PARIS IS NOT ENOUGH:

Groningen leads the world
(into a circular future)

Northern Back from the Future

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OUR TEAM

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Maria Murcia graduated from Chemical Engineering in Colombia where she grew up and lived until 5 years ago. She came to Europe awarded with an Erasmus Mundus excellence scholarship from the European Union, to complete a double master degree in Materials Science and Engineering. In France, she collaborated with studying materials for Solid oxide fuel cells in the National school of chemistry (Lille) and developing polymers for biomedical applications in the Laboratory of macromolecular physical chemistry (Nancy). After obtaining her masters diploma from the University of Lorraine (France) and Polytechnic University of Catalunya (Spain), she moved to the Netherlands to pursue a PhD at the UVA. Her current research in the group of Pr. Gert-Jan Gruter, focuses on studying polyesters derived from CO2.

Matthew Philips received his BSc degree in Chemical and Biomolecular Engineering, graduating with Highest Honors, from The Georgia Institute of Technology. After graduating, he worked for Liquid Light, a R&D company that spun out of Princeton University focusing on the electrochemical conversion of CO_2. He moved to the Netherlands and began working for Avantium in 2017 after the acquisition of Liquid Light. He is currently a guest PhD student at the University of Leiden under the supervision of Marc Koper.

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Introduction

The sea levels are rising, the earth gets warmer, the summers hotter and Greta Thunberg sails to New York. All that is connected to climate change and the Paris agreement which aims to avoid the latter. The long-term goal (by 2050) is to ensure that the increase in global average temperature stays well below 2 °C above pre-industrial levels.. However, these are not the only topics that dominate the headlines. There are whales and seagulls found dead with their stomachs full of plastic and it's snowing micro plastics in Antarctica. The economy faces a fourth revolution - called Industry 4.0 - leading philosophers and politicians to discuss basic income and the future of work. Business leaders around the world wonder how to sustain indefinite growth, whilst the gap between the rich and poor keeps increasing. All these problems are interconnected and affect our daily lives either now or in the future.

The province of Groningen wants to reach the ambitious goals set by the Netherlands for the reduction of CO_2 emissions. Several perspectives, such as the 'Industrie Agenda Eeemsdelta', define clear purposes and concrete requirements for the mid and long term future of the Chemport area. The region's potential to face the energy transition is undeniable: The Eemsdelta is located in an area with large agricultural activity, 2 seaports, around 150 companies and relevant knowledge institutions.

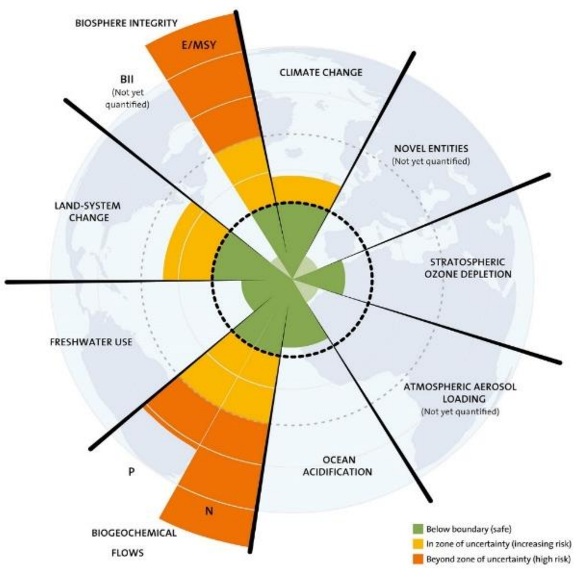
The chemical cluster Delfzijl has direct access to the North Sea, inland shipping, the motorway infrastructure of Northwest Europe and railroad [1]. Emmen, in nearby Drenthe, is specialized in the development and production of sustainable materials for the construction and infrastructure sectors. In addition, the region leads the fiber market in Europe. Overall, these regions are facing a great momentum in the push towards renewable energy transition and innovations connected to it. Increasing media coverage, recent elections for the new provincial coalition (6 seats for GroenLinks) and growing governmental initiatives are some events that confirm this.

