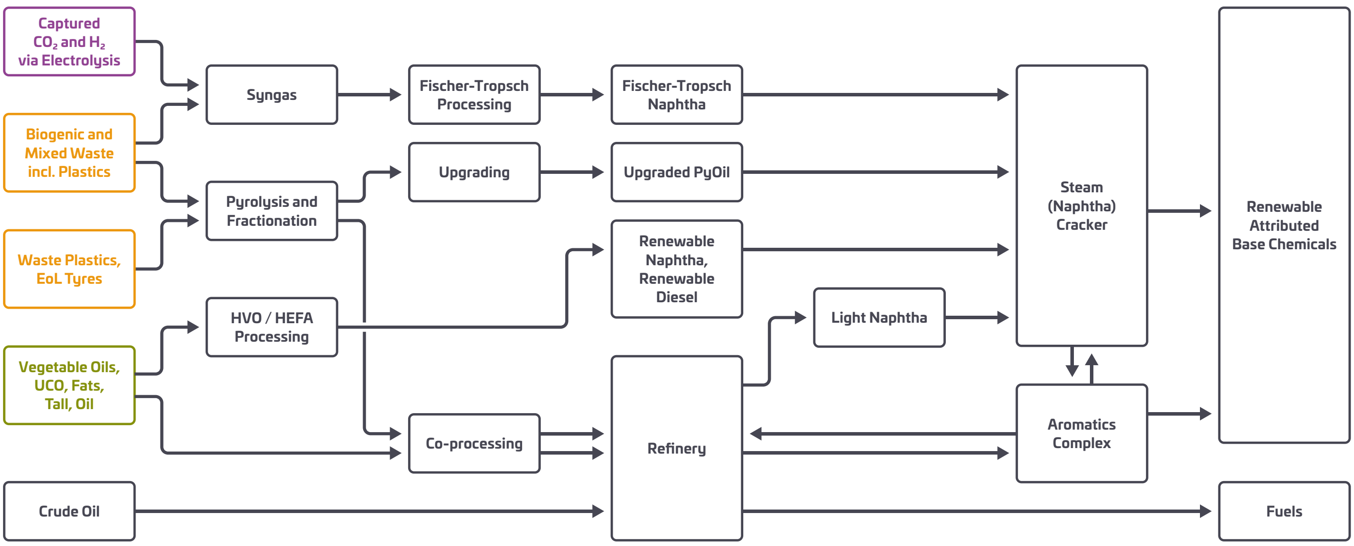
Alternative Naphtha

Replacing Fossil-Based Feedstocks in Refineries and Naphtha Crackers: Technologies and Market, Status and Outlook



Authors: Gillian Tweddle, Lars Krause, Pauline Ruiz, Achim Raschka, Aylin Özgen, Nicolas Hark and Michael Carus

July 2024

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Imprint

How to cite

(Tweddle et al. 2024); Tweddle, G., Krause, L., Ruiz, P., Raschka, A., Özgen, A., Hark, N. and Carus, M., 2024: Alternative Naphtha – Replacing Fossil-Based Feedstocks in Refineries and Naphtha Crackers: Technologies and Market, Status and Outlook.
https://doi.org/10.52548/JICP8041

Editor

nova-Institut für politische und ökologische Innovation GmbH, July 2024
www.nova-institute.eu

Authors

Gillian Tweddle, Stripe bv Consulting, Managing Partner and Principal Consultant
Lars Krause, nova-Institute, Senior Expert, Technology & Markets
Pauline Ruiz, nova-Institute, Expert Sustainability and Technology & Markets
Achim Raschka, nova-Institute, Head of the Department Technology & Markets
Aylin Özgen, nova-Institute, Student Assistant
Nicolas Hark, nova-Institute, Senior Specialist Economy & Policy
Michael Carus, Founder and CEO of nova-Institute and Executive Manager of RCI

V.i.S.d.P. (responsible)

Michael Carus, nova-Institut GmbH, Hürth (Germany)

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1 Executive Summary

Base chemicals – aromatics and olefins are the essential start point for some of the largest volume chemical polymers and products used today, such as polyethylene (PE), polypropylene (PP), polyester (PET), polystyrene (PS), polyamide (PA) and others. Currently these base chemicals are produced worldwide at large scale, almost entirely via fossil-based feedstocks. Fossil-based light naphtha is a key feedstock for steam cracking processes to produce olefins and polymers such as PE, PP in Europe and Asia. Fossil-based refinery naphthas are converted to reformate for the production of aromatics and polymers such as PS and PA. This means that there is an important and urgent need to find renewable carbon-based replacements to meet net-zero goals.

The concept of renewable attributed products and "alternative naphtha"

For the defossilisation of the chemical industry, it is crucial to find alternatives to fossil-based naphtha. The "alternative naphtha" concept makes use of existing refinery, steam cracking and chemical industry infrastructure where a proportion of fossil-based feedstocks – crude oil or fossil-based naphthas can be replaced by renewable carbon alternatives derived from the three sources of renewable carbon: CO_2, biomass and recycling.

