JOURNAL OF
BUSINESS CHEMISTRY

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

Practitioner's Section

Johanna Angela Thomann*, André Heeres and Errit Bekkering*****

The Northern Netherlands: Transformation of a gas-producing region into a forerunner in the biobased circular transition

The Northern Netherlands is an unique environment for sustainably-minded (bio)chemical businesses due to the regional availability of renewable feedstock, energy and existing infrastructure as well as the proximity to excellent knowledge centers and upscaling facilities. Within the last decades, several developments unravelled in the biobased circular transition. Exploring how these developments were initiated, the article means to show the opportunities that this region has to offer today. It also makes a strong argument for the economic potential arising from the creative combination of available feedstocks in an innovative ecosystem providing necessary frame-work conditions and fostering close intersectoral collaboration.

1 Introduction

The Northern Netherlands, spanning between the provinces Friesland, Groningen and Drenthe, is characterised by wide and open windy fields located at the North Sea/Wadden Sea coast. With a number of inhabitants of around 1.8 million, the North is less densely populated than the rest of the country and it has a strong agricultural sector (IWCN, 2022). While horticulture for flowers and vegetables is typical for the west of the country, crops like sugar beets, potatoes, rapeseed, corn, hemp and grass land are more prominent in the Northern parts close to Germany. As a consequence of this agricultural heritage, large food manufacturers like Cosun Beet Company (sugar beets) and Royal Avebe (potatoes) were established in the region. Due to the occurrence of salt layers from remnants of primeval seas, both sodium chloride and magnesium chloride are mined locally. Moreover, the Northern Netherlands has a strong chemical sector with two complementary industrial clusters. The cluster in Delfzijl in the province of Groningen focuses on the production of basic chemicals, while the cluster in Emmen in the province of Drenthe is specialised in polymer materials. The region is home to well-respected knowledge institutes including the University of Groningen, Hanze University of Applied Sciences in Groningen, the Stenden University of Applied Sciences in Drenthe/Friesland and Wetsus in Leeuwarden in Friesland.

Another characteristic of this region are its large natural gas reservoirs. The Groningen field is one of the world's largest gas fields with a capacity of 2,800 billion m³ (Nederlandse Aardolie Maatschapij NAM, n.d.). This led to a strong historical reliance on natural gas that was also important for the development of the energy intensive chemical clusters. Indeed, the share of natural gas in the national primary energy demand in 2010 was as high as 48.2%, whereas renewables contributed a mere 4%. The extraction of natural gas constituted 90.6% of the national energy production in 2010 (Energie Beheer Nederland EBN, 2022). Tragically, the exploitation of these gas reservoirs was associated with increased occurrences of earth quakes, thereby damaging houses in the province of Groningen. When the strongest earthquake occurred in 2012 with a magnitude of 3.6 on the Richter scale, the government responded to the public`s anger

* Johanna Angela Thomann, M.Sc., Hanze University of Applied Sciences, Zernikeplein 11, 9747 AS Groningen, The Netherlands, j.a.thomann@pl.hanze.nl
** Dr. André Heeres, Hanze University of Applied Sciences, Zernikeplein 11, 9747 AS Groningen, The Netherlands, a.heeres@pl.hanze.nl
*** Errit Bekkering, M.Sc., N.V NOM, Paterswoldseweg 810, 9728 BM Groningen, The Netherlands

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

and their environmental concerns. Consequently, plans for the phasing out of the gas extraction in the Groningen field by 2022 were published (Ministerie van Algemene Zaken, 2022). However, this had the loss of approximately 20.000 jobs as a consequence (Province of Groningen, n.d.). At the same time, the financial crisis in 2008 had also left its mark on the economy. Companies started to struggle with high energy prices and finding skilled workers due to trends of urbanization and other demographic changes. Meanwhile, warnings of the consequences of global warming and the call for climate action from scientists around the world received more recognition in the public discourse leading up to the Paris agreement in 2015 (United Nations Framework Convention on Climate Change, n.d.). With the growing awareness for sustainability, discussions on business practises that would respect planetary boundaries gained more and more attention questioning the linear fossil-fuelled extract-use-discharge system.

The situation of the chemical clusters at the time was described in a report from 2014, in which current struggles were addressed and a vision for the clusters was drafted (Willems, 2014). According to this source, the clusters were already working closely together as was reflected by a high labour productivity and a partly shared, decently functioning infrastructure. Nonetheless, common utilities within and in-between the clusters needed be further optimized (e.g. energy and waste flows). This included a joint steam pipeline for a closed-loop heat system. Innovation and entrepreneurship were lagging behind while the focus remained on the production of low-value bulk products. Chemicals produced in the chemical cluster Delfzijl included methanol, glycerol, sodium chloride, hydrochloric acid, sodium hydroxide, hydrogen peroxide, chlorine, monochloroacetic acid, formaldehyde and ethylenediamine. For the production of polymer materials (mainly polyesters like PET and aramides), the clusters in Delfzijl and Emmen were mostly relying on imports of fossil-based feedstocks like terephthalic acid, aniline, 1,4-butanediol, p-xylene among others.

Better alignment of the chemical clusters with the nearby knowledge centres was stressed as action point to promote the valorisation of academic knowledge and thus innovation. For this, suitable upscaling facilities were needed enabling research on all technology readiness levels (TRL). Along side, opportunities were identified in organising effective branding and acquisition for both clusters. This would help bridging public and private sectors as well as offer support for companies in business development and organising funding. For an overview of the situation 10 years ago, a SWOT analysis was performed (Table 1).

Table 1 SWOT analysis of the Northern Netherlands in the 2010s.

Strengths	Weaknesses
⇨ Agricultural sector ⇨ Large gas reservoirs ⇨ Complementary chemistry clusters in Delfzijl and Emmen ⇨ Knowledge centers (University of Groningen, Hanze University of Applied Sciences, NHL Stenden, Wetsus)	⇨ Strong focus on low-value bulk chemicals and materials ⇨ Strong national reliance on natural gas from Groningen
Opportunities	**Threats**
⇨ Alignment of chemical clusters with the knowledge institutes ⇨ Organising and strengthening of common utilities within and between clusters ⇨ Branding and acquisition for both clusters ⇨ Connecting the agricultural, energy and waste sectors to the chemical sector ⇨ Growing awareness for sustainability and transition to a biobased circular economy	⇨ Earthquakes, damaged houses, loss of trust of citizens ⇨ Financial crisis ⇨ Issues to find human resources and skilled labour ⇨ High prices of energy

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

Out of this situation, the need for a strategic repositioning became clear. As a consequence, ambitions were born to transform the regional economy into a biobased, circular one and as a joint initiative Chemport Europe was kicked off.