The current perspectives fit well with a sustainable economic growth vision. However, some problems are not addressed sufficiently. Therefore, we developed a vision for the Chemport Europe area that addresses problems beyond economic growth and CO_2 reduction. We expand the scope of sustainability using a triple bottom line framework within which we aim for a circular economy. We aim to provide a vision that allows a world operated within the planetary boundaries. This involves a triple helix approach with joint effort from not only industries, government and knowledge institutions, but also society.

Triple bottom line framework

The triple bottom line is a three-dimensional concept in which sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality, and social equity [2]. We believe that integrating this perspective in Chemport Europe's vision is necessary for successful implementation of the circular economy model. The circular economy relies on a decoupling of material consumption and economic growth and aims to keep products, components and materials at their highest utility and value at all times [2] [3]. All activities should be executed within the planetary boundaries and thus respect environmental restrictions and thresholds. Global limits on environmental resources are shown in Figure 1. These should not be transgressed to prevent the occurrence of irreversible environmental changes [4,5]. This shows that sustainable policies are required to cover a wider scope and reach beyond lowering CO_2 emissions. Today the bulk of production processes are of a fossil or, at best, a green linear fashion.

By definition each material is a chemical. Therefore the chemical industry plays an important role in establishing a closed-loop system of materials: without circular chemistry, there cannot be a circular economy. The twelve principles of circular chemistry, shown in Figure 1b, will serve as the guideline for our vision [6].



1.Prevent waste. It is better to prevent waste than to treat or clean up waste after it has been created.

2.Maximize atom economy. Chemical processes should maximize incorporation of all materials used into the final product.

3.Less hazardous synthesis. Chemical processes should avoid using or producing substances toxic to humans and the environment.

4.Design benign chemicals. Chemicals should be designed to achieve their function while minimizing their toxicity.

5.Use safer solvents and auxiliaries. Auxiliary substances should be rendered redundant wherever possible and harmless when used.

6.Increase energy efficiency. Energy requirements of chemical processes should be minimized.

7.Use renewable feedstocks. A raw material or feedstock should be renewable rather than depleting.

8.Reduce chemical derivatives. Reduce generation of derivatives, since such chemical steps require more reagents and produce additional waste.

9.Use catalytic (versus stoichiometric) conditions. Using catalysts is preferable compared to using reagents in stoichiometric amounts.

10.Design for degradation. Chemical products should be designed to deteriorate after fulfilling a function without persisting in the environment

11.Real-time analysis for pollution prevention. Analytical methods allow in-process monitoring and control prior to the formation of hazardous substances.

12.Minimize potential for accidents. Substances used in a chemical process should be chosen to minimize the potential for accidents.

Figure 1a. Planetary boundaries. Stockholm Resilience Centre. Credit: J. Lokrantz/Azote based on Steffen et al. 2015. **1b**. The twelve principles of circular chemistry

Vision

We envision a circular economy which is driven by circular chemistry and stays within the planetary boundaries. We define and explain our vision in three subcategories to reach sustainability on an environmental, economic and social level, with a focus on areas we think are not included sufficiently enough in the current visions.

Economic Sustainability

Economic sustainability refers to practices that support long-term economic growth without negatively impacting social, environmental, and cultural aspects of the community. This includes actions to conserve resources rather than consuming them without replacement. There are several measures the companies and governmental bodies in the Eemsdelta region can pursue to ensure economic sustainability.

One focus for the companies in region should be to capture carbon dioxide emitted in high quantities from industries in the site and diversifying the products that are made from CO_2. Many products can be made electrochemically from CO_2, which we believe is a good fit due to the massive amount of renewable electricity in the area. However, the technology readiness level (TRL) for a lot of the products is low. Therefore, we recommend taking immediate action by building pilot plants to accelerate the development of these technologies.

Another focus for companies should be on ownership of the source of the renewable energy in the area. Green hydrogen is a great alternative fuel source to pursue because it is made electrochemically with only inputs of water and electricity. However, the price of the electricity is one of the most important economic drivers for electrochemical processes. Therefore, if the electrochemical producers own the source of renewable energy they will have electricity available at the cost of production rather than the market price. This could give a huge advantage to electrochemical processes in the area.

There are other focuses that companies should consider for the area as well: the development of business models which secure revenues on a more service or lease based level, the optimization of processes using big data (and building onsite data centers for this), and production plant integration to conserve energy through wider heat exchanger networks. Furthermore, government officials can push for new legislation to aid in making these circular developments. This includes providing a tax break for companies consuming CO_2, subsidizing differences between renewable and non-renewable electricity, and introducing a bottle or packaging deposit scheme where consumers rent rather than buy bottles and packaging.

