



# TOWARDS A NEW CARBON-NEUTRAL ECONOMY IN THE GHENT AREA OF NORTH SEA PORT

**EXPLORATORY STUDY**  
for the development of carbon capture & utilisation  
for the Ghent area of North Sea Port

November 2019

# P R E F A C E



On 18 May 2016, the City of Ghent, Ghent University, North Sea Port, the Province of East Flanders, the POM (Provincial Development Agency) East Flanders and Cleantech Flanders signed the 'Commitment Declaration Cleantech Cluster Ghent Region'. The ambition is to excel as an active and robust cleantech ecosystem by 2030, in response to challenges in the field of energy, materials, water and mobility. From the outset, the reduction of industrial and urban CO<sub>2</sub> emissions was also defined as a challenge. The development of a Carbon Capture and Utility Hub (CCU hub) in Ghent contributes to tackling this challenge. In the summer of 2018, a unique consortium was set up with the ambition to transform the Ghent area of North Sea Port into a hub for carbon capture and reuse (Carbon Capture & Utilization (CCU)).

Following the initiative of the University of Ghent (CAPTURE) and the Bio Base Europe Pilot Plant (BBEPP), large local companies met with the City of Ghent, the Province of East Flanders, the POM East Flanders, North Sea Port, Cleantech Flanders and the spearhead clusters Catalisti (Chemistry and Plastics) and Flux50 (Energy).

In September 2018 a steering committee was set up which, with the financial support of the City of Ghent and the POM East Flanders, appointed an expert to carry out a technical preliminary study. The results of the study were presented during an event on 11 January 2019, to more than 40 participants from interested companies, policy bodies, investors and knowledge institutions.

The initiators believe this study will be the start of follow-up actions in the field of investment, scientific-technical innovations and policy. This report entails the results of this study with the aim to further inform companies, policy authorities, knowledge institutions and investors.

After the **1** Summary and **2** Introduction on climate challenges and energy transition, we dive into the concrete content: **3** Importance of CCU in the transition, **4** CCU production processes in Ghent, **5** Integrating production processes according to a circular model, **6** Cost/revenue model, and to conclude: **7** Conclusions and recommendations.

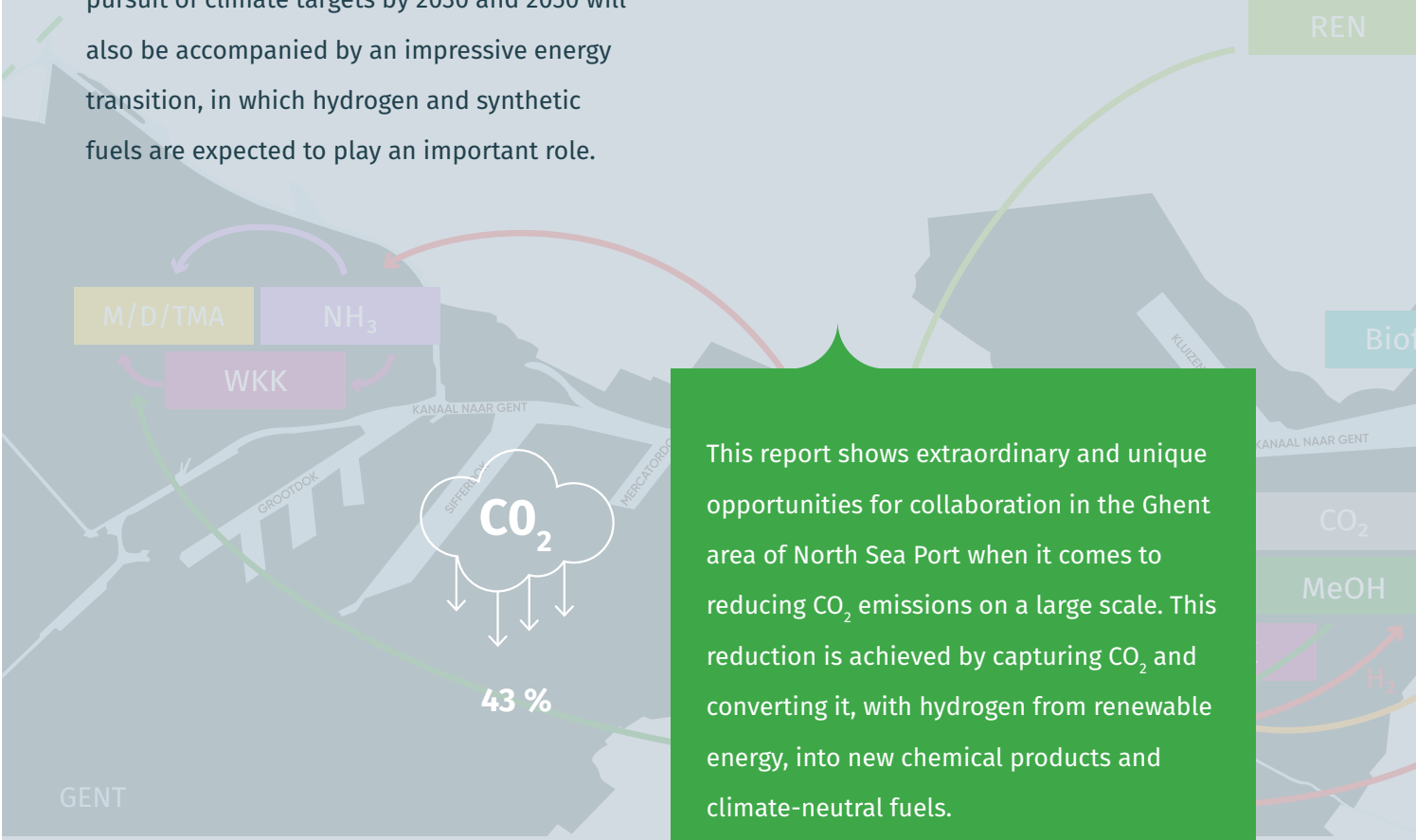
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# Summary

The companies included in the EU Emissions Trading System (ETS) face enormous challenges with respect to achieving the European climate and energy objectives for 2030. More specifically, reducing emissions by 43 % compared to 2005.

For these companies, CO<sub>2</sub> Capture and Utilisation (CCU) will play a major role. The pursuit of climate targets by 2030 and 2050 will also be accompanied by an impressive energy transition, in which hydrogen and synthetic fuels are expected to play an important role.



This report shows extraordinary and unique opportunities for collaboration in the Ghent area of North Sea Port when it comes to reducing CO<sub>2</sub> emissions on a large scale. This reduction is achieved by capturing CO<sub>2</sub> and converting it, with hydrogen from renewable energy, into new chemical products and climate-neutral fuels.

The development of the CCU strategy presented in this report can lead to the construction of four production units that will be optimally integrated because of location choice and available interconnections (via, for example, pipelines): **(1)** the production of hydrogen/oxygen (electrolysis), **(2)** the capture of carbon dioxide, **(3)** the production of methanol and **(4)** the production of ammonia. The production of formic acid can be added later. The further development of a circular model is achieved by dimensioning the heat requirements and valorising the oxygen by-product from the electrolysis.

The construction of the 4 production units by the energy, steel and chemical industries estimated to be a total investment of around € 500 million. <sup>(1)</sup>

The overall result is an equivalent reduction in CO<sub>2</sub> emissions of at least 647,000 tons per year. <sup>(2)</sup> At a later stage this can amount to more than 1 million tons.

An initial cost/benefit analysis shows that the costs for production, storage, compression and transport of 'green' hydrogen (as raw material for the local production of 'green' methanol) determine the production cost.

A temporary subsidy to bridge the difference between production cost and market price will be necessary for the industrial realization of the CCU strategy in the Ghent area of North Sea Port.

The development of an excellent CCU hub with new value chains is an ambitious and long-term process during which all stakeholders must work together.

**The exploratory study has shown that the supply side has a sufficiently large scale to be feasible. Due to the higher production costs, compared to current market prices for products of fossil origin, the green C products cannot yet compete and these economic constraints will have to be compensated temporarily until the CCU reaches a sufficiently large scale and has gone through a learning curve.**

(1) These data and analysis are based on an exploratory study in which the partners believe that the results are encouraging enough to further deepen and validate the work.

(2) See footnote 1.



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## Challenges & energy transition

As in all industrial zones around the world, economic activity in the Ghent area of North Sea Port is based on raw fossil materials and fuels, used in large quantities for heating, process heating, as a raw material in several chemical processes or as fuel for ships, trains, trucks, buses and passenger cars. These release large amounts of CO<sub>2</sub> and other harmful emissions (SO<sub>x</sub>, NO<sub>x</sub>, particulate matter, etc.).

