To: [redacted] [[redacted]@pzh.nl]
Cc: [redacted] [[redacted]@pzh.nl]
From: [redacted]
Sent: Tue 1/30/2018 2:39:51 PM
Subject: RE: onderzoeksopzet Shell Rijswijk
Received: Tue 1/30/2018 2:39:51 PM

[redacted],
Dank voor je reactie. Ik ga kijken of ik deze nog in kan brengen nu de deadline is verlopen.
Groet [redacted]

Van: [redacted]
Verzonden: dinsdag 30 januari 2018 15:13
Aan: [redacted]
CC: [redacted]
Onderwerp: RE: onderzoeksopzet Shell Rijswijk

[redacted],
Dank voor je vragen.
Wij kijken graag mee.
Je vragen zijn naar mijn inschatting terecht, net als de opmerking die je er bij maakt, dat het risico van shell is. Het is echter ook zo dat risico shell en beleidsruimte van gemeenten en provincie met elkaar verweven zijn. Immers hoe meer ruimte wij toestaan of beperkingen wij opleggen hoe meer we de opbrengstpotentie beinvloeden. In dat kader plaats ik ook dit onderzoek. Shell wil uiteraard de potentiele kopers kunnen meegeven welke mogelijkheden er op de locatie zijn.
Ik concludeer uit het stuk echter dat er beleidsmatig heel veel mogelijk is. (Het kan bijna alle kanten op.)
Indien shell zich beperkt ziet (of op enig moment in het proces gaat zien) door de planologische ruimte die ze wel of niet krijgen, zullen de financien een argument worden. Zoals eerder geadviseerd kunnen we een dergelijke redenering alleen in als zij dan ook alle baten meenemen. Dus ook de baa van het opheffen van de locatie etc. (Eerder aan [redacted] apart toegelicht.)
Over de uitvraag:

1. Ik zou vooral geinteresseerd zijn in de wijze van vermarkten en dat kent de bandbreedte van verkoop van deelgebouw voor deelgebouw tot verkoop van het hele gebouw tot aan verkoop of ontwikkeling van de hele locatie die groter is dan alleen het perceel van het shellgebouw
2. Daarbij hoort de vraag welk type bureau je nu wil inhuren. Huur je een bureau met expertise wonen of vooral onderwijs, of vooral bedrijven. Of wil je geen inhoudelijke richting en zoek je een bureau dat denkt in termen van vastgoedinvesteringen en kansen of in termen van locatie & conceptontwikkelingskansen. Er zijn bureaus die vooral lijnen hebben met grote investeerders en adviseren over kansrijke locatieontwikkeling.
3. Ik neig naar zo'n bureau.
4. Zijn de zoekrichtingen nevengeschikt in de ogen van de publieke partners? Of hebben wij ook nog voorkeur. (Het liefst onderwijs bijvoorbeeld of vinden wij grondgebonden woningen bijvoorbeeld ongewenst? Dan moeten we dat meegeven.)
5. Het lijkt me goed om de potentie van de richtingen te onderzoeken.
   Als ik het nu lees: "welke vraag is er vanuit onderwijsinstellingen naar de locatie Kessler Park?" Op die vraag is het antwoord natuurlijk: geen.
   Als we zo de uitvraag willen doen zou ik enerzijds concreter, anderzijds openen zijn. bijvoorbeeld: welke onderwijsinstelling heeft tussen nu en 3-5 jaar capaciteitsproblemen die mogelijk hier kunnen worden opgelost?

[redacted]

Van: [redacted]
Verzonden: vrijdag 26 januari 2018 15:02
Aan: [redacted]
CC: [redacted]
Onderwerp: FW: onderzoeksopzet Shell Rijswijk

Hoi [redacted],
Ik hang weer eens aan de bel. We gaan in het Shell-traject de volgende fase in. We gaan de kan rijkheid van de vier scenario's onderzoeken. Heb jij daar nog opmerkingen bij?
Zelf mis ik bijvoorbeeld de verwachte opbrengsten die met de scenario's gepaard gaan (tenzij je dit onder de risico's voor Shell plaatst). Een woningbouwscenario zal vermoedelijk een positiever effect hebben op de opbrengst voor Shell dan een onderwijs- of bedrijvenfunctie, terwijl deze zoals je eerder hebt aangegeven wel een 'duurzamer' (want gebruik van bestaande gebouwen) karakter hebben.
Kortom is het aan te bevelen de kansen en risico's al wat in te kleden of past een open opzet zoals nu gehanteerd juist goed?
Daarnaast natuurlijk alle ruimte om nog aanvullende punten te noemen.
Alvast dank voor reactie.
Groet [redacted]