2 Transition into the biobased circular economy

The transition towards a biobased circular economy takes place against the background of the climate crisis caused by the exploitation of fossil carbon and associated accelerated greenhouse gas emissions (Krätzig, 2019). Biomass, as an available renewable carbon source, is seen as a practical, more sustainable and thus favorable alternative (Yang et al, 2021; Escobar and Laibach, 2021). The origins of the biobased economy and the drafting of the bioeconomy strategy in the European Union were described elsewhere (Patermann and Aguilar, 2018; European Commission, 2018).

In a biobased circular economy, production processes are optimized and strongly integrated and use minimal resources such as water, energy and materials. The industrial activities are powered by renewable energy leading to substantially lower greenhouse gas emissions. The input streams are sustainably sourced moving away from fossil fuels and feedstock. Circularity in the context of biomass valorization refers to a cascading use of these raw materials; an approach that is applied in integrated biorefinery systems (Escobar and Laibach, 2021). Overall, maximal reuse and recycling of streams is aimed for, turning the linear system in to a circular one. This is also reflected in product design by building for longevity and durability (University of Groningen–Industry Relations Office, 2020; Yang et al, 2021).

3 Developments in the energy sector

As the topic of biobased circular economy is inherently intertwined with the energy transition, a discussion of one would be incomplete without talking about the other. For that reason, the developments in the energy sector will be described before delving into the biobased circular economy.

Here, energy transition refers to the change from a mostly fossil-based system geared to natural gas towards a renewable, largely decarbonized energy system. Besides changing the energy source, a crucial aspect lies within its responsible use. Electrification and optimization of industrial processes are on the agenda to yield highest possible energy efficiency in the chemical clusters. Local use of energy with as little conversion steps as feasible can be a way to reduce energy losses.

The clusters` main energy sources to date consist of coal, natural gas, household waste, biomass and electricity. Electricity and heat are thereby produced from various sources and either supplied to the energy grid or directly to industrial end-users. To date, the largest part of hydrogen in the cluster Delfzijl is produced from natural gas. This grey hydrogen serves as feedstock for the production of hydrogen peroxide and methanol. Hydrogen as by-product of chlorine production is currently used for heat and electricity production. By now, steam pipelines have enabled a closed-loop system for heat within the cluster.

Due to the planned electrification of industry, built environment and mobility, electricity demand is expected to increase significantly. In the current cluster energy report, energy by coal is expected to be fully replaced by bioenergy from waste biomass and green gas from biomass fermentation. It is expected that the demand in natural gas in the chemical cluster will only decrease from 13.1 TWh/year to 11.2 TWh/year by 2030 (Water Energy Solutions, 2022). In this projection, natural gas-based power plants remain in operation and a number of factories will not have adapted their processes. These developments are strongly affected by prices for natural gas, electricity and CO_2.

Towards 2050, a further increase in electricity consumption is expected. Natural gas consumption by the chemical cluster will be reduced to 3.7 TWh/year, but 19.7 TWh/year will still be needed for electricity generation in Eemshaven. Electricity producers in Eemshaven therefore plan to incorporate capture of CO_2 emissions into their operation for usage in other sectors (CCU) or storage in empty gas fields and potentially salt caverns (CCS) (Water Energy Solutions, 2022). Indeed, Carbon Capture and Storage (CSS) is also pursued as a national strategy with the North Sea Energy Outlook from 2020 indicating a total available storage capacity of 1.400 Mt in empty gas fields on the Dutch continental shelf and expected levels of CO_2 storage of 10.2 Mt per year in 2030 (Cleijne et al, 2020). A number of these empty gas fields are also located close by.

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

Being located at the North Sea coast, the North will play an important role in the roll-out of renewable energy capacity due to available space and favourable wind conditions. Off-shore wind energy is a crucial part of Dutch climate policy. Here, Delfzijl and Eemshaven are suitable locations to bring this electricity on-shore. Current targets for 2030 are a supply of offshore wind energy of 21 GW equalling to 16% of the current Dutch energy demand and 75% of current electricity needs. Importantly, the electricity demand is expected to grow over time. The North Sea Energy Outlook has indicated that an offshore wind capacity between 38 - 72 GW is needed by 2050. As a reaction to this, the North Sea Agreements contains plans to explore suitable spaces for another 20 to 40 GW of offshore wind energy capacity to meet the predicted demand (Netherlands Enterprise Agency RVO, 2022; Ministerie van Economische Zaken en Klimaat, 2020).

To adapt to the weather-dependent supply of solar and wind energy, bioenergy and hydrogen as energy carrier will diversify the energy mix. Notably, the Northern Netherlands has ambitions to become the leading hydrogen valley in Europe building on several strategic advantages. These are namely its expertise in gas trading, transport and storage, existing pipeline networks and infrastructure, the industrial clusters and off-shore wind parks. In a recent study, the suitability of the existing gas infrastructure was examined for the transmission of hydrogen (HyWay 27, 2021). In The Netherlands, different pipelines (i.e. for low and high caloric natural gas) are built in parallel throughout the country. With the phasing out of the gas extraction from the Groningen field (which is currently slowed down due to the difficult situation in the European gas market (Ministerie van Economische Zaken en Klimaat, 2022)), it becomes feasible to free up not needed capacity for green hydrogen.

With the replacement of valves and cleaning of pipes, the refurbished infrastructure is highly suitable for hydrogen and thus constitutes a cost effective step in the energy transition. New pipelines will only be needed to a small extent connecting industrial clusters, hydrogen producers and storage locations to the main grid where needed (Gasunie, 2022). The report provides an estimate of investment costs of around 1.5 billion euros (HyWay 27, 2021).