This approach allows for the volume of renewable carbon substituting for fossil carbon to be increased over time and combined with the "mass balance and attribution" (MBA) approach, allows attribution of the renewable carbon input to one or more output chemicals such that a higher renewable attribution, compared with the natural flow of chemicals in the production system, may be claimed for a given product when desired.

Progress towards substitution of fossil-based feedstocks with "alternative naphthas"

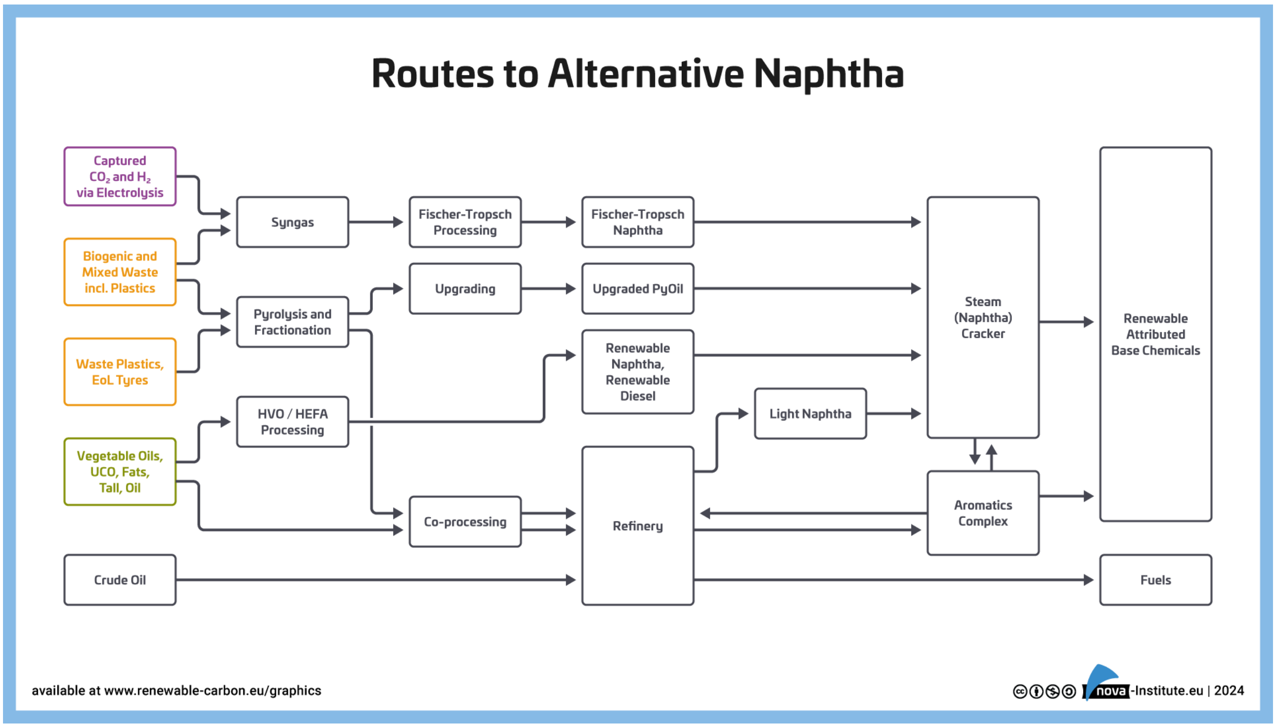

Figure 1: Routes to alternative naphtha

In Figure 1 the key routes to alternative naphtha are shown.

Co-processing

With co-processing, bio-based feedstocks, typically first-generation (such as rapeseed oil palm oil, sunflower oil, soybean oil etc.) are fed to existing refinery processes alongside fossil feedstocks. Light naphtha produced in the refinery as a feedstock for steam cracking and reformate for aromatics as well as fuels production can thus have an attributed renewable content. Renewable feedstocks may be attributed to fuels or chemicals or proportions of each.

HVO/HEFA

The process known as hydrotreated or hydrogenated vegetable oil (HVO) or hydrogenated esters and fatty acids (HEFA), is one which has been developed primarily to produce bio-based diesel and/or SAF (synthetic aviation fuel) via hydrogenation (hydrotreatment) and hydrocracking of bio-based feedstocks which include vegetable oils, waste oils such as used cooking oil and by-products from the processing of palm oil as well as tall oil, a by-product of the wood pulp and paper industry.

Production via HVO/HEFA has been taking place since the early/mid 2010's and overall output volumes have increased sharply since 2000. World capacity in 2023 was estimated at 18.2 million tonnes worldwide with planned projects to take capacity to close to 40 million tonnes by 2026. As well as bio-based diesel and SAF, one output of the process is bio-based naphtha at levels up to ~10% of total output.