For a number of industries, such as the steel industry, CO<sub>2</sub> emissions cannot be avoided since their production is intrinsically linked to chemical reactions of industrial processes used.

**IT IS A MAJOR CHALLENGE TO BECOME LESS DEPENDENT ON RAW FOSSIL MATERIALS AND FUELS.**



The European 2030 climate and energy framework defined 3 main goals to be achieved by 2030:

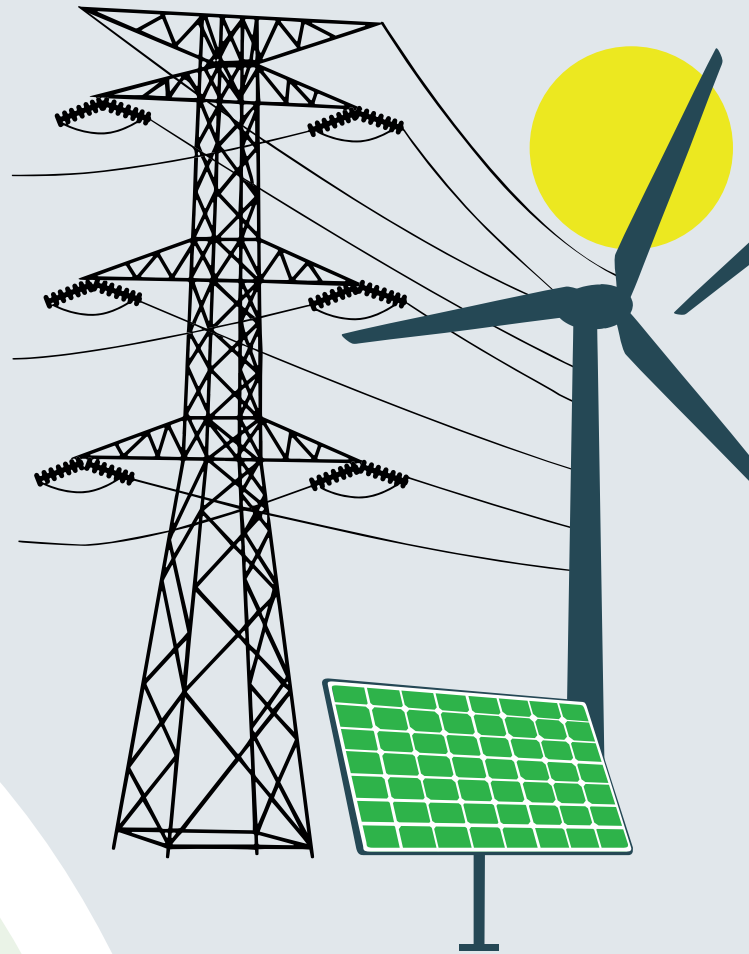
1. **a 40 % reduction in greenhouse gas emissions compared to 1990 levels. To achieve this 40 % target, the ETS (Emissions Trading System) will be adjusted for ETS sectors that must reduce their emissions by 43 % compared to 2005;**
2. **27 % share of renewable energy;**
3. **at least 27 % improvement in energy efficiency.**

The pursuit of climate targets by 2030 and 2050 will be accompanied by an impressive energy transition, both for the generation of energy from renewable energy sources, and for the increasing electricity needs of society, including industry.

Generating renewable energy usually means generating electricity from natural sources (wind, sun, geothermal, hydropower, etc.). However, these are largely unpredictable, and cause problems with respect to network management and energy storage. Global research is therefore being carried out to identify suitable energy carriers that can deal with these problems, such as batteries, but also (green) hydrogen and synthetic fuels.

Green hydrogen can be produced on a large scale, through the electrolysis of water, with electric power from renewable energy sources.

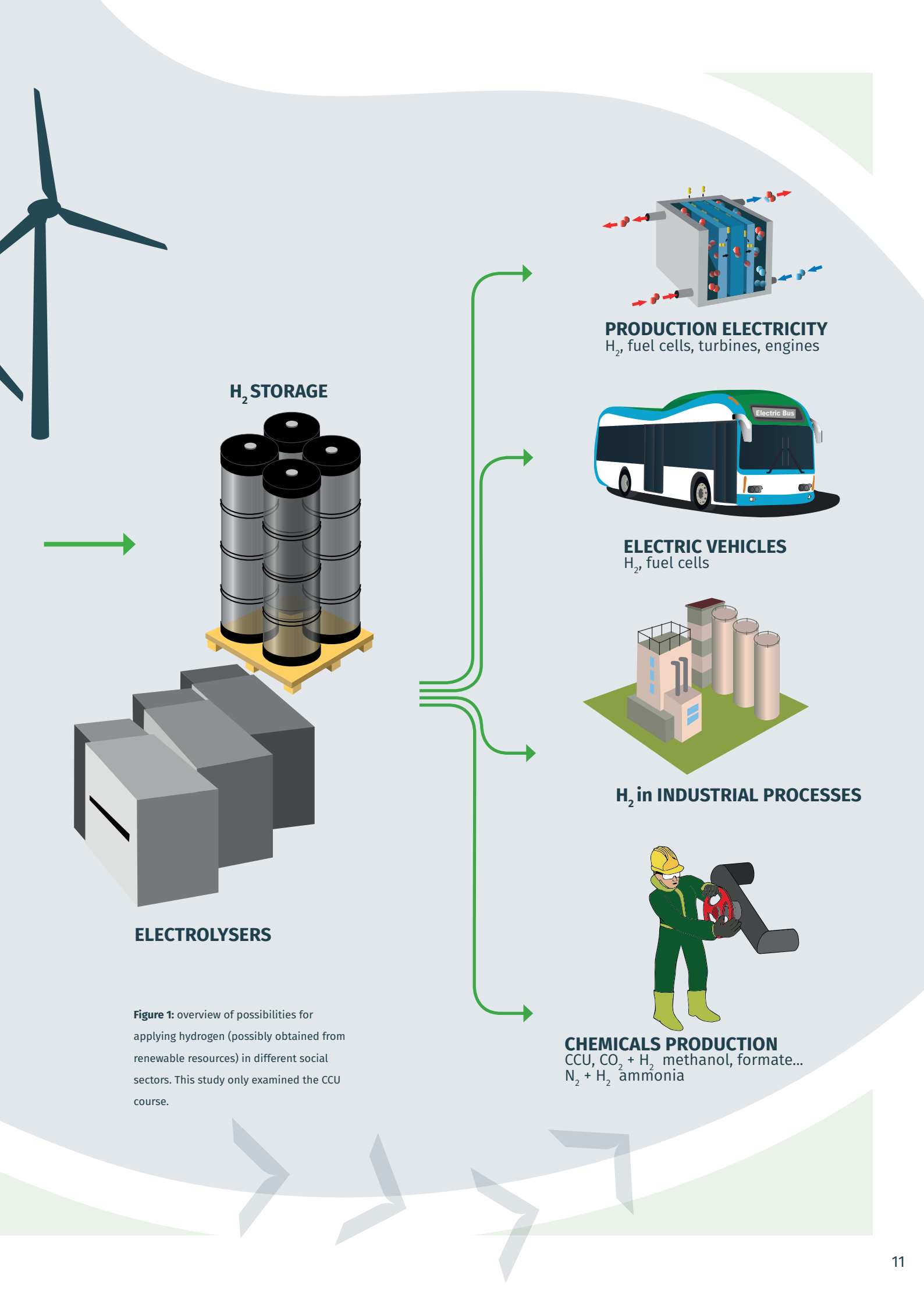
Hydrogen can be stored relatively easily, and is therefore a means to store wind and solar energy, which is naturally available in an unpredictable way.