In the North, a newly developed polymeric pipeline will be employed for local hydrogen transport within the cluster in Delfzijl that is low in cost and easily extendable (Groningen Seaports, 2022). Moreover, the deep-sea port in Eemshaven, salt caverns for underground storage and a newly built LNG terminal enable import and distribution of hydrogen in The Netherlands and Western Europe providing access to European off-take markets (Water Energy Solutions, 2022).

As an European model region, they aim to demonstrate an integrated sectoral approach and develop functioning self-sustaining business models surrounding a green hydrogen economy for which they received an EU grant of 20 million euros (Clean Hydrogen Joint Undertaking, 2020; Fields, n.d.). In an integrated value chain production, distribution, storage and end-use of green hydrogen are neatly connected. These ambitions are reflected in various ongoing projects along the entire value chain (Water Energy Solutions, 2022; Province of Groningen, 2020). In the NorthH2 project, plans were mapped out to expand the capacity of electrolysers using off-shore wind energy to produce 800.000 tonnes of green hydrogen per year by 2040 (Chemport Europe, 2020). Near term focus lies on the production of hydrogen as feedstock for the chemical industry. As a long term outlook, off-shore electrolysers are currently debated as additional hydrogen supply. Using existing gas pipelines for hydrogen transport and direct use of off-shore wind energy would circumvent the necessity of installing new cables in the marine environment and associated energy losses.

4 Intersectoral approach for a biobased circular economy

The circular resource and product streams in a bioeconomy require a concerted effort of different sectors. Looking at the chemical sector, implications and links with the energy, agricultural and waste sectors can be identified. Firstly, links between the energy and the chemical sector through H_2 and CO_2 as well as heat and electricity will be discussed. Secondly, links between the agricultural and chemical sector through biorefinery or biotechnological approaches will be highlighted. Lastly, the future role of the waste sector is explored employing principles of circularity. Relevant flagship projects that were started in the region will be introduced exemplifying the innovative potential of intersectoral collaboration.

Hydrogen links the energy sector with the chemical sector functioning as both energy carrier (Power2Gas) and renewable feedstock (Power2Chemicals). Green hydrogen

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

could replace grey or blue hydrogen in several processes such as the Haber-Bosch process to yield ammonia. Furthermore, it could be used for organic transformations of biomass-derived products and/or end-of-life plastics. Captured carbon dioxide is another important link being seen as carbon source for chemicals (Frieden, 2021). Of high interest is the production of green chemicals/fuels like methanol or kerosene using CO_2 and H_2 as feedstock, most often via syngas. Using microalgae and CO_2, biotechnological production of acetic acid and other compounds becomes feasible (Photanol, n.d.). Moreover, Avantium is looking into possibilities of using carbon dioxide for electrochemical valorisation routes, that they refer to as Volta technology (Avantium, 2021). The value of the chemicals made should thereby carry the cost of green hydrogen, electricity and/or CO_2 capture. Current benchmark is often a fossil based chemical without the costs of externalities and with the benefits of scale and 100 years of optimization. However, the chemical industry falls under the EU emission trading system (ETS). Through capping the amount of emission allowances and phasing out of free allowances in the future (KPMG, 2022), CO_2 – intense products will become more costly providing an advantage for low-emission biobased alternatives.

The value of the agricultural setting of the Northern Netherlands becomes apparent considering (bio-)chemical valorisation routes of agricultural products and residual streams. In 2017, Heeres and Heeres identified promising chemicals for this purpose by means of literature study and market and cost analysis. Target compounds of this report included epichlorohydrin, gluconic acid, levulinic acid, polyglucuronic acid, 1,2- and 1,3-propanediol, ethylene glycol, sorbitol, isosorbide and the aromatic compounds benzene, toluene and p-xylene. All of these can be synthesised from biobased feedstock, namely either glucose, cellulose, starch or glycerol using only reagents that are already available in the cluster.

Later in 2020, the saccharide agenda was published. This was meant as a roadmap for the use of (poly)saccharides as platform chemicals to produce various (di)alcohols and (di) acids (ter Braak and Smit, 2020). Conversion to other sugars such as xylitol and production of polyhydroxyalkanoates (PHA) was envisaged as well. The reconsideration of saccharose from sugar beets as chemical feedstock can thereby be seen as a response to decreasing demand and discussions on the negative health impacts of sugar consumption. More broadly, other 1st generation sugars like potato starch, 2nd generation sugars from woody biomass and 3rd generation sugars from residual streams are potential feedstocks as well. The saccharide agenda examined economic and technical viability of target compounds like monoethylene glycol (MEG), acetic acid, 1,4 butanediol (1,4 BDO), 2,5 furandicarboxylic acid (FDCA), xylitol and polyhydroxyalkanoates (PHA) (ter Braak and Smit, 2020). Some of which are currently used by regional companies but are mostly imported and sourced from fossil carbon (1,4 BDO and acetic acid).

An advanced example for the use of 2nd and 3rd generation sugars can be found at Avantium. The company developed and optimized a process to yield industrial sugars and lignin from agricultural residues. This so-called DAWN technology reached pilot-scale and uses hydrochloric acid produced in Delfzijl. The obtained sugars serve as feedstock for the production 2,5-furandicarboxylic acid (FDCA) and monoethylene glycol (MEG). A pilot plant to produce plant-based MEG was built in 2019. In 2022, Avantium begins the construction of its FDCA flagship plant that utilizes fructose as feedstock. The two compounds MEG and FDCA are the starting materials for the production of polyethylene furanoate (PEF). They are looking into the commercialisation and large scale production of biobased PEF that can be used for packages, textiles or foil (Avantium, 2021). Lignin, as by-product, has potential both as feedstock itself or fuel, due to its high energy content.

In a circular economy, products are kept in use for as long as possible and waste is redefined as resource. In a chemical context, plastic wastes and sewage from wastewater treatment plants become interesting as resources. Thus, the waste management sector is connected to the chemistry sector as well.