Bio-based naphtha, and dependent on the configuration of the steam cracker, renewable (bio-based) diesel from the HVO/HEFA process can replace fossil based light naphtha as a steam cracker feedstock. (Steam cracking operations vary considerably worldwide regarding acceptance of feedstocks. In the US and Middle East, steam crackers are set-up for lighter ethylene or gas-based feedstocks and not necessarily suitable for processing bio-based naphtha).

While there were an estimated 44 HVO/HEFA producing facilities worldwide in 2023, the number of companies active in providing feedstock for attributed chemicals via steam cracking is very much smaller and dominated by four key companies.

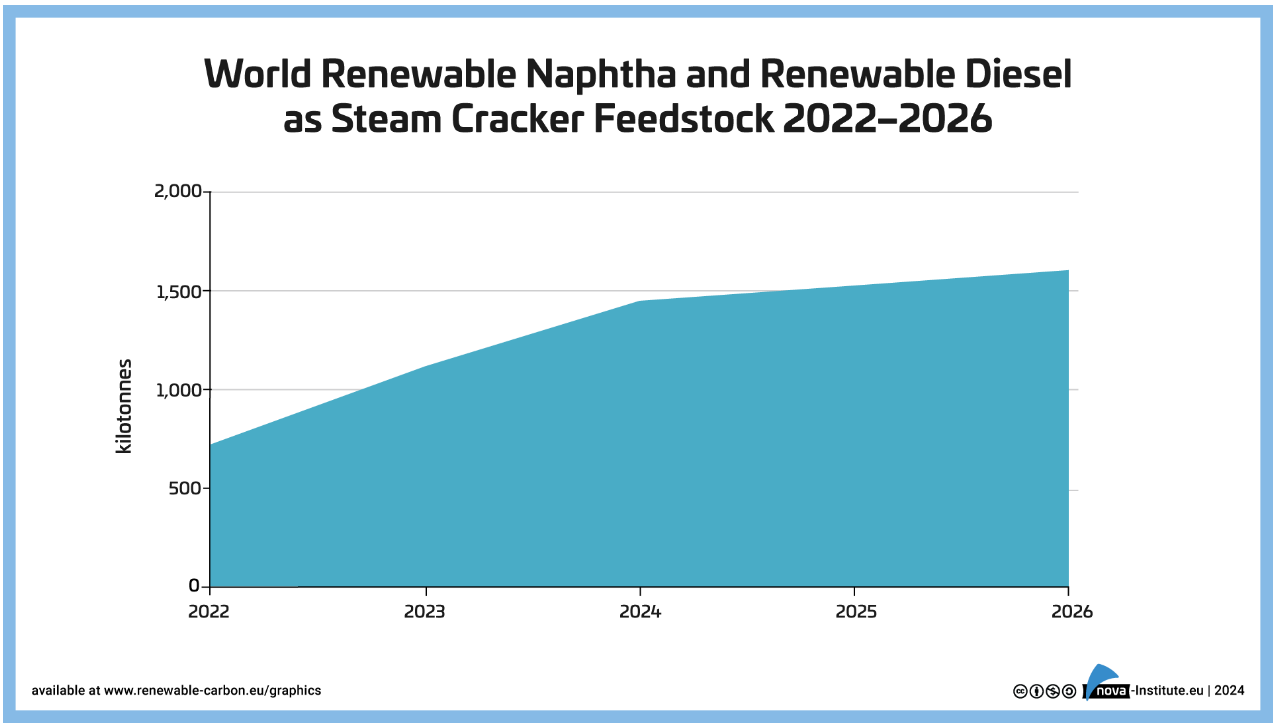

Figure 2: World production of renewable (bio-based) steam cracker feedstock from HVO/HEFA, 2022–2026, kt

In 2023, approximately 1,150 kt, or 1.15 million tonnes in total of renewable naphtha (RN) and renewable diesel (RD) were estimated to be used as steam cracker feedstock from which renewable attributed products were made. Based on currently known projects, production for the chemical industry is expected to rise to approximately 1.6 million tonnes by 2026.

Pyrolysis Oil (PyOil) from waste plastics and tyres

Pyrolysis oil from the treatment of waste plastics or end of life tyres, via "chemical recycling" or of biomass is a second source of "alternative naphtha" for the chemical industry. The pyrolysis of plastics and tyres has grown significantly in interest in the past 2-3 years because it is not only a means of treatment of plastic containing wastes which are often difficult to recycle by mechanical means, but also because it offers the potential for a level of circularity for plastics able to complement other sources of renewable feedstock for refineries and steam cracking.

Unlike HVO/HEFA outputs, PyOil is not a by-product of fuels production. The PyOil in total or fractions of the PyOil could also be used as fuel, though when used in this way, circularity is lost.