Van: [redacted] [[redacted]@mrdh.nl]
Verzonden: donderdag 25 januari 2018 16:36
Aan: [redacted]; [redacted]@delft.nl'; [redacted]; [redacted]@shell.com'; [redacted]@shell.com'; [redacted]; [redacted]@denhaag.nl'; [redacted]
CC: [redacted]
Onderwerp: onderzoeksopzet Shell Rijswijk

Beste mensen,
Zoals afgesproken ontvangen jullie hierbij de onderzoeksopzet zoals Shell, Rijswijk en MRDH die hebben voorbereid.
Deze gaan we dinsdagochtend versturen naar de bureaus die we uitnodigen voor een orienterend gesprek.
Na de gesprekken bespreken wij de reacties van de bureaus op 8 februari en zorgen we voor een definitieve uitvaag. Die leggen we dan voor aan de 5 bestuurders die voor een eerste keer bij elkaar komen op 15 februari.
Als jullie suggesties hebben dan ontvangen [redacted] en ik die graag uiterlijk dinsdagochtend 9 uur.
Hartelijke groet,

[redacted]
Economisch Vestigingsklimaat

MRDH
METROPOOLREGIO
ROTTERDAM DEN HAAG

Telefoon: [redacted]

To: [redacted][[redacted]@pzh.nl]
From: [redacted]
Sent: Tue 10/31/2017 11:02:23 AM
Subject: RE: Eerste opzet
Received: Tue 10/31/2017 11:02:24 AM

Top,
Dank je wel.
Groet [redacted]

Van: [redacted]
Verzonden: dinsdag 31 oktober 2017 11:20
Aan: [redacted]
Onderwerp: RE: Eerste opzet

Hoi [redacted],
Je hebt een heldere memo opgesteld.
Adri haar inzet wordt wel genoemd in de memo, maar misschien komt het niet echt naar voren. Aan het eind van de memo zou je de volgende tekst kunnen neerzetten:
Geadviseerd wordt:

- *Gezamenlijk te onderzoeken d.m.v. een extern bureau wat de economische en ruimtelijke gevolgen zijn van het vertrek van Shell en te komen tot een gezamenlijke strategie.*
- *Gezamenlijk een convenant op te stellen en te ondertekenen op basis van de uitkomsten van het bureau.*
- *Voorafgaand aan het convenant proces afspraken met Shell vast te leggen.*

Verdere of extra inzet zou ik niet weten.
Groet [redacted]

Van: [redacted]
Verzonden: dinsdag 31 oktober 2017 9:05
Aan: [redacted]
Onderwerp: Eerste opzet

Hoi [redacted],
Ik kon er niet veel meer van maken dan bijgaande. Heb jij nog aanvullingen. Ik zou met name duidelijker willen neerzetten wat we van Adri vragen, wat haar inzet zou moeten zijn.
Het stuk moet vandaag (of uiterlijk morgen) aangeleverd worden voor haar dagmap. Ik leg het na jouw opmerkingen ook nog even voor aan [redacted].
Groet [redacted]

Earth, Life & Social Sciences
Princetonlaan 6
3584 CB Utrecht
[redacted] 80015
3508 TA Utrecht
The Netherlands

www.tno.nl

T +31 88 866 42 56
F +31 88 866 44 75

TNO report - CONFIDENTIAL

Preliminary Technical Concept Assessment – The CO_2 Smart Grid

Version 1 – Q1 2018

Date	10 January 2018
Author(s)	[redacted] Mikunda, [redacted]

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Customer	The CO_2 Smart Grid
Project name	The CO_2 Smart Grid
Project number	nvt

Contents

1 Introduction and objective

The CO_2 Smart Grid is a climate initiative of around 30 stakeholders from industry, provincial governments and authorities, supported by research institutes and national ministerial departments. The initiative aims to plan and realise a large-scale CO_2 transportation infrastructure across the Netherlands. The main goal of the CO_2 Smart Grid is to reduce the CO_2 emissions to the atmosphere, by linking emitters and users, both current and potential, through an optimised 'smart' CO_2 grid which provides demand-matching through a combination of temporary and permanent CO_2 storage solutions.