In terms of wastewater treatment, Paques and Paques Biomaterials are to mention. Paques is a globally active service company specialized in wastewater treatment and resource recovery from sewage including nutrients, metals and cellulose from toilet paper (Recell Group BV, 2022). Paques Biomaterials is a spin-off that dedicated research towards the microbiological production and extraction of polyhydroxyalkanoates (PHA) using wastewater as feedstock (Paques Biomaterials, n.d.). Paques Biomaterials plans its demonstration plant for 2023 to validate the concept and scale-up the production of this naturally occurring,

ISSN 1613-9623

JOURNAL OF
BUSINESS CHEMISTRY

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

biodegradable polyester. Later on, a commercial extraction facility with a capacity of 6 kton PHA/year is planned in the industrial park Emmen (Gielen, 2022).

Another interesting approach is carried out by the start-up BioBTX in Groningen, which is a spin-off from Symeres and Ecoras. Employing integrated cascading catalytic pyrolysis techniques, they demonstrated how widely used aromatic compounds can be obtained from diverse waste products in two steps. These are pyrolysis in the absence of oxygen and subsequent aromatic formation in a catalytic reactor (*ex situ*) from which pure aromatic compounds can be isolated. Benzene, toluene and xylenes produced in this way serve as drop-in chemicals substituting fossil-based counterparts. Residual streams range from plastics to contaminated biomass. After the development of a mini plant, scale-up to commercial levels is aimed at. Besides that, downstream processing of aromatics is investigated to obtain other chemical building blocks (BioBTX, n.d.).

The chemical cluster in Emmen is very active in the field of recycling and biobased production of polyesters and aramides to reduce greenhouse gas emissions and move away from fossil feedstock. In the following, a few examples of ongoing efforts in the cluster are highlighted.

Mechanical recycling of polyethylene terephthalate (PET) is rendered difficult when the collected material is coloured, contaminated or mixed with other types of polymers. The CuRe project is a low energy chemical recycling process of such difficult to recycle end-of-life polyesters. After sorting and washing, partial depolymerisation, purification and repolymerization yields colourless granules similar to those obtained through mechanical recycling of clear/blue and clean polyester. The CuRe system allows for adaptation to different waste streams by incorporating modular add-on technologies. Partners of the CuRe consortium are Morssinkhof Group, DuFor/ Cumapol Group, DSM-Niaga and NHL Stenden University of Applied Sciences. Located in Emmen, the pilot plant has a capacity of 20 kg/h using a continuous process. The next phase after validation would be the conversion of a polymerisation line at Cumapol to the CuRe recycling system enabling an additional capacity of 25 kta (CuRe Polyester Rejuvenation, 2022).

At Clariter, challenging plastic waste of polyolefins (i.e. PE, PP and PS) can be chemically recycled to yield solvents, waxes and oils. Their three step process consists of thermal cracking, hydrocracking and distillation/separation (Clariter, 2022a). Together with regional partners, they plan to start a plant in Delfzijl with a processing capacity of 350,000 t/year in 2025, which would then be the largest sorting plant for the chemical recycling in Europe (Clariter, 2022b).

At Tejin Aramid in Emmen, aramide products are produced, one of which is Twaron© – a p-phenylene terephthalamide (PPTA), which is made from the monomers p-phenylenediamine (PPD) and terephthaloyl dichloride (TDC). Considerable effort has been put in setting up recycling programmes, that collect end-of-life Twaron© from industrial customers. These collected waste streams and process scrap material are turned into aramide pulp at their own recycling facility. Here, re-spining of recycled material is explored for yarn-to-yarn recycling (Teijin Aramid, 2021).

In 2020, a successful pilot study served as a proof-of-concept that biobased drop-in chemicals are suitable for Twaron© yarn production (Figure 1). While the biobased aramide yarn showed the same properties, it had a lower

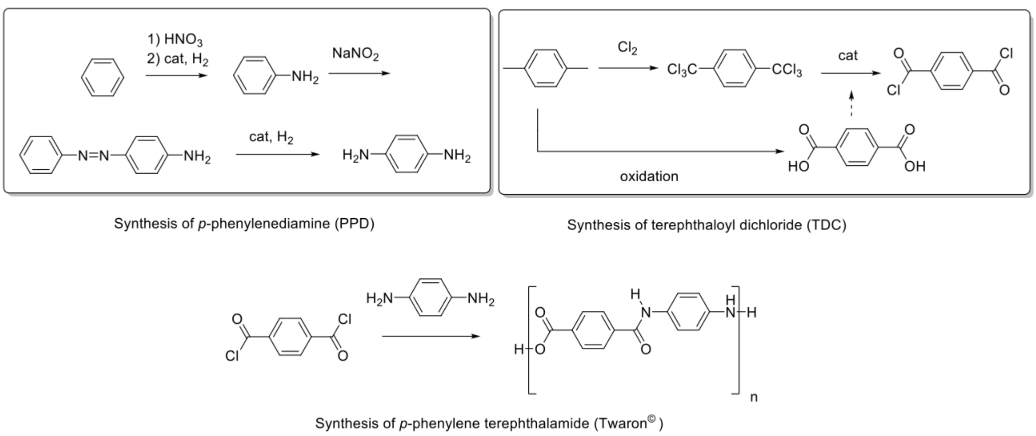

Figure 1 Synthesis of p phenylene terephthalamide (Twaron©) using biobased aromatics from BioBTX as feedstock.

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

CO_2 footprint. Collaborators were BioBTX, that provided biobased aromatic building blocks and Symeres, a company specialized in performing organic chemical research (Teijin Aramid, 2021).

Similarly, it was possible to demonstrate the production of bio-PET (polyethylene terephthalate) . Here, glycerol served as feedstock for the BioBTX process. Syncom was responsible for the conversion to suitable precursors terephthalic acid, while Cumapol and API performed the polymerisation to yield biobased PET. In collaboration with DuFor, Aarts Plastic and the Stenden University of Applied Sciences, the bio-PET was then formed into small containers for cosmetics (Kupfer, 2016).

These flagship projects ranging from biobased building blocks, drop-in chemicals and polymers to effective recycling strategies show ambitions and ongoing developments in the region. It can be seen that with a portfolio of available feedstocks, existing infrastructure, scientific creativity and entrepreneurship, important problems of the chemical industry can be addressed and economic value can be created!

5 With a portfolio of available feedstocks, existing infrastructure, scientific creativity and entrepreneurship, economic value can be created!