Social Sustainability

Social sustainability is a process for creating sustainable success that promotes well-being by understanding people's needs from the places they live and work. Socially sustainable communities are equitable, diverse, connected, democratic and provide a good quality of life. For companies, this results in high public acceptance of their activities and qualified and motivated workers.

The establishment of new windfarms and solar parks are key to the circular economy in the region. However, onshore windfarms and new chemical companies are not specifically welcome in the province of Groningen [7]. Social acceptance of new developments can usually be increased when people can directly derive personal benefits and feel like they are part of these new developments. Several forms of inclusion are available, such as public or workers ownership programs and secured supply conditions for basic amenities like heat, electricity and water. The local population can be included by offering possibilities to invest in a fund which is used to build new revenue creating operations such as wind parks or chemical production lines. This form of public private funding and investment also provides a new option for retirement security on a local basis.

Job security and opportunities as well as the mismatch between the required and existing education of workers should be carefully considered for the future of the region. Planned digitalization of industrial activities is projected to cause a drastic change in the working world where many activities that are currently performed by humans will be automated. Hence many jobs will be lost whilst new jobs might be created in different fields. Schemes to train people for new jobs can help to make this transition smoother. Furthermore, introducing manufacturing with more labor intensive production creates new value chains and additional jobs.

The earthquakes affecting houses in the region make people reluctant to support activities involving underground gas recovery and potentially storage. New plans to use the empty reservoirs to store CO_2 or even hydrogen should be reconsidered. The same goes with the use of geothermal energy, which requires drilling and has shown similar destructive effects on buildings elsewhere.

Lastly, people's well-being is strongly determined by the environment they live in. It is thus desirable to ensure and further reduce day-to-day pollution levels for air, water and land in both commercial and residential areas. This is where social sustainability is strongly interconnected with environmental sustainability.

Environmental Sustainability

Environmental sustainability involves the responsible interaction with the environment to avoid depletion or degradation of natural resources and allows for long-term environmental quality. In a circular sustainable future it is imperative to reduce uncirculated waste and preserve the materials and their building blocks. It is fundamental to change consumption patterns and develop new recycling strategies for existing materials. Equally, producers need to take responsibility for end-of-life of their products.

Although we separate plastic from other waste, only around 10 percent is actually recycled. The remaining 90 percent is incinerated, landfilled or pollutes the environment, most prominently the oceans. This issue, without action, is bound to become worse considering that plastic production is expected to double in the next 20 years according to the world economic forum [8]. A circular chemical process must integrate the use of new sustainable materials and address the plastic pollution problem together with the energy challenges. Plastic should be designed for reusability and derived from carbon 'above ground', meaning biomass, CO_2 or chemically recycled feedstock. This is particularly relevant since the Chemical Cluster Emmen possesses well-developed companies that produce polyesters, aramid, polyamides, composites and other specialty chemicals.

Eutrophication in local water bodies, river systems and oceans is a problem for the farming rich provinces. After its use as fertilizer, animal feed or food, large portions of the fixated nitrogen and phosphorus are lost to the environment, where they get highly diluted. The nutrients can be recovered in wastewater treatment plants or manure incinerators. However, they are considered as waste instead of feedstock; their recovery is not mandatory and only low value products are obtained. Legislative action can change this situation and stimulate the development of new recovery processes which should be tested on site.

Key focus areas

In the following scheme we show a detailed vision where the triple bottom line was integrated with the existing plans for the Chemport activities. The new additions to improve circularity are highlighted in yellow. To introduce some more hands on improvements we took six key focus areas which we turned circular.