The initiative is currently embarking of the start of a pre-feasibility phase, which aims to address a series of key questions to determine the societal, economic, and most importantly, the environmental benefits of the potential infrastructure. Furthermore, the pre-feasibility study will assess the characteristics and availability of the key technical and engineering components required to develop such a plan. The latter will include the development status of current and potential CO_2 suppliers, temporary and permanent (geological) storage possibilities and an inventory of current and potential future CO_2 users, which together will ultimately define the physical extent and operation of the CO_2 pipeline network.

To contribute to the technical understanding at this pre-feasibility phase, TNO, in collaboration with a number of the CO_2 Smart Grid stakeholders, proposes to develop a 'Technical Concept Assessment' for the CO_2 Smart Grid. The objective of this document is to provide an overview of the expected physical extent of the CO_2 Smart Grid, based upon an assessment of the existing CO_2 pipeline infrastructure in the Netherlands (operated by OCAP), potential CO_2 suppliers (both current and expected), potential geological storage locations, current CO_2 demand by the horticultural industry, and where available, future CO_2 demand for innovative re-use technologies[1].

This is the first version of the Technical Concept Assessment, based on the currently available information of the intentions of various stakeholders within the Smart Grid consortium. It is possible that as more concrete information becomes available that this document will be updated.

1.1 Climate mitigation challenges in the Netherlands

By 2020, The Netherlands has committed to reduce its CO_2 emissions by 14-17% against 1990 levels, in order to comply with European climate legislation. Furthermore, the Dutch State currently have a legal obligation to reduce CO2 emissions to 25% against the same baseline as a result of the 'Urgenda' court case ruling in 2015. However, national CO_2 emissions have actually increased from 160Mt to 170Mt since 1990's [PBL], and recent data suggests that emissions are continuing to rise (CBS, 2017).

[1] The inclusion of future re-use options in the Netherlands is dependent on outcomes of another study to be conducted in parallel by consultancy firm, Ecofys, with initial results expected by the end of July 2017.

The Netherlands has a strong industrial base, which contributes considerable GDP to the economy, however at the price of high CO_2 emissions. Figure 1 shows that for a number of key industrial sectors in the Netherlands, CO_2 emissions have remained relatively stable since 1990. A slight downward trend is apparent for the chemical sector. Noteworthy though, is that all sectors covered have managed to greatly increase industrial productivity over the same period, without allowing CO_2 emissions to rise. It can be deducted, that energy efficiency measures have been effective in these sectors.

Emissions from waste-to-energy plants on the other hand have grown steadily over the same period. This increase can be attributed to landfill bans which were introduced in the Netherlands in the mid-1990s, but also more recently, the increase in waste imported for incineration from other European countries such as the United Kingdom, Ireland and Italy. It is understood that a number of initiatives are underway to reduce the CO_2 emissions from waste incineration, including the CO_2 Smart Grid initiative.