A smaller scale example of close collaboration among local entities can be found in the Innovation Hub East-Groningen (IHOG). The hub was founded in 2019 as a collective of four local companies and two collaborating knowledge institutes with the goal to foster product innovations with regional feedstocks. The involved partners are the potato starch manufacturer Royal Avebe, Nedmag mining and producing magnesium salts and oxides, the hemp producer Hempflax and Zechsal who produces cosmetic products. Combined, eight feedstocks are available in Eastern Groningen: potato starch and protein, magnesium hydroxide, chloride and oxides and hemp fiber, proteins and CBD oil. Out of combinations of these feedstocks, ten application-oriented projects were developed. Research themes evolved around sustainable construction materials (i.e. starch-based adhesives and fire-resistant hemp materials for construction and insulation), dietary supplements (i.e. combinations of hemp and potato protein, Mg-fortified modified starch) and higher valorisation of hemp fiber (Innovation Hub East Gronignen, n.d. a). This way, IHOG has been involved in 230 student projects in 2021 in law, science and engineering, marketing and business and economics and even art. Indeed, a remarkable project has been conducted with the art academy Minerva of the Hanze University of Applied Sciences in Groningen. The design of Conscious Furniture collection, that was exhibited on the Dutch Design week in Eindhoven in 2022, is uniquely fit to communicate the IHOG`s mission and make it tangible for a wider audience (Dutch Design Week, 2022). The collection was prepared from hemp fibers, starch and magnesium additives. The National Program Groningen recently awarded a subsidy of 1 million euros to support the research projects with the aim of creating more employment and strengthen the local economy (Innovation Hub East Groningen, n.d. b).

6 What are framework conditions for such collaborations?

So after discussing developments in the transition towards a biobased circular economy, we can identify key framework conditions proven essential. It started with a shared vision and ambition. To shape this vision, time is needed as well as discussion and input from many stakeholders. Key framework conditions are the proximity of excellent knowledge centers, research and upscaling facilities, good coordination and connection between involved parties and available financing. The central role of existing and shared infrastructure was already discussed when describing developments in the context of energy efficiency and energy transition.

The University of Groningen (RUG) and the Hanze University of Applied Sciences both have a good international reputation and accomplished research groups concerned with chemistry, biorefinery and biotechnology. Notably, the RUG is among the top 100 worldwide and home to the Nobel prize winner in Chemistry in 2016 (University of Groningen, 2022). Moreover, they formed a collaborative for research regarding the bioeconomy region Northern Netherlands BERNN (Bio Economy Region Northern Netherlands, n.d.). The Stenden University of Applied Sciences has expertise in polymer chemistry and material science. Its ambition is to become a research hub for sustainable plastics for businesses in The Netherlands (NHL Stenden, n.d.). The

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

recently started Greenwise Campus in Emmen is focusing on closing the polymer loop (Greenwise Campus, 2022). Wetsus on the other hand has world-wide reputation for excellence in sustainable water technologies (Wetsus, 2022).

They bring value through academic knowledge and research in early TRL but also through the development of human capital on various education levels in the region. Skilled (international) workers that are bound to the region and can identify with sustainability goals of local businesses would be the ideal scenario fighting trends of urbanization and demographic changes.

The steps needed to bring an idea to a commercial product can be categorized as technology readiness levels (TRL). Levels entail basic technology research (1-2), research to prove feasibility (2-3), technology development (3-5), technology demonstration (5-6), system/subsystem development (6-8) and lastly, system test, launch and operation (9). For successful implementation, it is pivotal to be able to carry out research throughout these phases. The Northern Netherlands provides such research and upscaling facilities that are specialized in different research areas ranging from (bio)chemistry, renewable energy and hydrogen innovations, sustainable water technologies to polymer recycling (Chemport Europe, 2022a).

Highlighted here are the Zernike advanced processing facility (ZAP) and the Chemport Innovation Center (CIC). The ZAP facility can accommodate research projects regarding biomass valorisation and biobased chemistry on TRL 3-6. Notably, the earlier introduced start-up BioBTX is currently making use of ZAP facilities. It also takes in an educational role by organizing diverse events meaning to increase awareness for sustainability and green chemistry among students and researchers. For more mature projects, the Chemport Innovation Center (CIC) is the right address being located in the industrial area in Delfzijl. Here, start-ups can conduct research in the demonstration phase on TRL 6-8. Thereafter, CIC provides guidance for the transition towards market launch through its network, knowledge and permits. Finally, commercial scale can be organised and settled within the industrial areas in Delfzijl or Emmen.

In order to effectively stimulate the transition, the region established Chemport Europe. Chemport Europe describes itself as innovative ecosystem for chemicals and materials in the Northern Netherlands with a mission to accelerate the transition towards a biobased circular economy (Chemport Europe, 2022b). Founded by public and private partners, including the knowledge centers, it coordinates and schedules the activities in this field.

The organization Chemport Europe is divided in the pillars circular plastics, biomass, hydrogen and CO_2. The major key performance indicators of the ecosystem are reduction of CO_2 emissions, new economic activities (start-ups, new companies, additional investments of local companies) and employment. Furthermore, Chemport Europe assists with finding a suitable location and funding, has an extensive network of companies and offers help for growing businesses in the form of legal advice, marketing services, development programmes and permissions for processes. Chemport Europe bridges the public and the private sector by coordinating and initiating collaborations involving businesses across value chains, the government and knowledge centers. Indeed, it is seen as important to involve end-users where possible to avoid the pitfalls of a market push. As the name implies, while being rooted in the Northern Netherlands, creating links to European partners and international consortia is seen as imperative.

Summarising these different developments, an overview of currently available basic chemicals and biobased, renewable feedstocks from the energy and the agricultural sector as well as currently produced polymer materials/end-of-life plastics is given in Figure 2. With these platform chemicals and materials at hand, the biobased production of several other chemical building blocks can be envisioned and explored for profitable business cases. Some have been or are currently realized including the production of biobased aromatic compounds using either glycerol, low-value agricultural or plastic waste by BioBTX and are thus shown in the red block in Figure 2. Many more combinations are theoretically feasible and are listed in the yellow block in the figure below that have not been explicitly mentioned in the text.