Proposed new EU legislation now sets ambitious targets for recycled content in plastic packaging materials. Pyrolysis as a form of recycle offers great advantages in achieving the quality standards that packaging materials in contact sensitive applications must achieve. Legislation has not officially been introduced into EU law yet, but it can be expected that pyrolysis and other chemical recycling technologies will thus play a significant role in achieving more ambitious recycling targets and strongly support the production of PyOil from plastic wastes.

Tyre derived PyOil contains a significant bio-based content from the natural rubber used in tyre manufacture, making it attractive, in the case where a bio-based share receives incentives.

The industry is characterised by partnerships between developers and operators of pyrolysis technologies and downstream partners – the refinery and steam cracker operating companies or traders serving the chemical industry. The output PyOil is typically fractionated and while some co-processing in refineries can take place, an upgrading of the PyOil (typically via hydrotreatment) to remove contaminants is essential where it is to be processed by steam crackers.

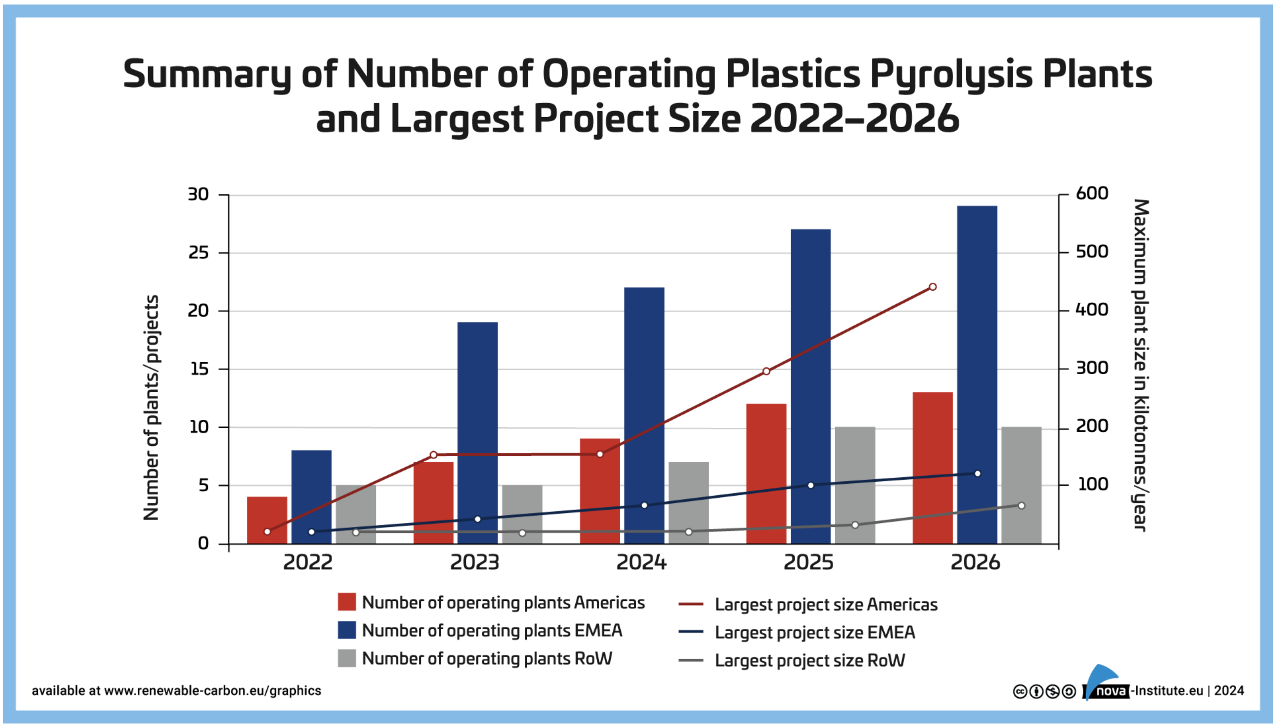

Figure 3: Summary of number of operating plastics pyrolysis plants and largest project size by region, 2022–2026, kt/year

The number of plastics pyrolysis plants linked to downstream partners or offtakers is relatively small as of 2023, with Europe leading as a region in the number of plants – estimated at 18 currently. The number of projects is steadily growing in all regions. While the typical capacity to process waste feedstock for such pyrolysis production lines is ~20 ktpa, some projects envisage multiple lines. Especially for the US, ambitious large-scale projects are planned for 2025, 2026 and onwards.

The environment for pyrolysis of plastics, often referred to as advanced or chemical recycling is not always supportive – with NGO’s and public opposition on the grounds of perceived threat of pollution, competition to mechanical recycling and high energy demand. In addition, many technologies used by the different pyrolysers, while in-operation, remain with development work continuing and confirmation of lifecycle analysis (LCA) to be completed.