Recycling network
Farmers
Food & feedstock
Wastewater treatment
Gas station
People as workers, consumers, investors
Society
LOHC
Liquefaction
MCA
HCl
Fertilizers & feed
P salts
NedMag
AkzoNobel
Acetic acid
Manure incineration
Mg salts
H_2O_2
Oxalic acid
CH_4
CO_2
BioMCN
MeOH
Chemicals for market
Public transport
Polymers for market
RePeat
Susphos
Cl_2
NaOH
Evonik
Char
Gluconic acid
Levulinic acid
ChemCom
Manure ash
Struvite
AkzoNobel
H_2
O_2
?
CCtop
Syngas
MEG
PDO
Sorbitol
Polymers
Manufacturing
Consumer products
Formate
Gasification
Aniline
Cl_2
Economy
Salt
Electrolysis
CO_2 electrolysis
Terephtalic acid
Biocoal
Mekong
Teijin
PTA
C_5/C_6
Glucose
?
BioBTX
?
ECH
PDO
MEG
HMF
CO_2
CO_2 from air
Energy storage
IT - cluster
Knowledge hub
Biomass
Torrefaction
Zambezi
HCl
Lignine
Benzene
Xylene
Bio-oil
Various
Monomers
Pyrolysis
Glycerine
2,5-FDCA
Polyglucoronate
NaClO
Ligno cellulose
Polymer recycling
Fructose
?
DGR
Integrated Pilot park
Used polymers
Crude Glycerine
Biorefinery
Environment
Plastic waste from ocean cleanup
Beets
Starch / Cellulose
offshore windparks
CHEMPORT EUROPE

CO_2 source and product diversification

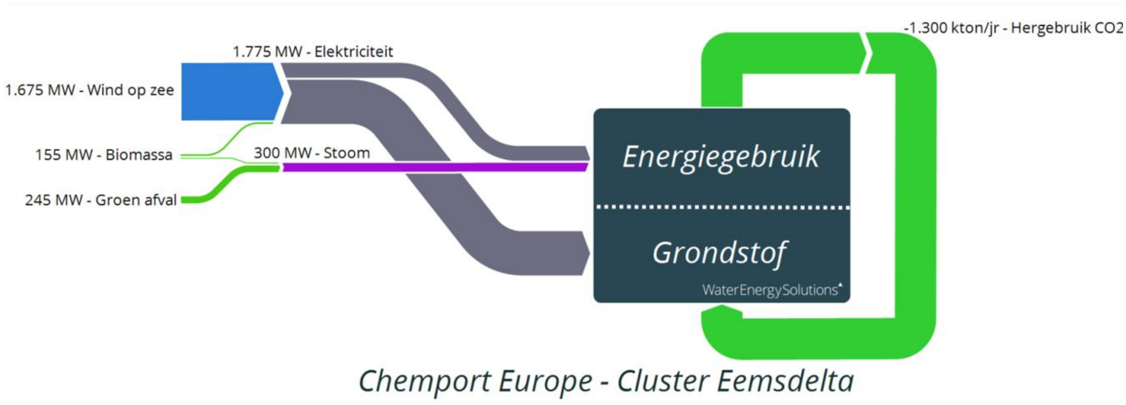


Figure 2. The expected situation in 2050

We see the CO_2 stream in the region is generated from inputs of biomass, as shown in Figure 2. In this concept, there is an accumulation of CO_2, unless some of the CO_2 is released, some of the methanol that is produced is sold, or some of the methanol is used in another process. These options do not seem to be the best. For example, if everyone started making methanol from CO_2 and selling it, the market would become oversaturated causing the price to drop which would directly impact the economics of the process.

We believe using the CO_2 to make products with a longer lifetime will have a larger impact on the environment. Therefore, we recommend diversifying the products that are made from CO_2 rather than focusing solely on methanol. There are several technologies that seem promising today to do this electrochemically, which we think would fit well with the vast amount of renewable energy that is envisioned to be available in the region. Figure 3 shows some of the possible chemicals that can be made from CO_2 electrochemically [9].