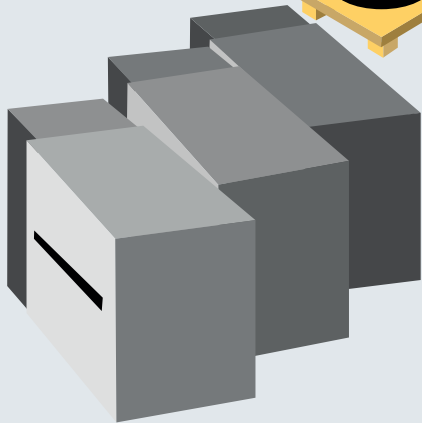
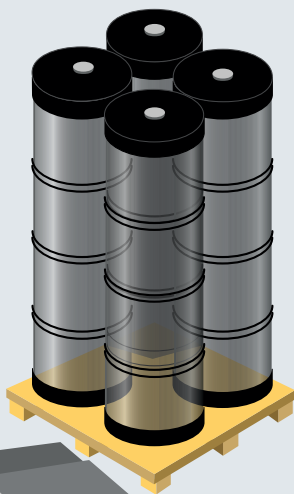
Hydrogen is a universal product that serves as a climate-neutral resource and fuel in various applications. **(see also Figure 1)**

- Electricity generation, when there is insufficient wind or solar energy available;
- The propulsion of vehicles: ships, trains, road vehicles;
- Industrial processes: various companies in the Ghent area of North Sea Port use large quantities of hydrogen (note that grey hydrogen is currently still available <sup>(3)</sup>);
- As a raw material for the production of climate-neutral (green) chemicals.

(3) grey hydrogen is produced by splitting natural gas, releasing CO<sub>2</sub>.

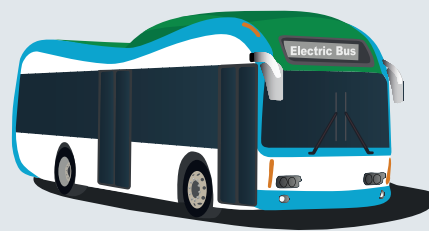
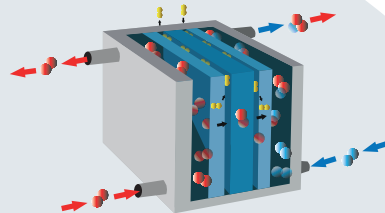


**H<sub>2</sub> STORAGE**

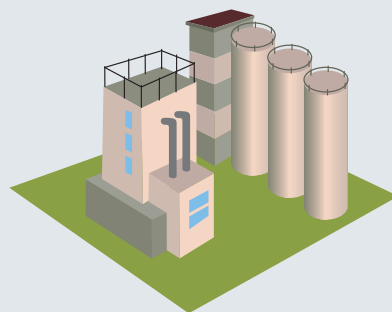


**ELECTROLYSERS**

**PRODUCTION ELECTRICITY**  
H<sub>2</sub>, fuel cells, turbines, engines



**ELECTRIC VEHICLES**  
H<sub>2</sub>, fuel cells



**H<sub>2</sub> in INDUSTRIAL PROCESSES**



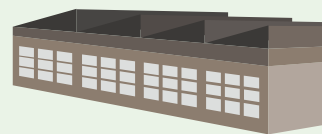
**CHEMICALS PRODUCTION**  
CCU, CO<sub>2</sub> + H<sub>2</sub> methanol, formate...  
N<sub>2</sub> + H<sub>2</sub> ammonia

**Figure 1:** overview of possibilities for applying hydrogen (possibly obtained from renewable resources) in different social sectors. This study only examined the CCU course.

# 3

## Importance of CCU for energy transition

CCU can be an important tool for the transition to a climate-neutral society as raw materials and fuels can be produced from captured CO<sub>2</sub> and H<sub>2</sub> from renewable energy sources.



CO<sub>2</sub> emitter

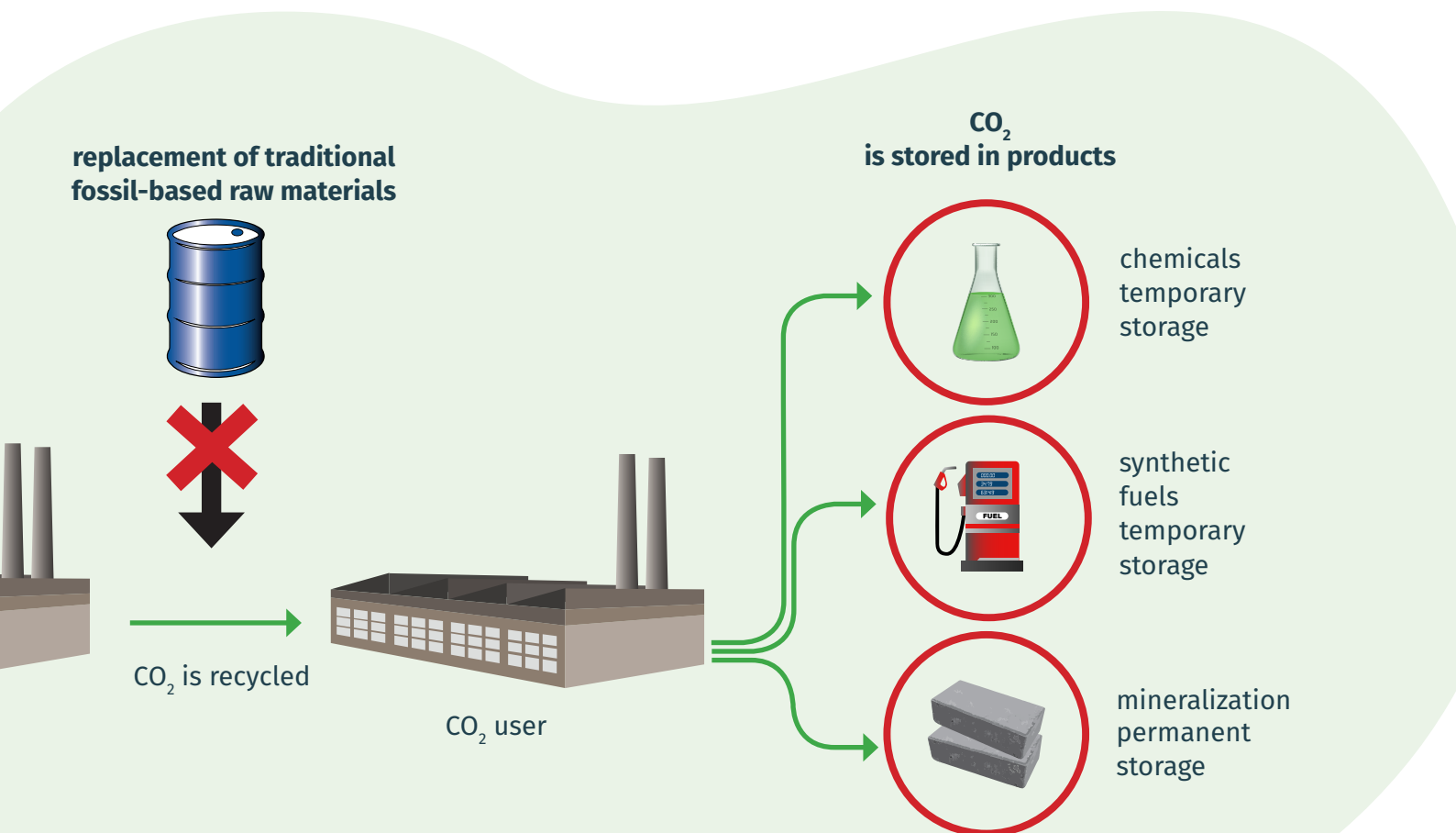
## WHY IS CCU IMPORTANT?

Greenhouse gas emissions (such as CO<sub>2</sub>) that are inherently linked to the chemical reactions of specific industrial processes, such as the production of steel, are difficult to eliminate. At a certain moment, process optimization reaches its technological end point. To further reduce the total CO<sub>2</sub> emissions from such a process, capture and purification of the smoke and waste gases will be necessary. The purified CO<sub>2</sub> can then be stored in underground layers (Carbon Capture & Storage (CCS)) or reused in, for example, e-fuels (climate-neutral fuels), polymers, raw materials for chemical production, building materials, etc (when used again, we talk about CCU).

CCS and CCU will play an important role in achieving the objectives of the Paris Climate Agreement.

Thanks to recent technological developments and increasing availability of renewable energy sources, policy shows a higher interest in applying and further developing CCU solutions. In particular, in manufacturing raw materials and fuels from captured CO<sub>2</sub> and green hydrogen.

Figure 2 <sup>(4)</sup>: shows that CCU can lead to the elimination of fossil raw materials and fossil fuels.



(4) Source: Scot project briefing paper EU-ETS to incentivise CO<sub>2</sub> utilisation ([www.scotproject.org](http://www.scotproject.org))

**According to the ‘Towards a Flemish Industrial Low-Carbon Transition Framework study’<sup>(5)</sup>, CCU is a promising option to achieve the necessary emission reductions in energy-intensive industries, as it is closely linked to the Flemish industrial profile and locally available expertise.** Various factors such as cost, legal impediments, need for further research, missing infrastructure etc. make it more difficult for CCU to break through. To this end, a mix of different technologies must be applied within and between industrial sectors.