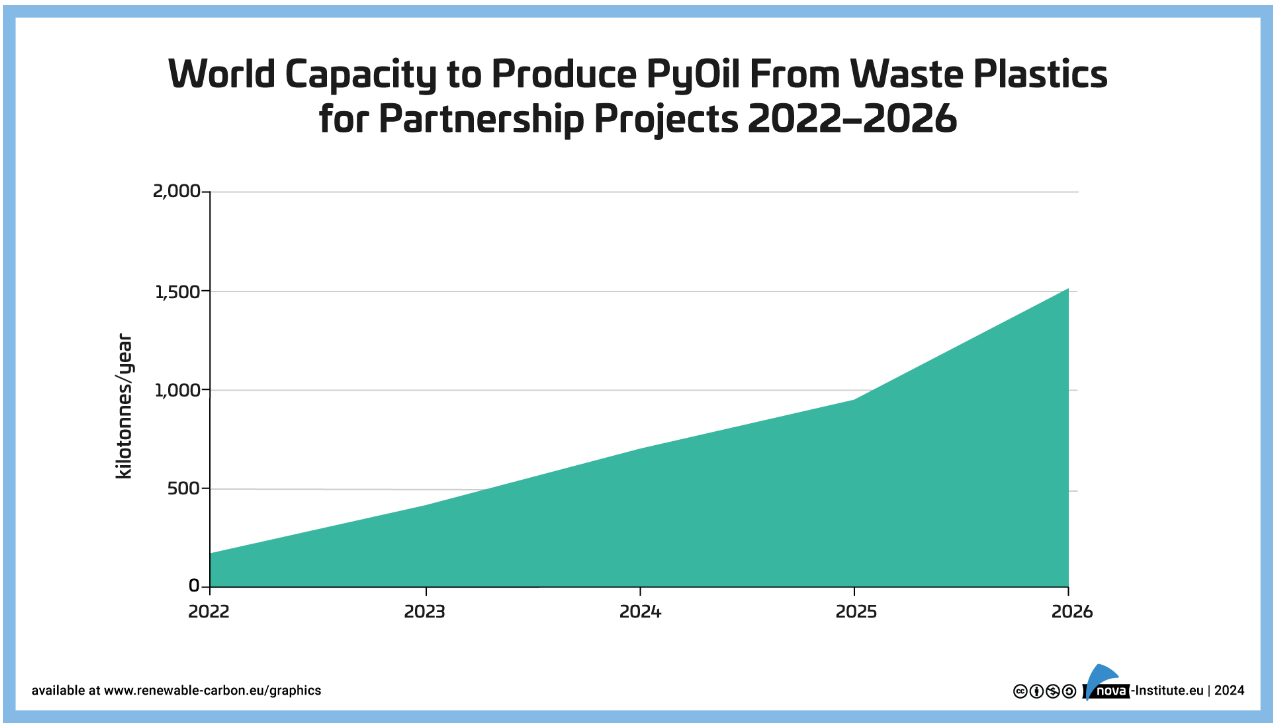

Figure 4: World capacity to produce PyOil from waste plastics for partnership projects, 2022–2026, kt/year

Nonetheless, the capacity available to produce PyOil in total could grow to >1,500 ktpa by 2026 if current projects with refinery and chemical industry offtakers continue as planned.

The contributions to chemical production from each of plastics PyOil and HVO/HEFA are thus expected to be at similar levels, at 1.5 to 1.6 million tonnes/year in each case by 2026, though this would require plastics pyrolysis oil production at capacity. With worldwide demand for ethylene alone at >150 million tonnes/year, it is clear that there is room for increased volumes of alternative naphtha by expansion of plastics pyrolysis, by the contribution of HVO/HEFA but also via other routes. Pyrolysis of waste tyres is expected to contribute a further ~190 ktpa of capacity by 2026.

Gasification and Fischer-Tropsch

Gasification of biogenic wastes or plastic containing wastes to produce Syngas (a mixture of carbon dioxide and hydrogen), which is then converted to a mixture of renewable naphtha, diesel and sustainable aviation fuel (SAF) via the Fischer-Tropsch process is a further possible contributor of alternative naphtha. While production from plastics is a possible route, activity to produce fuels and chemicals in this way is very limited with large-scale projects based on the gasification of mainly wood waste biomass the focus for this technology. While 450 ktpa for North America and 74 ktpa of capacity for Europe are envisaged from wood waste mainly, outputs are expected to be for fuel use only.

Fischer-Tropsch naphtha from carbon capture

The production of 'syncrude', or synthetic crude oil for fuels and chemicals from captured carbon also relies on the Fischer-Tropsch process. CO_2 may be sourced and captured from industrial emission sources, from biogenic waste gas streams or extracted from the air using direct air capture (DAC) systems as the start point for this production.