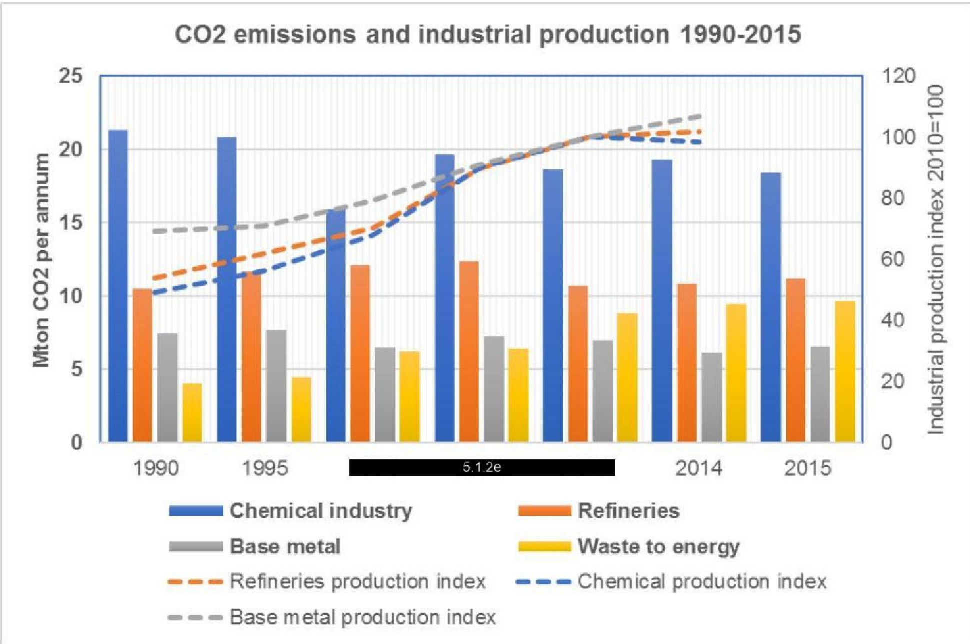

Figure 1 CO_2 emissions and industrial production in the Dutch chemical, refining and base metal sectors between 1990 and 2015.

In October 2017, the newly formed cabinet of the Dutch political parties VVD, CDA, D66 and the ChristenUnie, released the long-awaited coalition agreement, a document outlining the key policies of the Dutch government for the period of 2017-2021. The plans include an ambitious acceleration in national climate policy to contribute in reaching the goals of the Paris Climate Agreement. The agreement highlighted that CO_2 capture and storage (CCS) must play a central role in decarbonizing Dutch heavy industry.

The main target of the coalition government is a 49% reduction in CO_2 emissions from 1990 levels by 2030, equating to an annual reduction of 56 Mt CO_2. The emission reduction targets will be formalized in a new climate law. Based on scenarios from the Netherlands Environmental Assessment Agency (PBL), an overview of the foreseen reductions per sector and associated measures have been included (see Table below). Noteworthy is the contribution of CCUS towards the overall target, with an 18 Mt reduction from the industrial sector, and a 2 Mt reduction from the waste incineration sector foreseen.

Table 1 Indicative share of CO_2 emission reductions per sector in the Dutch coalition agreement

Indicative share per sector of 49% emission reduction plan for 2030		
Sector	Reduction in 2030 (Mt)	Measures
Industry	1 3 18	Recycling Process efficiency CO_2 capture and storage
Transport	1.5 2	Efficient tyres, European standards, electric cars Biofuels and urban initiatives
Built environment	3 2 2	Optimum energy use in office buildings Insultation of residential buildings, heat networks and heat pumps Energy efficient housing developments
Power production	1 12 2 4 1	Efficient lighting Closure of coal-fired power stations CO_2 capture and storage from waste incineration plants Extra offshore wind developments Extra solar energy developments
Land use and agriculture	1.5 1 1	Intelligent land-use planning Reduction in methane emissions Energy production from greenhouse sector

Furthermore, the document also highlighted that the industrial clusters of both Rotterdam and Amsterdam must be supported in realizing the deployment of CCUS.

1.2 Potential impact of the CO_2 Smart Grid concept

The need for Dutch industry to reduce emissions is all too evident. The CO_2 Smart Grid could play an important role in kick starting an infrastructure for the reuse and permanent storage of CO_2. The CO_2 Smart Grid concept is particularly suited to the Netherlands for a number of reasons, many of which are fully unique to the Dutch economy:

Geographical factors

- A considerable amount of Dutch CO_2 emissions are located within a radius of 100 km. For example, the industrialised harbours of Rotterdam and Amsterdam, and the integrated steel mill in Ijmuiden contribute approximately 1/3 of total Dutch CO_2 emissions (this figure would be much higher if one considers point sources alone).
- There is ample potential CO_2 storage capacity on the Dutch continental shelf, sufficient for an estimated 1000 Mt of CO_2 storage.

Knowledge and experience

- There is an existing CO_2 transportation network which have been operating successfully for a number of years, which runs between the harbours of Rotterdam and Amsterdam (OCAP).
- There is considerable knowledge on CCS, and a growing body of knowledge on CO_2 utilisation which Dutch universities, research institutes and the private sector.