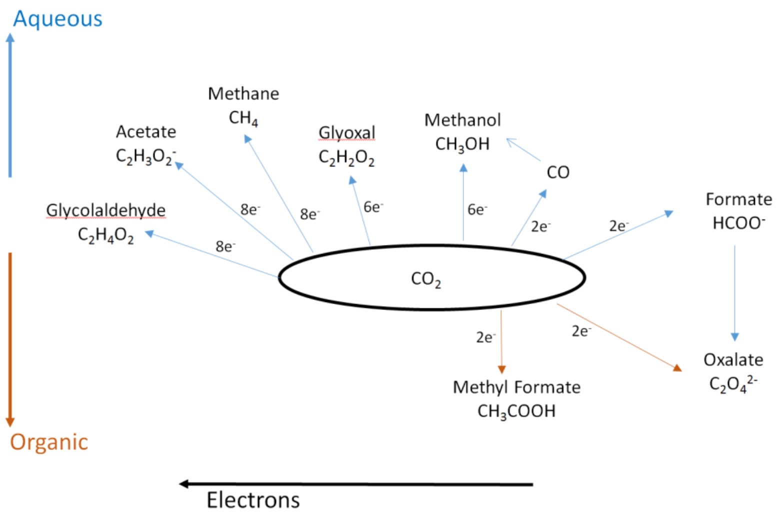


Figure 3. possible chemicals derived electrochemically from CO_2

Although there are many products possible from electrochemical reduction of CO_2, recent papers conclude that CO and formate are currently the most economically viable products to pursue [10–13]. Therefore, we recommend trying to achieve a pilot plant with these technologies in the next 5 years. This would allow for the technology to adequately develop to a scale for fitting into the 2050 goal. Furthermore, the growth in the technology for these two products could potentially help make other electrochemical routes more economically feasible for 2050.

Avantium, a company with 2 Pilot Plants in Delfzijl, can make CO or formate from CO_2 electrochemically at high rates with high selectivity using a gas diffusion electrode. This formate can then be converted into many valuable chemicals such as glycolic acid, glyoxalic acid, and ethylene glycol, products that have synergy with chemical companies in the region. USA based Dioxide Materials also uses a gas diffusion electrode to electrochemically convert CO_2 to CO at high rates with high selectivity [14].

Additionally, for the consideration of circularity, this scheme proposes to use CO_2 made from burning biomass, however, we recommend the additional capture from industries in the site such as Eneco, Nouryon. As result of their processes, high concentrations of CO_2 are available. We also suggest the capture and use of CO_2 from air. This would allow the region to have a much higher impact on the environment and could offset CO_2 that is imported into the region (e.g. CO_2 produced from production of commodities) and organic chemicals exported from the region. Climeworks and Skytree are two European companies that are developing technology for direct CO_2 capture from air. Amsterdam based Skytree is currently working with Gensoric on a CO_2 to methanol process [15]. While Climeworks is an Avantium partner in a EU subsidy, Celbicon, partially focusses on converting captured CO_2 to CO [16].

In order to convince policy makers to put restrictions on non-sustainable energy sources, processes or materials, or to subsidize sustainable processes it is very important to provide sustainable alternatives. In order to do this, significant investments are required to develop and prove sustainable technologies.

Source of energy

Although there is a lot of renewable energy in the Eemsdelta region, the ownership of the sources and the way the sources are connected with the grid, should be carefully considered for economic sustainability. If the renewable energy sources are not owned internally, and the energy is purchased from a separate party from the grid, then the electricity price will be higher than in a separated or internally owned system. This is because the energy providers have no incentive or reason to sell their energy at the cost of its production. This is an important factor to consider because the price of energy is a major economic driver for electrochemical processes and will directly impact the cost of producing green hydrogen and chemicals from CO_2. Therefore, we recommend either developing a separated renewable energy system which also consists of onsite energy storage for maintaining the supply of energy at peak and off-peak hours, or lobbying for a financial incentive (refund, tax break, etc) when electricity is used in the region for electrochemical processes. The Eneco-Google partnership for green solar energy from Sunport Delfzijl is a good example.

We believe research and development in an energy storage system for the chemical plants in the region should begin as soon as possible. There are several methods that currently seem promising to do this. Tesla has demonstrated a 80MWh battery system in Ontario California

[17]. A 12 MWh vanadium flow battery has been demonstrated in Donegal, Ireland by VRB Power Systems Inc [18]. Additionally, bromine batteries are a little less developed but seem to be a promising technology for the future [19].

We think a way to incorporate the people in the region, in terms of owning a dedicated renewable energy source for the area, would be to include the option for local people to invest in the capital costs associated with the construction and maintenance costs of the windmills in some sort of pension plan. Giving the people an opportunity to invest could also ease concerns of windmills appearing closer to their home. Furthermore, it would allow people to also receive a benefit from this project.