In a net-zero scenario, feedstocks for chemicals overall will be covered to a large extent by bio-based feedstocks and recycled materials (produced from mechanical and advanced recycling technologies) but it is expected that captured carbon will be required as a feedstock up to 25% levels.[1] Consideration on the contribution of CCU technologies to alternative naphtha is thus important.

As with HVO/HEFA the demand for fuels is expected to be the driver for availability of CO_2 based feedstock for chemicals in the form of alternative naphtha.

The EU adopted regulations in October 2023, with specific targets for the use of Sustainable Aviation Fuels (SAF) and within this category, sub-targets for Synthetic Aviation Fuels. Synthetic Aviation Fuels are based on the definition of RFNBO (renewable fuels of non-biological origin) and include CO_2 derived fuels. The ReFuel EU targets which form part of the regulations require 5% synthetic fuel within a quota of 20% SAF by 2035 increasing to 15% synthetic fuel within a quota of 42% SAF use in aviation fuel overall by 2045, and finally 70% SAF use in 2050, with a minimum share of 35% for synthetic fuel and a maximum share of 35% for bio-based SAF.

In the US, the White House announced a plan in September 2021 calling for production of at least 3 billion gallons (100 million tonnes) of SAF per year by 2030. The US Inflation Reduction Act of 2022 provides a $US60/tonne incentive for CO_2 use.

Technologies for the combination of carbon capture, production of syngas, conversion to synthetic crude oil via Fischer-Tropsch technology and separation of products to required outputs such as SAF, diesel, naphtha, waxes and other chemicals, are being investigated and implemented in 25 or more projects worldwide. Projects involve multiple technologies, where expertise on the capture of carbon, conversion of CO_2 and H_2 to syngas as well as Fischer-Tropsch technology may be provided by separate companies or organisations.

Most projects for fuels via carbon capture and the associated production of naphtha are not expected to be realised until after 2026 and are currently foreseen for the period 2026-2030, when the resulting CO_2-based hydrocarbon capacity could increase to close to 800,000 tpa worldwide should all the currently active projects go ahead.

1 Kähler, F., Porc, O. and Carus, M. 2023. RCI Carbon Flows Report: Compilation of supply and demand of fossil and renewable carbon on a global and European level. Editor: Renewable Carbon Initiative, May 2023. Available at: www.renewable-carbon-initiative.com

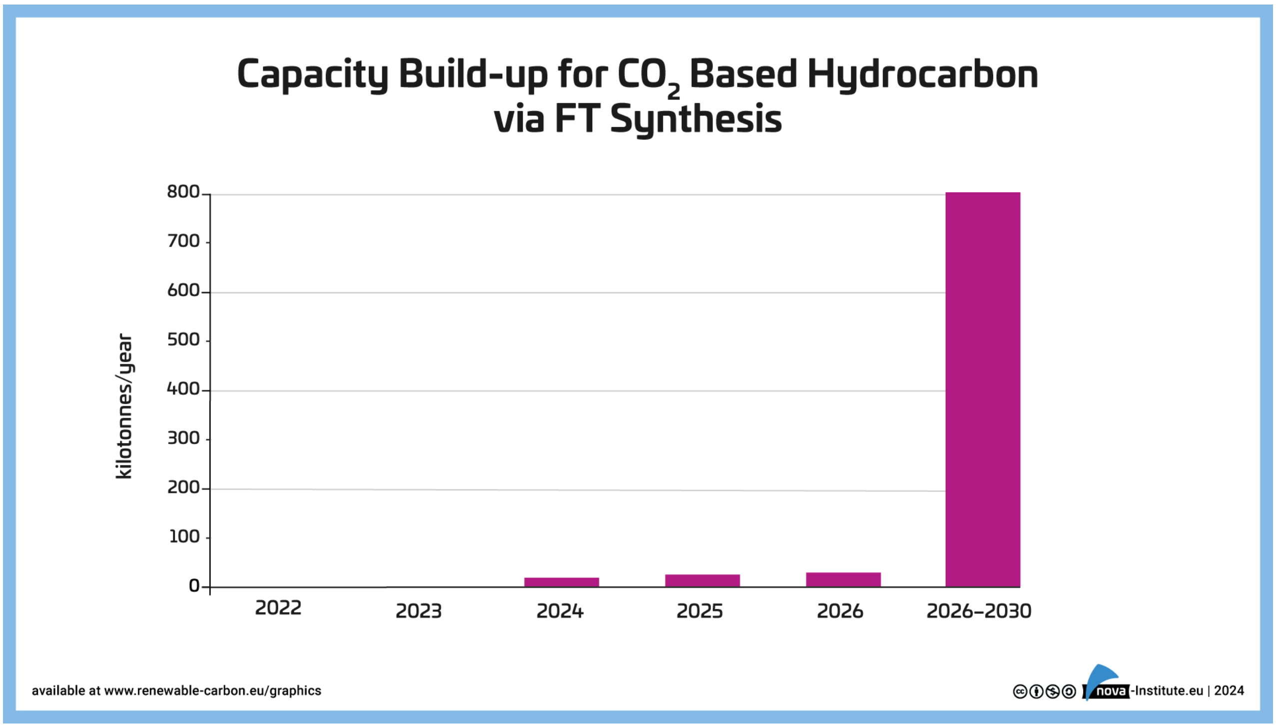

Figure 5: Capacity build-up for CO_2 based hydrocarbon via FT synthesis, 2022–2030, kt/year

Apart from demonstration facilities, two European commercial scale projects and one in the US are expected to be operational in 2024.