*However, the CCU application strongly depends on local conditions, e.g. the availability of pure CO<sub>2</sub> streams, storage locations for CO<sub>2</sub>, affordable and reliable biomass and/or hydrogen production (H<sub>2</sub>) (for example via renewable electricity), potential for industrial symbiosis, and so on. The application of these new technologies implies high capital investments (CAPEX), but also the operational expenditure (OPEX) (related to the new technologies) is often still higher compared to the conventional process technologies.<sup>(6)</sup>*

(5) Flemish government, Department of Environment, Department of Energy, Climate and Green Economy, 2018

(6) See footnote 5

The energy transition in Flanders will have an important impact on industrial competitiveness and the industrial low-carbon transition and vice versa. The energy transition and the low-carbon transition will have to be aligned: the creation of CCU hubs are part of the energy issue (energy hubs).

Synthetic fuels (e-fuels or carbon-neutral fuels) are produced exclusively by combining captured CO<sub>2</sub> with hydrogen from renewable energy (Power-to-X (PtX), Power-to-Liquids (PtL) and Power-to-Gas (PtG)). The most important advantage of these synthetic fuels, from a technical point of view, is that they are not very different in use compared to fossil fuels and that they can be used in existing fuel engines<sup>(7)</sup> provided that a number of (relatively simple) adjustments are made. For the distribution of e-fuels, existing networks of gas stations can be used and e-fuels can therefore be gradually mixed into existing fuels. Although the production of synthetic fuels is a complex and expensive process, experts assume that, after a scale-up and in case of favourable electricity prices, the production price of carbon-neutral fuels will eventually fall.

Because these fuels are also lower in nitrogen and sulphur emissions, there is great interest from the shipping sector. Based on the results of current projects in which methanol is used as marine fuel (including Stena Germanica), a reduction of SOx emissions up to 99 %, NOx up to 60 %, CO<sub>2</sub> up to 25 % and particulate matter reduction up to 95 %<sup>(8)</sup> is expected.

(7) Methanol as a fuel for internal combustion engines, Verhelst et al., 2019, PROGRESS IN ENERGY AND COMBUSTION SCIENCE

(8) [www.ship-technology.com/projects/stena-germanica-ropax-ferry](http://www.ship-technology.com/projects/stena-germanica-ropax-ferry)

# Production processes for CCU in North Sea Port

**‘North Sea Port’ is a unique location to implement CCU production processes in the context of a circular energy transition programme.**

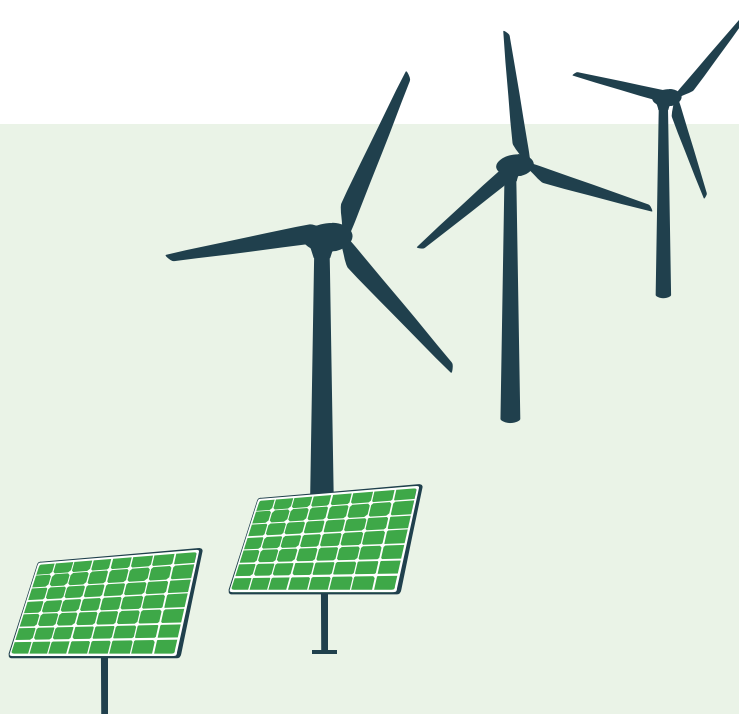
If we, as a society, want to achieve the 2030/2050 climate targets, we must now start a large scale programme that initiates industrial scale processes to convert carbon dioxide from residual flows and hydrogen from renewable energy sources into green raw materials and fuels. Based on data of production processes of local companies, a strategy was developed to aim for a circular model in which CO<sub>2</sub> emissions from one company are converted into raw materials for another company. In this way, a double effect is obtained: on the one hand, CO<sub>2</sub> is captured that would otherwise end up in the atmosphere and on the other hand, a climate-neutral energy carrier is produced to replace fossil raw materials and fuels.

North Sea Port has the following (unique) local strengths to realize a large scale energy transition programme with a circular model:

- Easy access to renewable electricity from wind farms in the North Sea via the existing high-voltage grid.
- The availability of wind and solar energy where hydrogen (H<sub>2</sub>) is a designated energy vector.
- Important high-quality CO<sub>2</sub> and CO sources in relatively high concentrations and large volumes.
- Potentially large industrial buyers of hydrogen, oxygen and chemical products (methanol, ammonia, formic acid).
- The possibility to locally utilize heat and residual flows in a smart way.
- 525 industrial companies in the port area that could potentially get involved in the CCU hub.

4





- An intense logistical activity: transport by road, rail and water and thus a potential market for H<sub>2</sub> and synthetic fuels.
- A sufficient scale effect has the advantage that considerable amounts of CO<sub>2</sub> are captured and processed and therefore the cost per unit of green raw materials and fuels produced is considerably lower.
- The vast port area of Ghent offers sufficient available space to set up the required new infrastructure for the production and transport of green raw materials and fuels.
- To be able to evaluate the aforementioned (unique) local assets and to frame them in a strategic approach, an exploratory study was carried out by Advanced Energy Technologies.

This study was commissioned by the City of Ghent, North Sea Port, POM East Flanders and the University of Ghent (CAPTURE platform). The study examines the feasibility of creating a CCU hub in the Ghent area of North Sea Port that captures, purifies and converts CO<sub>2</sub> into chemical raw materials and fuels that can be used in the local industry of the port, but also elsewhere.

The following 5 sections provide insight into the various opportunities and production processes that were identified within the exploratory study.

## 4.1.

### Production of green hydrogen from renewable energy on the Rodenhuize site

- Access to renewable electricity from wind farms in the North Sea via the existing high-voltage grid.
- The availability of wind and solar energy where hydrogen (H<sub>2</sub>) is the preferred energy vector.

The starting point of the CCU strategy for the Ghent area of North Sea Port is the production of hydrogen from renewable energy sources, mainly from offshore wind farms.

In the course of 2018, ELIA, the operator of the Belgian high-voltage grid, commissioned a direct connection between the United Kingdom, the North Sea and the mainland: the STEVIN project. This connection, at a voltage of 380 kV (kiloVolt), passes through the ENGIE Rodenhuize site and is linked in Zomergem with the high-voltage line the Netherlands-Belgium-France (see Figure 3). In the Ghent area of North Sea Port there is therefore direct access to large quantities of renewable wind energy.

The site of the ENGIE Rodenhuize power plant already has a 380 kV transformer which is used by ELIA to connect the networks at a voltage of 36 kV, 150 kV and 380 kV.

An additional 380 kV transformer would allow to use the energy from renewable energy sources (onshore and offshore wind farms, solar parks) for the production of hydrogen.