After revising the status ten years ago and discuss current developments and regional success stories, another SWOT analysis is performed for the status of today.

Strengths of the Northern Netherlands for realizing the biobased circular economy lie within its knowledge centers that hold expertise in relevant research areas and educate the

JOURNAL OF
BUSINESS CHEMISTRY

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

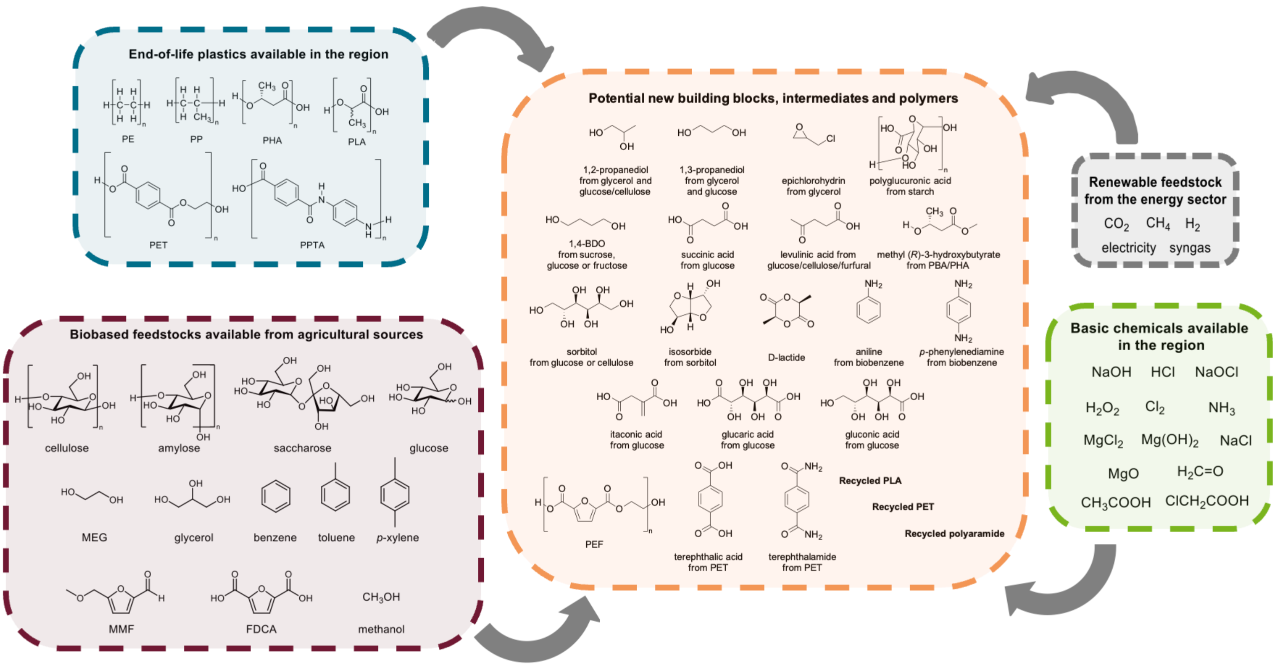

Figure 2 Synthesis of new propositions/high value chemicals from end-of-life plastics (blue), biomass (red), the energy sector (grey) and available reagents in the chemical clusters (green).

next generation of skilled workers. The agricultural heritage of the region as well as its expertise in gas production and trade can be carried over in the biobased circular economy keeping the links between sectors in mind. Undoubtedly, the chemical clusters Delfzijl and Emmen remain a strong side of the region. The elaborated flagship projects were developed from scratch within the region making use of the available research and upscaling facilities. These partially already led to the availability of biobased building blocks and intermediate for the chemical industry, inviting more valorisation routes and innovation. The clusters are well connected through Chemport Europe and linked to the public space. More strengths lie within the existing infrastructure for gas and electricity and logistics including harbours. Lastly, the availability of sufficient renewable energy is paramount for the future.

In terms of weaknesses, the share of renewables in the national energy mix to date is still relatively small (10.2% of the national primary energy demand in 2020) (Energie Beheer Nederland EBN, 2022). Visibility of the Northern Netherlands is an issue as headquarters of companies mostly are not located in the North. More entrepreneurs and skilled workers are needed to make the best use of the academic knowledge that lies at its doorsteps. Threats for the transition are delays and setbacks in the urgently needed expansion of renewable energy production and accommodation to its inherent volatility. These can be caused by enormous price fluctuations for oil and gas in the crisis-plagued energy markets and a potential restarting of gas extraction in Groningen.

Economic depression and unforeseen events (wars, pandemics) are serious threats as well. Moreover, lagging regulation can hinder good developments, for example regulations concerning waste management have to be adapted to enable its use as resource. Generally, with the progression of global warming extreme weather events will increase that will directly or indirectly affect The Netherlands.

Ending on a positive note, the North offers tremendous opportunities to realize the energy transition and the transition towards a biobased circular economy by close intersectoral collaboration and good use of available financing. The economic potential of such a transition should be reflected in larger employment and enhance the location`s attractivity for companies and people, while better education and academic research in the field will pay off in human capital later on. There is support from society for the circular transition and a shared, uniting ambition to meet the climate goals of the Paris Agreement.

JOURNAL OF
BUSINESS CHEMISTRY

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

Table 2 SWOT analysis of the Northern Netherlands in 2022.