Hydrogen as fuel

The use of hydrogen as a fuel is not a new idea and many of the major car and truck producers developed hydrogen powered engine systems. It could moreover bring an end to the use of heavily polluting shipping fuel [20]. Apart from smaller companies, Toyota and Hyundai already released passenger cars and trucks. Other companies, such as Mercedes Benz, Volkswagen and BMW, whom worked on hydrogen cars since the mid-1990s and had shut down their test fleets – the main reason being the lack of hydrogen fuel stations and hype of battery-electric cars – now entered the game again [21]. Even China's father of electric cars says hydrogen is the future [22]. The Delfzijl region already has 20 hydrogen powered buses [23].

Although battery-electric cars are a good solution for short distances, hydrogen has big advantages on the longer range and higher load applications [24]. In Switzerland, H2 Energy has shown that a concerted effort of fuel station operators, hydrogen producers, trucking companies and truck producers, as well as the regulative bodies, can stimulate the introduction of a hydrogen distribution network simultaneously with the introduction of hydrogen-fueled vehicles. To promote hydrogen fueled transport in the Netherlands we suggest going forward in a similar way and create a market for hydrogen in the future. There are many benefits in this case: residents are relieved from toxic fuel exhausts, no CO_2 is emitted in the process whilst long distances (at least till Switzerland) can be covered and the production of hydrogen as fuel becomes economically viable. Legislative incentives, such as a hydrogen car subsidy or a taxing of fossil fuels, can also aid in this effort.

Although hydrogen fuel technology is becoming more mature, it still has some drawbacks. If hydrogen is used as a fuel directly, its storage in compressed liquid form is more difficult and losses through evaporation are relatively high [25]. This requires extensive safety equipment – storage is much more complicated than a simple gas-tank in gasoline or diesel driven cars. However, new technologies are also available, such as the LOHC technologies from the German company Hydrogenious and Arnhem based HyGEAR B.V. Their approach is to make handling of hydrogen easy by storing it in a chemical carrier [26,27]. At the hydrogen production site the hydrogen is loaded on a carrier and released on the consumption side. Loading and unloading use a catalytic process and losses are only 3kWh/kg of hydrogen compared to 6.4kWh/kg required to liquefy hydrogen and transport it in its molecular form [28]. The carrier itself can be reused multiple times. The carrier is non-toxic and not classified as a dangerous good. Multi-month storage without any losses is possible, whilst hydrogen in its pure form evaporates from the tank within days [25,29,30].
The state of the art allows for high-capacity hydrogen handling and can use existing fuel infrastructure, which reduces cost to scale out. Industrial hydrogen distribution without the

need of pipelines is feasible and at the same time more efficient and safe. This way a greater market for hydrogen from the Eemsdelta can be reached as it can link hydrogen production and hydrogen consumption sites in a flexible and simple way at low cost. It furthermore can be ideally integrated in the local industrial heat exchange system, which would further benefit the loading and unloading economics [31,32].

Nutrient recovery

In the north of Holland the farming industry is involved in some important unclosed circles which are connected to farming and food consumption. Parts of the nutrients get even exported at high cost together with the manure surpluses caused by intensive farming [33]. Not only the waste but also the production of Nitrogen and Phosphorus containing materials is problematic. Nitrogen can be fixed as ammonia from air with the Haber-Bosch process but is very energy intensive and accounts for 1.2% of world energy consumption [34,35]. Therefore, a re-use of ammonia is desirable to decrease the energy consumption (and CO_2 emissions). Other than nitrogen, phosphorus is not available in its elementary form but can be obtained from the finite source phosphate rock. None of this primary source is located in the EU but mainly in Morocco, China and the US – creating high dependencies for secure food production [36]. Wastewater treatment plants and manure incineration facilities are the best place to recover nutrients in farming rich regions [37]. Precipitation to struvite crystals is the most applied method to recover ammonia and phosphates from wastewater [38,39].

However, struvite precipitation is expensive and not circular yet as it is mostly landfilled [40]. It is not accepted by farmers as a fertilizer and can be used for little else. Thus, regeneration and further processing to recover the magnesium, phosphoric acid and ammonia and process these to valuable chemicals is desired.

A suitable process at pilot scale in the North of the Netherlands is being developed by Amsterdam based SusPhos company (Figure 4). Unlike most other P-recovery technologies, the products of the SusPhos process are not limited to the fertilizer industry, but have applications in higher value markets, such as flame retardants, ceramics and feed additives.