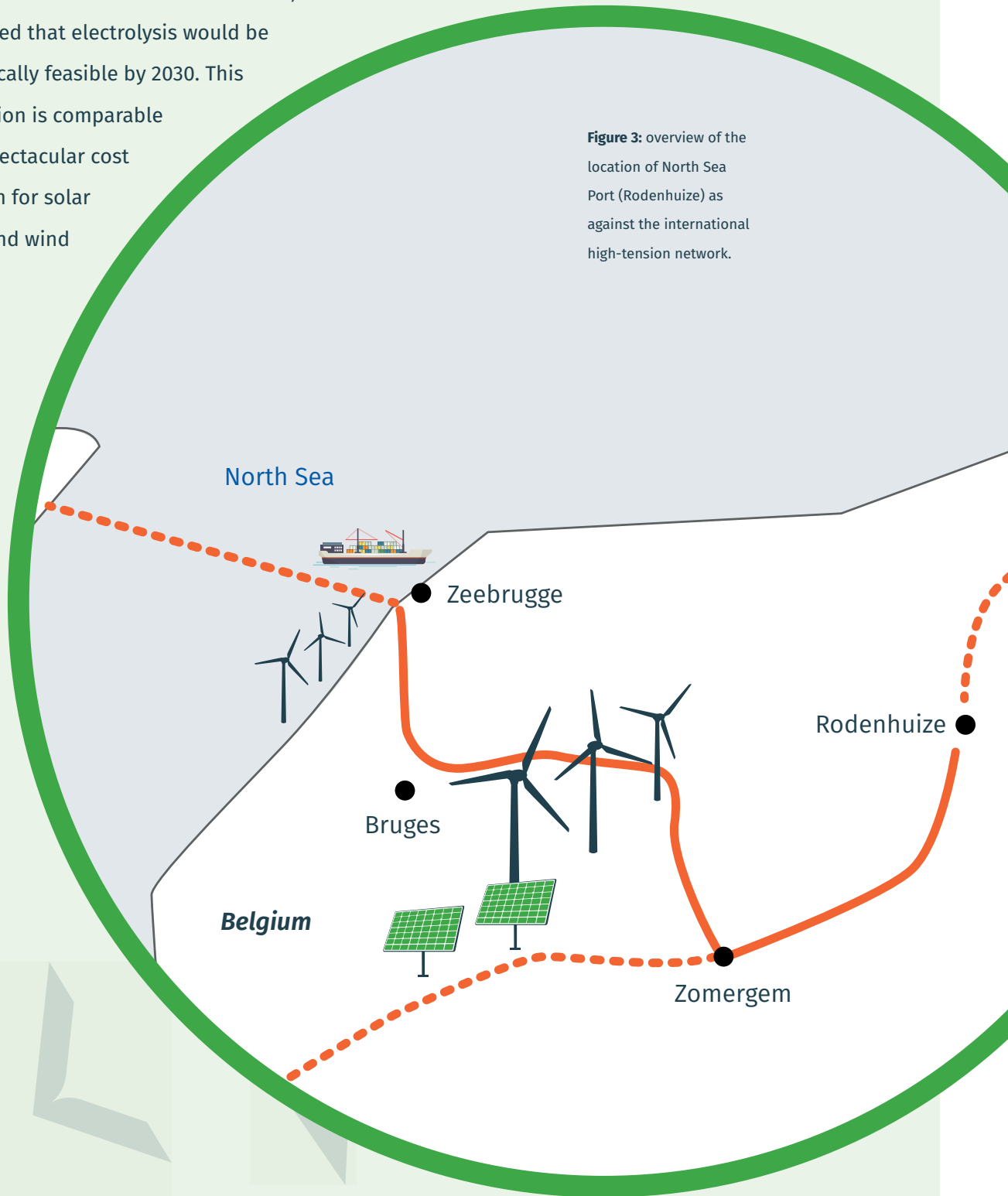
With such a transformer one can bring in up to 450 MW (megawatt) of electrical power, which corresponds to an electrolytic hydrogen (H<sub>2</sub>) production up to 100,000 Nm<sup>3</sup>/h (9 t/h). This also releases 50,000 Nm<sup>3</sup>/h of oxygen (O<sub>2</sub>) (72 t/h), which can be used in the converters of the steel industry. This capacity can be increased to 600 MW at a later stage.

Electrolysis units can respond to the quantity of available renewable energy (converting excess electricity into hydrogen if the supply of renewable energy exceeds demand) as well as to grid saturation. The units can be controlled continuously and are thus able to absorb more or less energy from the grid. Hydrogen can also be stored in a buffer, it is a form of energy storage, like a battery.

As such, the flexibility of electrolysers allows higher penetration rates of renewable electricity sources on the existing grid.

For the time being, electrolysis for the production of H<sub>2</sub> is still more expensive than the conventional methods for H<sub>2</sub> production from fossil sources. However, it is expected that electrolysis would be economically feasible by 2030. This expectation is comparable to the spectacular cost reduction for solar panels and wind energy.

**Figure 3:** overview of the location of North Sea Port (Rodenhuize) as against the international high-tension network.



## 4.2.

### Collection of CO<sub>2</sub> on the Knippegroen site

Important high-quality CO<sub>2</sub> sources, with high concentrations and volumes

In the port of Ghent, 86 % of CO<sub>2</sub> emissions are produced by the steel production. The Knippegroen site hosts a power plant operated by Engie, in which the blast furnace gases from the ArcelorMittal steel company are valorised. The Knippegroen site is particularly suitable for capturing CO<sub>2</sub> because the emissions are released at one location and the composition of these emissions is well known (high concentration of 30 % CO<sub>2</sub>).

There are other important sources of CO<sub>2</sub> in the port area. Just across the Belgian-Dutch border, Yara has an important location that manufactures fertilizer products, releasing large amounts of CO<sub>2</sub>.

## 4.3.

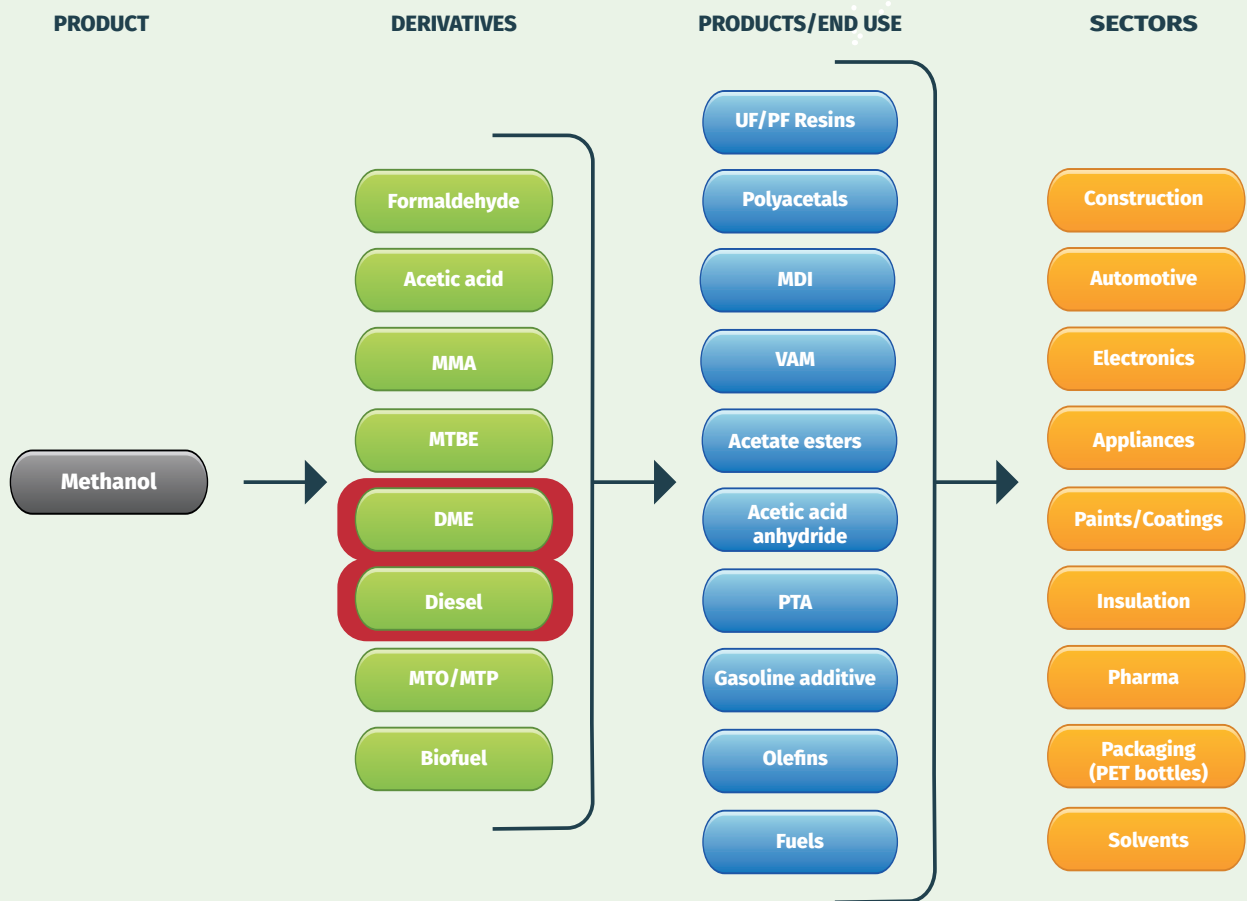
### Synthesis of hydrogen and CO<sub>2</sub> to green methanol: power to methanol