Industry and economy

- There is existing demand for CO_2 from the Dutch horticultural sector, of between 0.8 to 1.2 Mt CO_2, of which only half is currently met through the OCAP system. If more CO_2 can be provided this sector can further reduce its reliance on natural gas combustion and invest further in waste heat and renewable energy technologies. Reducing energy and nutrient costs for this sector can help it to become more sustainable and compete with growing competition from European and non-European producers.
- The Netherlands has a large and innovative petrochemical and chemical sector where opportunities lie for the reuse of CO_2 for polymer production and synthesis of cleaner burner transportation fuels.
- There are opportunities in the concrete manufacturing industry for CO_2 storage through carbonate mineralisation.

1.3 Foreseen benefits of the CO_2 Smart Grid initiative

Beyond the potential for reduced CO_2 emissions, a coordinated initiative, such as the CO_2 Smart Grid, has a number of foreseen advantages. For example, potential economies of scale can be taken advantage of, making sure new CO_2 transportation and storage infrastructure is developed to allow potential third-party users to gain access, without having to construct separate costly point to point pipelines. Approximately 70% of the construction costs for CO_2 pipelines in the Netherlands are associated with engineering and construction, rather than materials (pers. comm. [redacted] 5.1.2e

Having multiple parties in an initiative such as the CO_2 Smart Grid, can also reduce the financial risks to individual parties. Shared investment across a number of development phases of the project could help overcome financial barriers to the project moving forward.

Finally, the establishment of a CO_2 Smart grid can lay the foundations for a CCU R&D hub in the Netherlands, attracting international companies and start-ups, strengthening the knowledge position of the Netherlands and boosting export potential of both CCU knowledge and products.

2 Current and future CO_2 projects in the Netherlands

2.1 Existing sources

2.1.1 CO_2 from hydrogen production and bio-refineries

There are currently a number of existing industrial installations in the Netherlands which have to remove CO_2 as an inherent part of the production process. These processes are generally related to the production of hydrogen, from either steam-methane reforming, the gasification of liquid fossil fuels or the fermentation of biogenic material. Hydrogen is produced at a number of places around the Netherlands, such as Geleen (Chemelot), Sluiskil [redacted] and in the Rotterdam harbour (Shell, Air Products, Air Liquid, [redacted] etc). A number of these companies sell CO_2 in liquid form to a ranges of users, however only the Shell Pernis refinery and the [redacted] biorefinery are connected to the OCAP CO_2 network. These two sources deliver approximately 450 kt CO_2 per year to the OCAP network.

2.2 Potential future sources

2.2.1 TATA Steel HIsarna production process

Process: TATA Steel in Ijmuiden are developing a new innovative technology for the production of primary steel. The technology, which could replace the use of the conventional blast furnace, and can directly use raw materials (iron ore and coal) without the need for agglomeration or coking. This new process can reduce emission of primary steel production by 20% compared to a conventional blast furnace route. However, the exhaust stream of the HIsarna process in rich in CO_2, and it's expected that this CO_2 can be removed at a relatively low cost, compared to for example coal and gas-fired power plants.

Status: Currently testing a pilot facility. If successful a CO_2 capture unit could be built by 2020. A full-scale HIsarna plant, producing 1 million tonnes of primary steel per year could be built by 2024 if pilot testing is successful.

CO_2 availability: 2020 – 100 kt, 2024 – 1 Mt.

2.2.2 AEB Amsterdam

Process: AEB Amsterdam is a large waste-to-energy plant in the harbour of Amsterdam. The company joined a 'Green Deal' initiative with the Dutch Ministry of Economic Affairs to develop a CO_2 capture facility at the plant, and deliver the CO_2 to the Horticultural sector in the region. It is understood that the company has the ambition to capture 450 kt CO_2 per year (pers. comm. [redacted] The capture costs of CO_2 capture from waste incineration are however higher (€40-50/tonneCO_2) than for example hydrogen production and fermentation processes (€5-15/tonneCO_2).

Status: FEED study – ambition start capture 2020

CO_2 availability: 450 kt CO_2/yr

2.2.3 *AVR Rotterdam*

AVR is a waste-to-energy installation in the Rotterdam harbour. CO_2 capture is one of the potential routes that the company is developing to reduce its overall environmental impact. AVR has a CO_2 capture installed at a waste incineration plant in Arnhem.