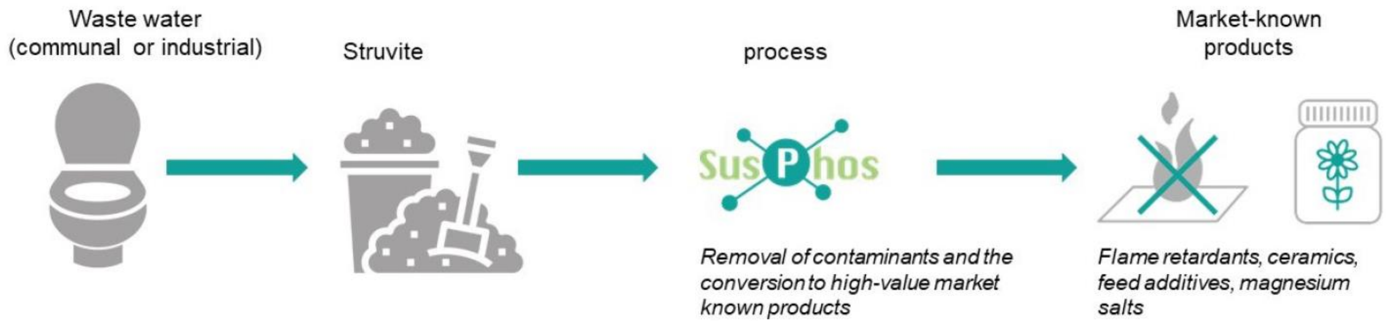


Figure 4. Susphos process from wastewater via struvite to market known products

For recovery from manure struvite precipitation is not suitable. However, researchers at the WUR developed the RePeat process which relies on an acid-base approach and was successfully tested on pilot scale at Groot Zevert [33,41].

NedMag from Veendam, the world's main supplier of Magnesium salts for various applications, could be another important partner. Recovered magnesium salts could fit well in their portfolio and reduce the amount of mining activities which are often seen with a skeptical eye by the local population. Other local parties are the starch-potato cooperative Avebe from Veendam which seeks to improve their nutrient recycling in their process.

A more circular process where Nitrogen and Phosphorus are recovered locally can thus reduce energy consumption in the production process and reduce the reliance on mines outside the European Union. We believe that the Eemsdelta and the Groningen region should receive financial incentives for closing these circles, as it can relieve pressure on the local environment and industries – chemistry, farming and food producers. Although various recovery technologies are available, they still need optimization and better integration for which we think the Eemsdelta can be an ideal place. Succesful implementation will require a region wide framework with cooperation between waterbodies and farmers, as well as governmental regulations that require the recovery of these nutrients and consider its sources a feedstock rather than waste.

Renewable polymers

The plastics industry plays an important role in society and certainly also in the Chemport Europe area. Carbon emissions emerge at multiple stages of the plastic lifecycle: production, distribution and disposal (e.g. incineration, decomposition). In addition to this, almost all plastics (99%) currently available in the market are fossil based. In the Netherlands, 8 million tons of plastics are produced annually. The recycling of a part of these materials only extends the "residence time" of carbon in these materials. Eventually, in the absence of landfill, all materials end up as CO_2 after incineration. Incinerating 8 million tons of plastics, results in 20 million tons of CO_2 emissions for the Netherlands alone, which is unacceptable in a carbon neutral scenario.

Taking action on the plastic pollution problem and to a further developing the need for more sustainable materials, should not only involve industries. A shift in consumer mindsets and behavior patterns is required. For this, an inclusive strategy where everyone can make part of the transition can start by reinforcing governmental campaigns (via social media, TV, campaigns at schools, etc) to promote plastic consumption in a different way; this is, prioritizing products and services designed for reuse (=cleaning instead of recycling). In other words, applying the waste hierarchy order of preference: avoid-reuse-recycle before incineration or landfill. Plastic packaging is the major plastic waste generator. Therefore, initiatives such as increasing the amount of public water fountains, the quantity and variety of dispensers in the supermarkets (already existent for nuts and cereals for example), encourage reuse and diminish the need for new single use plastic. In the EU, a ban on single use packaging has been accepted.