Large potential industrial customers for hydrogen and chemical products (methanol, ammonia) produced from hydrogen, CO<sub>2</sub> and renewable energy

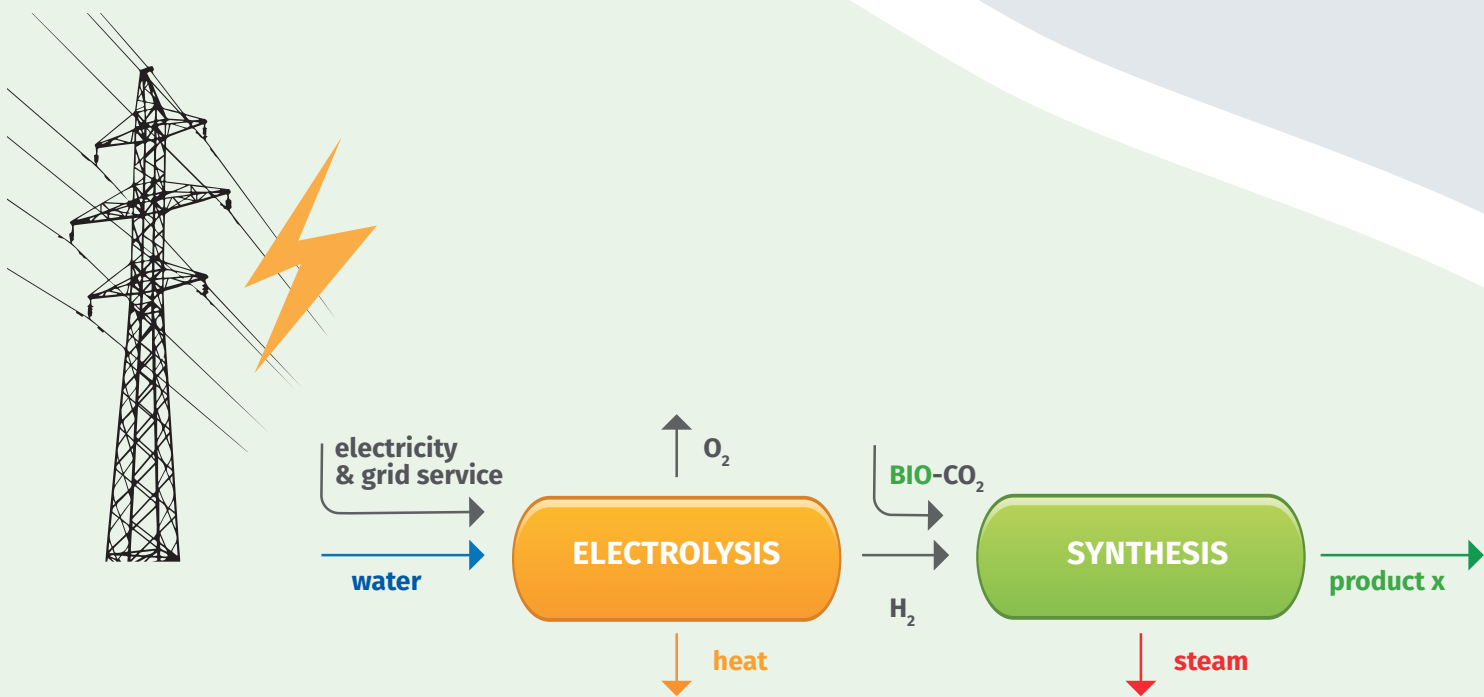
For several decades, methanol has been produced by hydrogenating CO from fossil resources such as oil and natural gas.

The worldwide demand for methanol amounts to 90 million tons/year, of which around 10 % in Europe.

Methanol is a basic product in the chemical industry, used to produce many other chemical products and fuels (**Figure 5**).



**Figure 4:** application possibilities for methanol. Source: National Gas Company



**Figure 5:** schematic overview of green methanol production from renewable electricity.

Via a synthesis process, hydrogen from renewable energy and CO<sub>2</sub> can be combined into green methanol. **(Figure 6).**

The electrolysis process for the production of hydrogen and oxygen has long been known. Up to now, the alkali technology has mainly been used. The new PEM (Proton Exchange Membrane) technology is in full development and opens up perspectives for a drastic reduction in production costs and improvement of energy efficiency. Various manufacturers already offer this technology on an industrial scale.

Methanol is used for, among other things, the production of biodiesel. Two companies in the Ghent port area are active in the production of biodiesel. Methanol can also be used in the port for the production of methylamines and urea formaldehyde concentrate. Methanol, together with LNG and ammonia, is considered by the shipping sector as one of the alternative

fuels to achieve the climate objectives in their sector <sup>(9)</sup>.

In the port area of Ghent there is a lot of shipping and train traffic. These modes of transport use diesel oil as a fuel and release large amounts of harmful emissions. These can be avoided, among other things, by replacing diesel oil with green methanol in the short term or hydrogen in the long term. The newer ship engines can run on a mixture of 95 % methanol and 5 % diesel. Depending on the type, older engines can be converted into dual-fuel engines that can replace up to 60 to 70 % of the required diesel oil with green methanol.

(9) Methanol as an alternative fuel for vessels, Maritime Knowledge Centre, TNO and TU Delft, Netherlands Maritime Land and Ministry of Economic Affairs , 2018

The greater the share of intermittent renewable energy sources in total electricity production, the greater the need to store some of the generated renewable energy. It already occurs that the supply of renewable energy is higher than the demand for electricity (and this situation is expected to occur more frequently). The production of hydrogen and methanol based on renewable energy sources offers a solution for this. Methanol can be used as a way to store H<sub>2</sub> in liquid form. The advantage is that liquids are easier to store and transport under atmospheric conditions. Due to the higher energy density, the volume of the liquid methanol is substantially lower compared to hydrogen gas.

#### 4.4.

### Synthesis from hydrogen and nitrogen to green ammonia

Currently, large scale ammonia production is done by steam reforming of natural gas. Depending on the production process, it was estimated that about 1.7 tons of CO<sub>2</sub> is released per ton of ammonia produced.

In addition to methanol, also green ammonia can be produced from green hydrogen, more specifically, via a synthesis process using nitrogen, which does not emit any CO<sub>2</sub> (the Haber process also known as Haber-Bosch process).

By using the Haber process for the production of ammonia, 1.7 tons of CO<sub>2</sub> emissions can be avoided per ton of ammonia produced.

The synthesis process also produces heat, which can be recovered and reused.

In the Ghent area of North Sea Port, large quantities of ammonia are also used to produce methylamines. Local production and use of ammonia can limit the transport costs and the safety risks associated with this transport. Most likely, the safety regulations for transport and



storage of ammonia will become even stricter in the future. This means that local production coupled with direct use and limited storage needs and capacity will be stimulated.

As in the case of methanol, the shipping industry is also investigating the use of ammonia as an alternative fuel. In addition, ammonia is also considered as a source for H<sub>2</sub> storage in times of a renewable energy surplus <sup>(10)</sup>.

#### 4.5.

### Synthesis of hydrogen and CO<sub>2</sub> to formic acid

Formic acid is widely used in various industries. Like methanol, formic acid can be produced by the synthesis of hydrogen and carbon dioxide.

Compared to methanol, the production of formic acid offers the additional advantage that a larger amount of CO<sub>2</sub> can be processed per unit of hydrogen. In the port area of Ghent there is room for an annual production of 100,000 tons of formic acid. This requires 7,700 tons of hydrogen. 85,000 tons of CO<sub>2</sub> is captured and processed.

#### 4.6.

### By-products: oxygen and heat

The production of hydrogen on the basis of renewable energy occurs, as mentioned above, by the electrolysis of water. The electricity generated by the renewable energy sources splits a water molecule (H<sub>2</sub>O) into a hydrogen (H<sub>2</sub>) and an oxygen (O<sub>2</sub>) molecule. The released green oxygen can be used in steel production in the port of Ghent, where it replaces grey O<sub>2</sub> that is currently being produced on the basis of 'grey' electrical energy (produced with CO<sub>2</sub> emissions).

The heat management of the production processes can also be optimized as the heat is produced and used locally. Heat is released when producing methanol and ammonia. This heat can be used in processes that require heat: the capture and purification of CO<sub>2</sub> and the production of methylamines. The residual heat from the electrolysis process can be used, among other things, for various drying processes.