Status: Design phase, ambition to deliver by 2020/21

CO_2 availability: 250 – 300 kt CO_2/yr

2.3 Development of foreseen CO_2 supply to Smart Grid 2020-2030.

Based on the current availability of CO_2 from existing sources linked to the OCAP network, and from the ambitions of a number of Smart Grid partners, and visualisation of the potential CO_2 supply to the Smart Grid is provided below (Figure 2). With CO_2 becoming available from the HIsarna demonstration plant in 2020, combined with considerable CO_2 from the waste to energy plants of AEB and AVR, the total CO_2 to be transported could reach 1.25 Mt/year by 2021. It is not clear if the waste incinerators will capture CO_2 during the entire year, as there is currently little demand for CO_2 from the horticultural sector in the winter months.

If the HIsarna pilot plant and CO_2 capture facility is successfully demonstrated, a full-size industrial plant could be realised by 2024. In this case, total potential CO_2 supply to the Smart Grid could reach 2.15 Mt/year by this time. It is highly likely that should this supply be realised, the CO_2 Smart Grid would need to be connected to additional transportation infrastructure to access geological CO_2 storage locations in the North Sea.

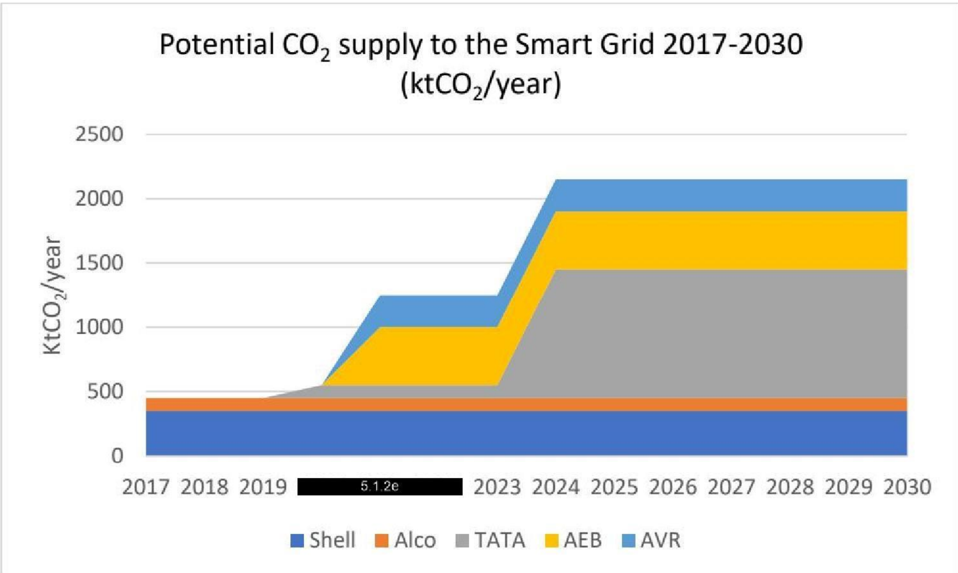

Figure 2: Potential CO_2 supply to the Smart Grid 2017-2030 (ktCO_2/year)

3 Geological CO_2 storage locations in the North Sea

The CO_2 Smart Grid Feasibility Study identified 3 strategies for a Smart Grid to develop, namely; (1) a CCU grid, (2) a demonstration-size CCUS grid and, (3) a large-scale CCUS grid. Whereas the first option of a market-driven CCU grid could be developed in the near term with limited public subsidies, the maximum societal value good be achieved by incorporating the initially CCU focused Smart Grid into a large scale CO_2 transportation and geological storage network. The latter development would require much greater intervention by the Dutch government in the form of subsidies and policy mechanisms to address the current market failures.

Should an initial CCU grid become part of a large CCUS infrastructure, there is considerable offshore CO_2 storage capacity available in either soon to be decommissioned natural gas production fields, or known saline aquifer formations in the North Sea. A number of potentially interesting fields and formations, both in terms of locations, geological suitability and storage capacity are outline below.