New technologies for recycling and production of sustainable plastics are being developed in the region. Emmen contains two important recycling facilities: Morssinkhof Sustainable Products and Cumapol. They recycle PET, the most common plastic used in packaging for bottle, trays, etc. Morssinkhof has successfully developed a technology for mechanical recycling of PET. However, this method leaves a lot of polyester waste unused (e.g heavy colored and non-food contact approved plastic) .

Recently, an emergent new recycling technology: CuRe, has been introduced by Cumapol and will be developed in the upcoming 2 years at their new pilot plant in partnership with DSM-Niaga, Morssinkhof, DuFor and NHL Stenden. CuRe (Figure 5) is based on the depolymerization of PET using glycol, and it would allow recycling mixed and colored PET. With this, polyester that is usually incinerated or landfilled could be recycled into its constituent monomers for new PET production and the glycol used for such process can be recovered and reused.

Avantium is constructing a new demonstration plant in Delfzijl for the production of bio-based mono-ethylene glycol (MEG) directly from renewable sugars. The site is expected to start operating this year and would signify a source of renewable ethylene glycol feedstock within the Chemport Europe for the depolymerization process of Cumapol.

Furthermore, BioBTX (Groningen) recently opened a pilot plant to develop their process for converting biomass to aromatic compounds though which biobased terephthalic acid can be obtained. The latter, is one of the constituent monomers for PET production. Strengthening the cooperation between the aforementioned companies can lead towards a closed loop recycling process for the production of sustainable new polyester from recycled feedstock.

Offering new subsidies and grants and providing governmental incentives would help in accelerating the development of these technologies and support emerging research in plastic recycling. The success of these new strategies will also rely on effective systems for collection of plastic waste. In this regard, the already established deposit scheme offered by the supermarkets works well, but a lot of plastic waste still remains without being collected. The municipality can contribute by creating committees in different neighborhoods to pick up plastic waste directly from homes and take it to the collection points.

Another relevant polymer manufacturer in the area is Tejin, which produces aramid fiber. Currently, they have a system with collection points for the material, which is later recycled in Emmen by converting it into a pulp (Twaron Eco) used for asbestos replacement in high-tech applications. In this case, new subsidies and grants would be valuable for research on the diversification of aramid waste.

Figure 5. CuRe technology pathway

Pilot scale matching

With the emerging technologies in the Chemport Europe area, implementing a new strategy for pilot scale process development will be necessary. Otherwise, it will be difficult to maintain a good production flow in loops where some processes rely on side streams or products from another processes in the pilot park. For this, a committee of onsite engineers could be appointed to support, advice and monitor to allow that technologies are developed in a compatible way.

As part of this, each company would provide to the committee relevant aspects of their production, such as schedules, strategies, milestones and deadlines. This information could be shared via internal networks (e.g. shared portal for all companies in the cluster and an additional shared portal for the ones that are involved in the same loop). Other roles beyond process integration would include process validation and evaluation of the scalability of new production models on the site. A key aspect for successful development of the pilot park will be flexible operation. This will be facilitated by digitalization of the industry. Moreover, this coherent growth should not only involve the pilot park. In order to successfully drive the chemical clusters and the region towards a more circular operation, the scale-up and development of the already existing industries in the site must also progress simultaneously. It therefore makes sense to align the timelines of different processes, which could even involve different parties. In line with this view, it could be beneficial to actively scout for companies that fit the vision and timelines of parties involved in EuroChemport to set up shop in Delfzijl.

Concluding remarks

The vision described by the Eemsdelta presents well defined goals for the mid- (2030) and long-term (2050). Although the proposed pathway fits very well with their vision, we believe that it is very centered on economic growth and does not acknowledge sufficiently the environmental and social sustainability. As a complementary vision, we suggest to apply the triple bottom line approach, to drive their pursuit of circular economy in the region.

Simultaneous and coherent growth and scale-up will be necessary for successful development of the new technologies in the chemical clusters. For this, a stepwise approach will be required where different elements are organized at the same time. Development of the hydrogen economy, the green electricity market, the biobased market for example, must be done in a cooperative and simultaneous way. In other words, prioritizing innovation and scale-up on value chain bases.

Moreover, the biggest potential for hydrogen is as industrial feedstock. Therefore, the scale up of hydrogen production must be prioritized before moving in to accelerating development in the mobility sector because the availability of green hydrogen will stimulate other sectors to implement it in their technologies.

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