully been prioritized. Sustainable biomass availability is similarly constrained, with competing demands from bioenergy, negative emission demand for Net-Zero targets, and use in e.g. construction materials. Hydrogen availability is a critical bottleneck, particularly for CO_2-based routes, where green hydrogen supply must scale dramatically to enable large-scale deployment. During the transition of the cluster, fossil-based hydrogen could be temporarily used while green hydrogen production is scaled up.

Given these constraints, hydrogen, methanol and/or product imports will almost inevitably play a role. Infrastructure requirements for feedstock collection, sorting, and transport add logistical complexity and emissions. Trade-offs between circularity (e.g., using local waste streams) and sustainability (e.g., minimizing GHG emissions through optimized feedstock selection and energy sourcing) must be navigated case-by-case, considering regional contexts and policy priorities. Identifying this balance between circularity and sustainability is not only limited to syngas but is a fundamental challenge of the energy transition.

Policy Frameworks for Circular Syngas Value Chains

Circular syngas value chains are shaped by a complex and continuously evolving landscape of European and national policies that create both enabling conditions and constraints. A critical challenge lies in split incentives between different policy frameworks, which can lead to unbalanced developments when viewed from an overarching carbon balance perspective. Energy policies prioritize renewable fuel production and emissions reduction, circular economy policies emphasize material recycling and waste hierarchy, carbon pricing mechanisms drive decarbonization through market instruments, and industrial policies focus on competitiveness and strategic positioning. These objectives do not always align, and the resulting policy fragmentation creates uncertainty for large-scale investment decisions.

Moreover, policies continue to evolve through EU trilogues, national implementation processes, and responses to experiences from practice, meaning that the regulatory environment remains in flux. This dynamic context requires syngas value chain development to be adaptive, engaging proactively with policymakers to help shape frameworks that recognize the multi-objective nature of circular carbon technologies.
In Deliverable 4 we will revisit policies in more detail to review their impact on value chain investments.

Circularity and Sustainability (3/3)

Gaps and considerations for future work

This report establishes the technical archetypes and feedstock availability for circular syngas value chains but does not perform full life cycle assessments (LCA) or detailed sustainability scoring. Key gaps include quantitative comparison of GHG emissions across different feedstock-to-product pathways, assessment of land use and biodiversity impacts for biomass sourcing, and analysis of water footprint and residual stream management at scale. The optimal balance between circularity objectives (such as, maximizing use of waste and CO_2) and sustainability performance (minimizing overall environmental impact) will depend on factors including renewable energy availability, infrastructure development, policy incentives, and regional resource constraints, reaching far beyond the scope of this archetype analysis. These considerations must be addressed in subsequent follow-up studies.

Colophon

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