Strengths	Weaknesses
⇨ Excellent knowledge centers ⇨ Expertise in chemistry, biotechnology and biorefinery ⇨ Expertise in recycling (Emmen) ⇨ Human Capital (students) from well-known institutes ⇨ Strong agricultural sector providing biomass and CO_2 ⇨ Chemical clusters Delfzijl and Emmen ⇨ Flagships projects all developed in the region (BioBTX, Paques Biomaterials, CuRe) ⇨ Accessibility of building blocks/intermediates ⇨ Well-organized, strong collaboration between private and public through Chemport Europe ⇨ Research and upscaling facilities (TRL 1-9) ⇨ Infrastructure and logistics ⇨ Access to renewable energy ⇨ Space	⇨ Visibility ⇨ Headquarters R&D of most companies not within the region ⇨ Not enough entrepreneurs ⇨ Valorisation of academic knowledge ⇨ Shortage of skilled labour for companies ⇨ Small share of renewable energy in the Dutch energy mix
Opportunities	**Threats**
⇨ Close collaboration of sectors (agriculture, energy, waste, chemistry) ⇨ Energy transition: hydrogen valley and offshore wind parks ⇨ Financing available to support the circular transition (subsidies) ⇨ Economic potential of the biobased circular transition ⇨ Substitute the employment previously active in gas mining activities ⇨ Increase attractivity of location for people and companies ⇨ Human Capital, educate the next generation of workers ⇨ Support from society for the circular transition ⇨ Meet the climate goals (CO_2 neutrality) ⇨ Increasing prices of CO_2 emissions (EU ETS) ⇨ Underground infrastructure that could be used for gas storage (i.e. salt caverns)	⇨ Unstable energy market ⇨ Unforeseen events (war, COVID, etc.) ⇨ Economic depression ⇨ Restarting the gas mining ⇨ Supply of renewable energy is growing slowly ⇨ Climate change: weather extremes, rising sea levels ⇨ Lagging regulation

JOURNAL OF
BUSINESS CHEMISTRY

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

7 Conclusion and Outlook

In recent years, several promising developments are coming forward in the Northern Netherlands giving hope for the chemical industry to overcome its fossil fuel addiction. Providing necessary infrastructure, logistics and expertise combined with access to renewable energy and feedstocks, the Northern Netherlands is an attractive location and partner for sustainably minded businesses and start-ups that aim to play a role in the biobased circular transition. Making use of upscaling facilities within a well connected ecosystem, available renewable building blocks and intermediate chemicals, entrepreneurs will find great inspiration and opportunities in the North to develop new combinations and grow together. That is, of course, only within planetary boundaries that respect the agreed upon environmental targets for 2030 and 2050 (European Commission, 2019). The authors strongly believe that there is huge potential and willingness of this region to become a forerunner and an ally for the transition towards a circular and biobased economy in Europe. With the omnipresent crises, it is more than ever necessary to work together across sectors and regions and not loose our focus on the reorganisation of our current unsustainable practises (Paulus, 2021).

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

References

Avantium. (2021): Technologies, available at https://www.avantium.com/technologies/, accessed 3 October 2022.

Bio Economy Region Northern Netherlands. (n.d.): BERNN, available at https://www.bernn.nl/, accessed 12 October 2022.

BioBTX. (n.d.): BioBTX - Leader in Renewable and Biobased Aromatics, available at https://biobtx.com/, accessed 6 October 2022.

Chemport Europe. (2020): Start of Europe's largest green hydrogen project, available at https://www.chemport.eu/news/article/north2/, accessed 13 October 2022.

Chemport Europe. (2022a): Research & Development facilities - Chemport Europe, available at https://www.chemport.eu/discover/ecosystem/research-facilities/, accessed 14 October 2022.

Chemport Europe. (2022b): We are Chemport Europe: Changing the nature of chemistry, available at https://www.chemport.eu/discover/about/who-we-are/Chemport, accessed 14 October 2022.

Clariter. (2022a): Technology – Clariter, available at https://clariter.com/solution/, accessed 28 October 2022.

Clariter. (2022b): State-of-the-art plant designed to process non-recyclable plastic waste into feedstock for chemical recycling operations of Clariter and BioBTX – Clariter, available at https://clariter.com/news/state-of-the-art-plant-designed-to-process-non-recyclable-plastic-waste-into-feedstock-for-chemical-recycling-operations-of-clariter-and-biobtxt/, accessed 28 October.

Clean Hydrogen Joint Undertaking. (2020): HEAVENN, available at https://www.clean-hydrogen.europa.eu/projects-repository/heavenn_en, accessed 9 October 2022.

Cleijne, H., de Ronde, M., Duvoort, M., de Kleuver, W., & Raadschelders, J. (2020): North Sea Energy Outlook (NEO), DNV GL, Arnhem, pp. 1-92.

CuRe Polyester Rejuvenation. (2022): About CuRe, available at https://curetechnology.com/about-cure-technology/, accessed 9 October 2022.

Energie Beheer Nederland EBN. (2022): Feiten en cijfers, available at https://www.energieinnederland.nl/feiten-en-cijfers/uitgebreid/, accessed 5 October 2022.

European Commission. (2018): Review of the 2012 European Bioeconomy Strategy, available at https://data.europa.eu/doi/10.2777/086770, accessed 1 December 2022.

European Commission. (2019): A European Green Deal, available at https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en, accessed 15 October 2022.

Escobar, N., & Laibach, N. (2021): Sustainability check for bio-based technologies: A review of process-based and life cycle approaches. Renewable and Sustainable Energy Reviews, 135 (110213), pp. 1-20.

Dutch Design Week. (2022): Exploring hemp, magnesium and potato starch - IHOG & Academie Minerva Groningen | Dutch Design Week, available at https://ddw.nl/en/programme/7863/exploring-hemp-magnesium-and-potato-starch, accessed 25 October 2022.

Fields, S. (n.d.): Heavenn - About, available at https://heavenn.org/about/, accessed 8 October 2022.

Frieden, F. (2021): Carbon Capture and Utilization – A new building block for Circular Economy?, Journal of Business Chemistry, 18 (3), pp. 80–95.

Gasunie. (2022): Gasunie starts construction of national hydrogen network in the Netherlands, available at https://www.gasunie.nl/en/news/gasunie-starts-construction-of-national-hydrogen-network-in-the-netherlands, accessed 1 December 2022.

Gielen, P. (2022): Paques bouwt PHA-extractie demofabriek in Emmen, available at https://www.agro-chemie.nl/nieuws/paques-bouwt-pha-extractie-demofabriek-in-emmen/, accessed 13 October 2022.

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

Greenwise Campus. (2022): Home, available at https://greenwisecampus.nl/, accessed 24 October 2022.

Groningen Seaports. (2022): Hydrogen - Hydrogen Backbone Delfzijl, available at https://www.groningen-seaports.com/en/hydrogen/, accessed 1 December 2022.