3.1 Q16-Maas

The Q16-Maas field is located just offshore of the Maasvlakte, and is actually produced from an onshore installation operated by Oranje Nassau Energie. The production of gas and condensates from the Q16-Maas field commenced in 2014, and is expected to continue to 2020 and perhaps later. Given the close proximity of the field to the OCAP pipeline, TNO was asked to conduct a pre-feasibility study for using the field as dual-purpose CO_2 storage, but also as a CO_2 buffering location. During periods of low demand of CO_2 from the horticultural sector in the winter, surplus CO_2 would be injected into the Q16-Maas and then re-produced once demand increased in the busier spring/summer seasons. No technical or engineering showstoppers were identified for the use of the Q16-Maas field as either a permanent CO_2 storage location, or as a dual-purpose CO_2 storage/buffer system. However further research is ongoing regarding potential reaction of the CO_2 with the geology, and the extent of gas cleaning necessary prior to delivery to the OCAP network after (re)production.

Storage capacity: ~ 2 Mt (high confidence)

Theoretical availability: 2017 (as dual-purpose buffer)
~ 2021 (as standalone storage site)

3.2 P18-4 gas field

The P18-4 field is a near-depleted gas field at a depth of 3.5 km under the seabed, located approximately 20 km off the Dutch coast in the North Sea. P18-4 is one of a number of gas fields in the P18 and P15 licensing blocks on the Dutch continental shelf of which TAQA Off-shore B.V. holds the production licenses. The gas production has reduced the field pressure from 340 bar to 20 bar, and the field has since been identified as a highly suitable CO_2 storage formation, with an approximate capacity of 8 $MtCO_2$. TAQA received an irrevocable CO_2 storage permit under the EU Directive on the geological storage of CO_2 (2009/31/EC) for P18-4 in September 2013.

Storage capacity: ~ 8 Mt (high confidence)

Theoretical availability: 2017

3.3 P18-2 gas field

The P18-2 gas field is the largest field in the P18 block, located near the P18-4 field. The P18-2 gas field is also connected to the P18-A platform. The gas field has been producing since 1992, and the original amount of gas in place is estimated at 13.4 bcm. The gas field is expected to cease production in 2018. As part of the EIA of the ROAD project conducted in 2011, an initial risk assessment for CO_2 storage in the P18-2 field has been completed. The field is expected to have much the same geological characteristics as P18-4, and therefore be very suitable for CO_2 storage. Prior to any storage permit application, the condition of a number of suspended and abandoned wells needs to be re-assessed. Based on the amount of gas originally in place, the fields has a theoretical CO_2 storage capacity of 32 $MtCO_2$.

Storage capacity: ~ 32 Mt (theoretical)

Theoretical availability: 2020 (end production +2 years for characterisation / permitting)

3.4 P15 Complex

The P15 complex is a cluster of gas fields together with the Rijn oil field located approximately 20km north-west from the P18 fields. The gas fields are connected to the P15-D platform, where the gas is processed to sales specification and exported through a 40 km 26" pipeline to the Maasvlakte, near Rotterdam. A number of gas fields, specifically the P15-9, P15-11 and P15-13 are expended but are highly suitable for CO_2 storage. An approximate total CO_2 storage capacity of 34 $MtCO_2$ is theoretically available. An initial storage assessment of the above fields concluded that the containment characteristics of the field are good and that risks for CO_2 storage are minimal 5.1.2e et al., 2011). The depleted gas fields of the P15 complex are considered as logical follow-on storage sites after P18-4 and P18-2.

Storage capacity: ~ 34 Mt (theoretical)

Theoretical availability: 2020 (end production +2 years for characterisation / permitting)

3.5 Q1 saline formation

The saline formation in the Q1 block that contains the Q1 oil fields could become the prime storage location for CO_2 captured in the Amsterdam and Rotterdam regions. The oil fields in the Q1 block, located at about 40 km west of Den Helder, are close to the end of production, producing both water and oil. Water has been injected to optimize production from the fields. The water has been drawn from the saline formation in the crests of which are located the oil fields. As a result of these production activities, the pressure in the saline formation is now well below the hydrostatic (original) pressure. The voidage created by the production of water and oil can be used for CO_2 storage. A preliminary estimate of the storage capacity of the saline formation is in the order of 100 Mt CO_2 [redacted] et al., 2011). Continuing production of saline formation water is also an option, which could further increase the field's storage potential significantly. In addition to the significant storage capacity, the saline formation can potentially accommodate high to very high injection rates (several megatonnes per well per year).