With rising production of synthetic aviation fuels beyond 2030, there will be a production of co-product naphtha which could be available to the chemical industry.

"Alcohol-to-Jet"

"Alcohol to jet" are chemical process technologies which could contribute some further co-product naphtha to chemical processing. Alcohols such as methanol, ethanol and isobutanol may be "upgraded" to produce synthetic kerosine (SAF). Typically, a 10% (by weight) by-product naphtha could be produced as part of the process.

A future review on availability of alternative naphtha for the chemical industry may indicate "alcohol-to-jet" processes could be included as a route to alternative naphtha in Figure 1. Technology developers and licensors are active in developing and optimising processes and as the technologies mature and volumes become available to the market, this source of naphtha may warrant increased consideration!

Authors

Gillian Tweddle (Belgium) has been active in the chemical industry for more than 30 years with experience covering technical and market aspects. Since 2002, Gillian has worked as a senior consultant covering strategic, market and technical assessments and projects for chemicals and value chains covering a wide range of chemical intermediates and specialty chemicals including market history and projections for bio-based and biodegradable polymers. Gillian has been supporting nova's Technology & Markets department as an external expert since mid 2021.

Lars Krause is trained as a biologist, after completing his master's degree, he passed his PhD studies in the field of colloid chemistry at the RWTH Aachen in collaboration with a research centre. Beside his academic education he collected several years of industrial experience in the field of project management, science, and technology at companies from different branches including the aerospace sector, crop science, and ecotoxicology. He works since 2020 at nova's Technology & Markets department. As senior expert he is mainly responsible for monitoring technologies and innovations in the recycling sector.

Pauline Ruiz is trained as a chemist and holds a Master's degree in Polymer Engineering from the European School of Chemistry, Polymers and Materials Science (France). She collected several years of experience in project management and research and development in various fields including the coating and rubber industries. She joined the nova team in 2020 in the Sustainability department. She is an expert in bio- and CO_2-based chemicals and polymers and supports the nova team in several projects related to sustainability, life cycle assessment, technology and markets.

Achim Raschka has been working at nova since 2008, in 2013 he became Head of Technology and Markets. He is involved in different national and international research programs beside industrial consulting concerning the material use of renewable carbon, CO_2- and bio-based products, biotechnological and chemical conversion technologies, and sustainable feedstocks for Industrial Biotechnology as well as Carbon Capture and Utilisation (CCU).

Nicolas Hark joined the nova-team in 2020 and is a senior specialist in the Economy and Policy department. He holds degrees in Agricultural Economics from Bonn University and Humboldt University of Berlin and focuses on policies and economics regarding the renewable carbon industries. He supports the nova-team and the Renewable Carbon Initiative's working group "Policy" with regulation and policy analyses, economic market analyses and general project management. Nicolas is involved in various industry and EU projects (Horizon 2020) regarding the bio-based and renewable carbon economy and developments in this field.

Michael Carus is one of the leading European experts, market researchers and policy advisers of the renewable carbon economy – including bio-based, CO_2-based and recycling. At the end of 1994, he and five other scientists founded the private and independent nova-Institute for Ecology and Innovation. Ever since the beginning, Carus has been involved in the company as owner and one of the two Managing Directors. Today nova-Institute has nearly 50 scientists from a wide range of disciplines, covering markets, technologies, sustainability, communication and policy. In the year 2020, Carus founded the Renewable Carbon Initiative (RCI), which has today more than 60 members from chemical and material industries

Table of Content

List of Figures

List of Tables

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nova-Institute is a private and independent research institute, founded in 1994. nova offers research and consultancy with a focus on the transition of the chemical and material industry to renewable carbon.

What are future challenges, environmental benefits and successful strategies to substitute fossil carbon with biomass, direct CO_2 utilisation and recycling? What are the most promising concepts and applications? We offer our unique understanding to support the transition of your business into a climate neutral future.