(10) Ammonia for power, Avalera-Medina et al, Progress in Energy and Combustion Science, 2018



The CCU strategy comprises four production processes and sites: **(1)** the production of hydrogen/oxygen, **(2)** the capture of carbon dioxide, **(3)** the production of methanol and **(4)** the production of ammonia. By choosing smart locations for these four production processes and interconnecting them via, for example, pipelines, the benefits of the integration must be maximally achieved:

- **(1)** Hydrogen and oxygen are produced where large quantities of renewable energy are available: the Rodenhuize site. Via relatively short pipelines, H<sub>2</sub> and O<sub>2</sub> can be brought to the sites that need these raw materials. The heat released from the electrolysis process can be used for drying processes.
- **(2) (3)** The CO<sub>2</sub> is captured at the source in Knippegroen and after purification immediately used as a raw material for methanol production. This way no CO<sub>2</sub> has to be transported. The heat released from the on-site methanol production can also be used in the process of capturing and purifying CO<sub>2</sub>.
- **(4)** The production of ammonia takes place at the site where methylamines are made. Due to safety risks, ammonia is best produced at the customer's site.

Heat is released during the production of ammonia, and it can be used effectively for the production of methylamines. Natural gas is currently being used to generate the necessary heat; by replacing this with recycled heat, CO<sub>2</sub> emissions from the use of natural gas can be avoided.

Finally, the necessary electrical energy for driving pumps, compressors and other devices in all these processes is also derived from renewable energy.

The raw materials flows and the mutual integration are shown in **figure 7**.

The production of these green raw materials and fuels is accompanied by an annual CO<sub>2</sub> capture of 305,000 tons per year and ensures an additional avoided CO<sub>2</sub> emission of 342,000 tons per year. The overall result is an equivalent reduction in CO<sub>2</sub> emissions of 647,000 tons per year.

It should be noted that other companies may be involved in the realization of the interconnections that have not been included in this preliminary study. Therefore the avoided and captured CO<sub>2</sub> volumes can be even higher with further integration and higher efficiency of activities on the territory of North Sea Port.

## PHASED ROLL-OUT OF THE CCU HUB STRATEGY

The global CCU hub strategy will be realized in successive steps.

### CCU LIGHT

The first phase will consist of the development of a methanol synthesis plant with a capacity of 46,000 tons/year.

The necessary green hydrogen will be obtained from an electrolysis plant with an electrical capacity of 63 MW.

Around 63,000 tons of CO<sub>2</sub> will be captured and processed. The methanol produced in this way will be used in the local production of biodiesel.

### CCU FULL SCALE

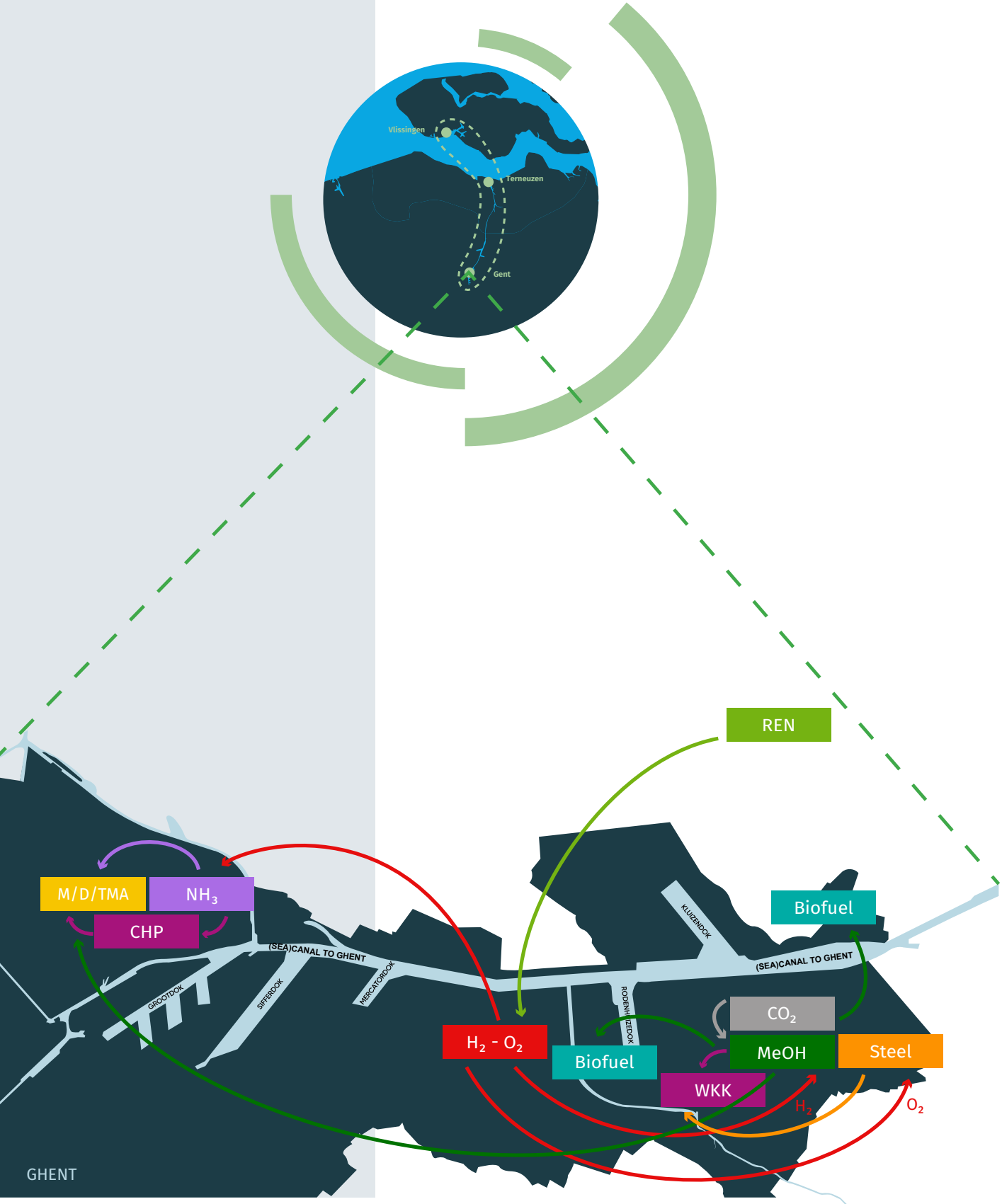
In a second phase, green methanol and ammonia will be produced for the methylamine industry. The electrical capacity to produce the necessary green hydrogen will increase to 300 MW.

In a third phase, green methanol will also be used to produce urea formaldehyde. In addition, green hydrogen and methanol will be used in rail and waterway transport applications. Formic acid will also be produced, which will increase the electrical power required for green hydrogen to around 600 MW.

The amount of CO<sub>2</sub> captured and avoided will possibly amount to more than one million tons per year.

REN	renewable energy – North Sea wind farms – 300 MW – 1,300 GWh/y
H <sub>2</sub> - O <sub>2</sub>	electrolysis – hydrogen (H <sub>2</sub> ) 41,500 tons/y- oxygen (O <sub>2</sub> ) 330,000 tons/y – Rodenhuizedok site
CO <sub>2</sub>	carbon dioxide capture – 120,000 tons/y – ArcelorMittal site / Knippegroen
MeOH	green methanol production – 180,000 tons/y – avoided CO <sub>2</sub> emission of 265,000 tons/y
NH <sub>3</sub>	green ammonia production – 45,000 tons/y – avoided CO <sub>2</sub> emission of 77,000 tons/y
Biofuel	biofuel production
Steel	steel production
M/D/TMA	methylamines production
CHP	integration of heat flows

**Figure 7:** Possible scenario for a lay-out of the different components of an integrated CCU hub in the Ghent part of North Sea Port.