Heeres, H. J., & Heeres, A. (2017): Biobased opportunities voor de Eemsmondregio, available at https://www.chemport.eu/downloads/, accessed 27 September 2022.

HyWay 27. (2021): HyWay 27: realisation of a national hydrogen network, available at https://www.hyway27.nl/en/latest-news/hyway-27-realisation-of-a-national-hydrogen-network, accessed 1 December 2022.

Innovation Hub East Groningen IHOG. (n.d.-a): IHOG | Innovatiehub Oost-Groningen, available at https://ihog.nl/, accessed 5 October 2022.

Innovation Hub East Groningen IHOG. (n.d.-b): Projecten | IHOG, available at https://ihog.nl/projecten/, accessed 3 October 2022.

KPMG. (2022): Decarbonizing the chemical industry in Europe and beyond., available at https://home.kpmg/xx/en/home/insights/2022/11/decarbonizing-the-chemical-industry-in-europe-and-beyond.html, accessed 15 December 2022.

Krätzig, C. (2019): Der Klimawandel ist keine Glaubenssache., available at https://www.uni-hamburg.de/newsroom/im-fokus/2019/09-27-klimaleugner.html, accessed 1 December 2022.

Kupfer, M. (2016): Netherlands: 100% bio-based PET container for cosmetics. Renewable Carbon News, available at https://renewable-carbon.eu/news/netherlands-100-bio-based-pet-container-for-cosmetics/, accessed 10 October 2022.

Ministerie van Algemene Zaken. (2022): Afbouw gaswinning Groningen, available at https://www.rijksoverheid.nl/onderwerpen/gaswinning-in-groningen/afbouw-gaswinning-groningen, accessed 15 September 2022.

Ministerie van Economische Zaken en Klimaat. (2020): North Sea Energy Outlook establishes framework conditions for future growth of offshore wind energy, available at https://www.government.nl/latest/news/2020/12/04/north-sea-energy-outlook-establishes-framework-conditions-for-future-growth-of-offshore-wind-energy, accessed 23 October 2022.

Ministerie van Economische Zaken en Klimaat. (2022): Groningen gas field on the back burner in October, available at https://www.government.nl/latest/news/2022/06/20/groningen-gas-field-on-the-back-burner-in-october, accessed 1 December.

Nederlandse Aardolie Maatschappij NAM. (n.d.): English information, available at https://www.nam.nl/english-information.html, available at 5 October 2022.

Netherlands Enterprise Agency RVO. (2022): New Offshore Wind Energy Roadmap | RVO.nl, available at https://english.rvo.nl/information/offshore-wind-energy/new-offshore-wind-energy-roadmap, accessed 6 October 2022.

NHL Stenden. (n.d.): Circular Plastics | NHL Stenden, available at https://www.nhlstenden.com/en/research/circular-plastics, accessed 14 October 2022.

Paulus, J. (2021): Is the EU Green Deal channelling a transition towards a sustainable chemical industry?, Journal of Business Chemistry, 18 (3), pp. 96–104.

Paques Biomaterials. (n.d.): Biopolymers | Paques Biomaterials, available at https://www.paquesbiomaterials.nl/, accessed 15 October 2022.

Patermann, C. & Aguilar, A. (2018): The origins of the bioeconomy in the European Union. New Biotechnology, 40, pp. 20–24.

Photanol. (n.d.): Photanol, available at https://photanol.com/, accessed 15 October 2022.

Vol. 20, Iss.1, February 2023
URN: urn:nbn:de:hbz:6-11059727368
DOI: 10.17879/11059720490

Province of Groningen. (2020): The Northern Netherlands Hydrogen Investment Plan 2020, available at https://www.provinciegroningen.nl/fileadmin/user_upload/Documenten/Beleid_en_documenten/Documentenzoeker/Klimaat_en_energie/Energie_transitie/Investment_plan_Hydrogen_Northern_Netherlands_2020.pdf, accessed 10 October 2022.

Province of Groningen. (n.d.): Just Transition Fund, available at https://www.provinciegroningen.nl/subsidies/werken-en-ondernemen/just-transition-fund/, accessed 1 December 2022.

Recell Group BV. (2022): Recell I Greens entire supply chains | We extract cellulose from waste streams, available at https://recell.eu/, accessed 23 October 2022.

Willems, R. (2014): Chemiecluster op stoom - Actieplan chemiecluster Eemsdelta, Werkgroep versterking chemiecluster Eemsdelta, Groningen, pp. 1-24.

Teijin Aramid. (2021): Teijin proves ability to produce Twaron® from green raw materials, available at https://www.teijinaramid.com/en/insights/twaron-from-green-raw-materials/, accessed 23 October 2022.

ter Braak, S., & Smit, T. (2020): Saccharide Agenda, available at https://www.chemport.eu/downloads/, accessed 25 September 2022.

The International Welcome Center North IWCN. (2022): Facts & Figures The International Welcome Center North – IWCN, available at https://iwcn.nl/businesses/business-information/facts-figures/, accessed 5 October 2022.

United Nations Framework Convention on Climate Change. (n.d.): The Paris Agreement. United Nations Climate Change, available at https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, accessed 20 October 2022.

University of Groningen. (2022): Positie in internationale rankings, available at https://www.rug.nl/about-ug/profile/facts-and-figures/position-international-rankings, accessed 23 October 2022.

University of Groningen - Industry Relations Office. (2020): Green Industry Innovation Agenda, available at https://www.rug.nl/society-business/doing-research-together/industry-relations/innovation-agenda/greenindustry.pdf, accessed at 31 August 2022.

Water Energy Solutions. (2022): Cluster Energie Strategie 2022, Industrietafel Noord-Nederland, pp. 1-22.

Wetsus. (2022): About Wetsus, available at https://www.wetsus.nl/about-wetsus/, accessed 20 October 2022.

Yang, L., Wang, X. C., Dai, M., Chen, B., Qiao, Y., Deng, H., Zhang, D., Zhang, Y., Villas Bôas de Almeida, C. M., Chiu, A. S., Klemeš, J. J., & Wang, Y. (2021): Shifting from fossil-based economy to bio-based economy: Status quo, challenges, and prospects. Energy, 228 (120533), pp. 1-15.