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nova-Institut GmbH
Leyboldstraße 16
50354 Hürth, Germany
T +49 2233 – 460 14 00
contact@nova-institut.de
www.nova-institute.eu
www.renewable-carbon.eu
F +49 2233 – 460 14 01

CEO: Michael Carus | COO: Linda Engel

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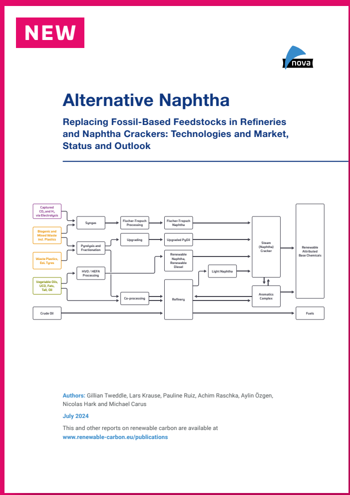

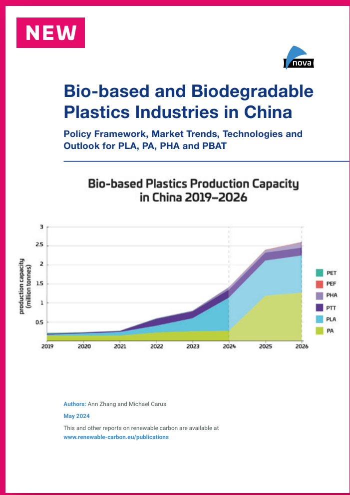

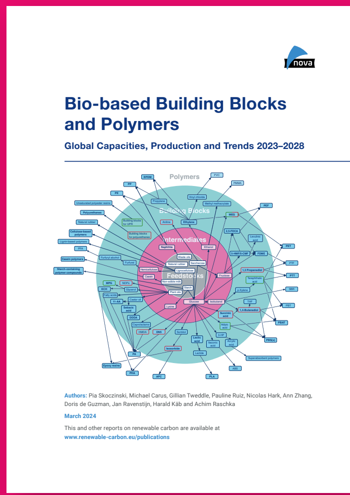

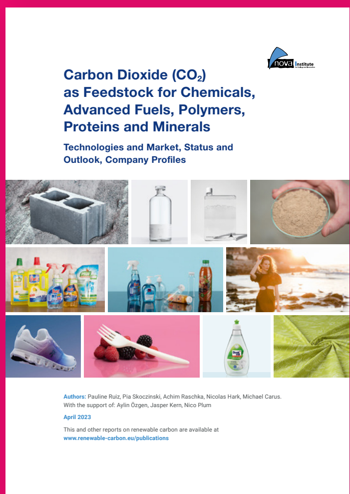

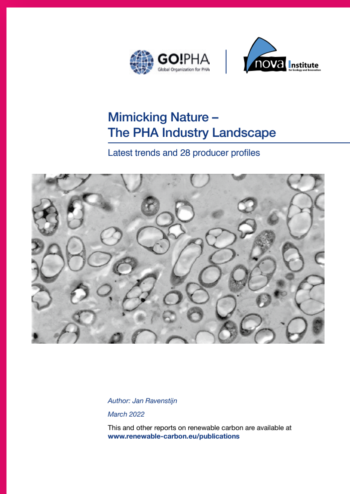

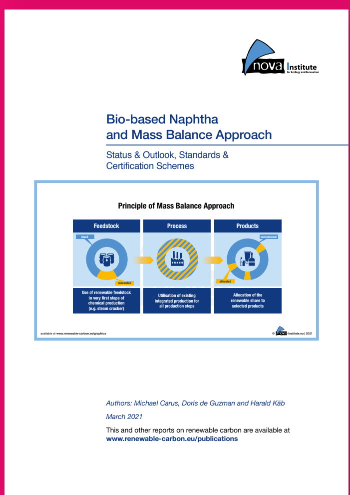

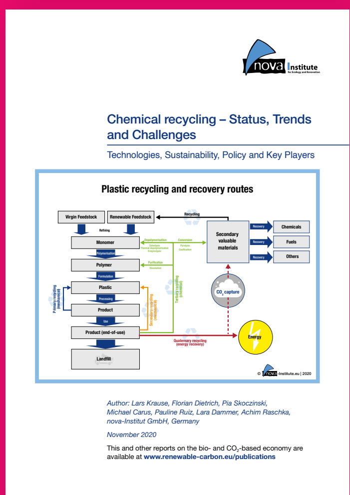

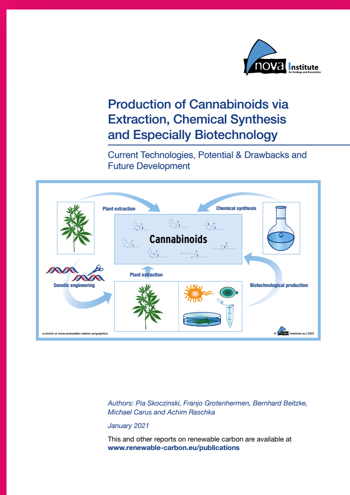

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