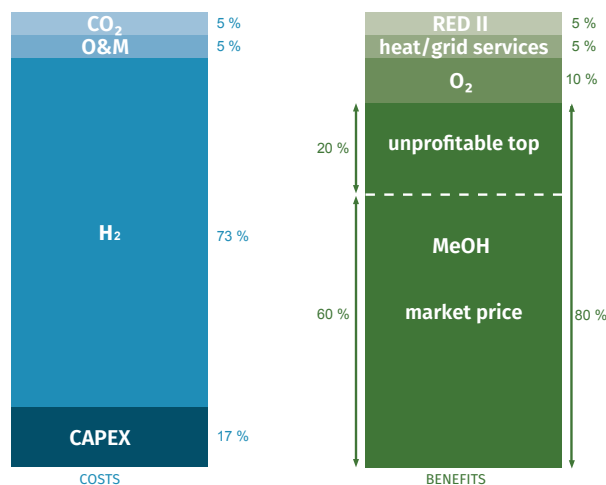
# Cost/benefit model: power to methanol

A sufficiently large scale effect has a double advantage: considerable amounts of CO<sub>2</sub> are collected and processed, and the unit price of green raw materials and fuels produced decreases considerably.

For the production of hydrogen, oxygen, methanol and for capturing carbon dioxide, an initial cost-benefit model was developed based on a number of assumptions: annual capture of 305,000 tons of CO<sub>2</sub>, production of 41,500 tons of H<sub>2</sub> and 330,000 tons of O<sub>2</sub>.

The construction of the 4 production units represents a total investment by the energy and chemical industries of approximately € 500 million. The results show that the costs for production, storage, compression and transport of 'green' hydrogen, (to be used as a raw material for local production of 'green' methanol) determine the major part of the production cost.

6



**Figure 8:** Global overview of the cost/benefit model for the production of methanol from renewable energy and captured CO<sub>2</sub> in North Sea Port. (O&M = Operation & Maintenance; RED II = Renewable Energy Directive)

The analysis (**see Figure 8**) shows that the cost price of 'green' methanol can currently not compete with the market price of 'grey' methanol extracted from fossil raw materials (natural gas or coal). By valorising the O<sub>2</sub> by-product and heat recovery for industrial processes and by regulation in RED II, the unprofitable top (the gap), the difference between cost price and market price, can be limited to 20 %.

The processes mentioned above, for the production of hydrogen, methanol and ammonia, have a high TRL (Technology Readiness Level), do not require a long development phase and are already being

applied on an industrial scale. The industrial processes already mentioned have the necessary maturity, but specific adjustments are needed to allow the processes to work together, on the right scale and with customized local production units.

Through further optimization and improvement of the production processes, experts expect that the 'gap' will decrease in the future. A similar evolution has occurred in the development phase of wind turbines and photovoltaic panels. Initially, the cost of renewable energy from solar and wind energy was considerably higher than the market price of electricity, and a supporting subsidy policy was needed. Over the years, innovative technologies were developed and wind turbines and solar panels were produced on a large scale. This allowed the subsidies to be phased out gradually. At the moment, the first offshore wind farms are being built in Europe, producing renewable electricity without any supporting subsidies.

A similar temporary support policy, to bridge the difference in cost price between 'green' methanol and ammonia and the market price, is also necessary for the realization of a CCU hub in the port area of Ghent. This can be done, for example, through a higher compensation for, among other things, CO<sub>2</sub> captured and avoided and transportation costs avoided.

This study now mainly looked into the use of methanol for chemical production processes in companies that are price competitors in a global market.

A route that is not fully developed in this study is the direct use of methanol or methanol-based fuels for local heavy transport (trains, ships, harbour cranes, etc.). Local support instruments could help to set up an initial investment to get this economy off the ground so that it can reach a sufficiently large scale over time.

## Future developments

**In addition, it is expected that other products that have a higher market value than methanol can be made from H<sub>2</sub>, CO<sub>2</sub> and O<sub>2</sub>. Methanol could also be further converted into products with a higher market value. These routes are, however, not further elaborated in this study since the necessary technologies are currently still in the R&D phase.**



# Conclusions and recommendations

**The companies included in the EU Emissions Trading System (ETS) in North Sea Port face enormous challenges in achieving the European climate and energy objectives for 2030. More specifically, they have to reduce emissions by 43 % compared to 2005.**

For these companies, the development of carbon capture and utilisation (CCU) processes, in which CO<sub>2</sub> is captured and used to produce new chemical products and e-fuels, will play a major role.

The pursuit of climate targets by 2030 and 2050 will also be accompanied by an impressive energy transition, both for the generation of energy from renewable energy sources, and for the increasing electrification of society, including industry. Generating renewable energy usually means generating electricity from natural sources (wind, sun, geothermal, hydropower, etc.). However, these are largely unpredictable in nature, accompanied by problems for energy management and storage.

A global search is therefore being carried out for suitable energy carriers that can deal with these problems, such as batteries, but also hydrogen and synthetic fuels.

The creation of a CCU hub in the port area offers extraordinary and unique opportunities to reduce CO<sub>2</sub> emissions on a large scale through a carbon capture and utilization strategy based on renewable energy.



The port area has a number of (unique) local assets to realize a large scale CCU programme according to a circular model:

- Access to renewable electricity from wind farms in the North Sea via the existing high-voltage grid, with which hydrogen can be produced via electrolysis.
  - The availability of wind and solar energy where hydrogen (H<sub>2</sub>) is the preferred energy vector.
  - Important quality CO<sub>2</sub> and CO sources, in relatively high concentrations and large volumes.
  - Potentially large industrial buyers of chemical products and e-fuels (methanol, ammonia), which can be produced on the basis of hydrogen, CO<sub>2</sub> and renewable energy. The ability to utilize the by-products: residual heat and oxygen.
- An intense logistical activity: transport by road, rail and water that forms a potential market for H<sub>2</sub>, chemical products and e-fuels.
  - A sufficient scale effect has the advantage that considerable amounts of CO<sub>2</sub> are captured and processed; and therefore the unit price of green raw materials and fuels produced is considerably lower.

At the industrial sites, the four production units are optimally integrated by location choice and interconnections (via pipelines, for example): **(1)** the production of hydrogen/oxygen, **(2)** the capture of carbon dioxide, **(3)** the production of methanol and **(4)** the production of ammonia. The further expansion of a circular model is achieved by aligning the heat requirements and valorising the O<sub>2</sub> by-product.

The CCU hub strategy includes:

- **(1)** Hydrogen and oxygen are produced where large quantities of renewable energy are available: the Rodenhuize site. Via relatively short pipelines, H<sub>2</sub> and O<sub>2</sub> can be brought to the sites that need these raw materials. The heat released from the electrolysis process can be used for e.g. drying processes.
- **(2) (3)** The CO<sub>2</sub> is collected in at Knippegroen at the source and after purification it is immediately used as a raw material for methanol. This way no CO<sub>2</sub> has to be transported. The heat released from the methanol production on site can also be used in the process of capturing and purifying CO<sub>2</sub>.
- **(4)** The production of ammonia takes place at the site where methylamines are made. Ammonia is best produced at the customer's site on the basis of safety risks, as opposed to methanol. Heat is being released during the production of ammonia, and it can be used effectively for the production of methylamines.

The overall result is an equivalent reduction in CO<sub>2</sub> emissions of 647,000 tons per year (= the sum of the CO<sub>2</sub> avoided and captured).

The construction of the 4 production units represents a total investment by the energy, steel and chemical industries of around € 500 million. An initial cost/revenue analysis shows that the costs for production, storage, compression and transport of 'green' hydrogen from renewable energy, as a raw material for the local production of 'green' methanol, determine the production costs. The cost of 'green' methanol can currently not compete with the market price of 'grey' methanol extracted from fossil raw materials (natural gas or coal). By valorising the O<sub>2</sub> by-product and heat recovery for industrial processes and by regulation in Renewable Energy Directive II, the unprofitable top (the gap), the difference between cost price and market price, can be limited to 20 % **(see figure 8)**.

The industrial processes mentioned in the report already have the necessary maturity, but specific adjustments are needed to allow the processes to work together, at the right scale and with customized local production units. Through further optimization and improvement of production processes, experts expect that the unprofitable top will decrease in the future. A similar evolution occurred in the development phase of wind turbines and solar panels, which initially required a support policy. The first wind farms which can produce renewable electricity at competitive costs, are currently being built at sea.

A temporary supporting policy to bridge the difference between production costs and market prices is necessary for the industrial realization of the CCU hub in the port area of Ghent.

The development of an excelling CCU hub including new value chains is an ambitious and long-term process in which all stakeholders must work together.

Strengthening cross-border cooperation for the further development of the CCU hub will be important.

This exploratory study shows that the supply side has a sufficiently large scale at a technical and spatial level to be feasible. Due to the higher production costs compared to current market prices for products of fossil origin, the green C products cannot yet compete. Economic constraints will have to be adjusted temporarily until the CCU hub has undergone a sufficient scale and an economic learning curve.

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**advanced energy technologies**