Storage capacity: ~ 100 Mt + (theoretical)

Theoretical availability: 2024 (needs further site characterisation and test injection, plus permitting)

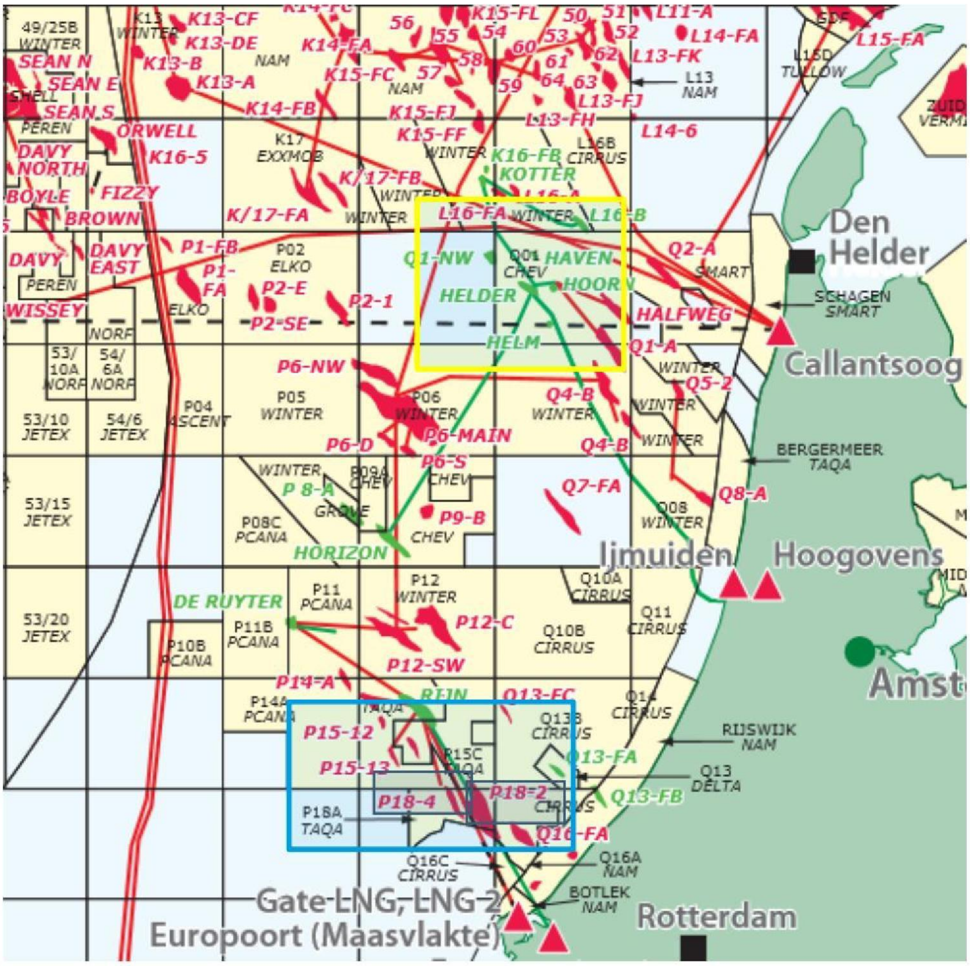

Figure 3: Locations of P18 and P15 gas fields (blue outline), and the Q1 saline formation (yellow outline)

4 Current and future CO_2 users

4.1 Demand from the horticultural sector

The Netherlands greenhouse sector, or 'horticulture under glass', is a global leader in the production and export of vegetables, cut flowers and pot plants. In 2014, the production of these three groups of crops had a total added value of €5.2 billion (LEI, 2015), representing approximately 10% of the total economic output of the entire Dutch agricultural sector.

Sufficient warmth, light and enhanced CO_2 levels in a greenhouse are essential for creating the optimal growing conditions for all commercial crops. The combustion of natural gas in combined heat and power (CHP) installations, is the most common route to create such an environment[2]. Generally speaking, CO_2 concentrations in a greenhouse are normally increased to 600-1000ppm, whereby 400ppm represents atmospheric conditions.

However, steadily increasing natural gas prices, and decreasing electricity prices are having a negative impact on the economic viability of CHP installations. Growers are looking for alternative, more sustainable ways to heat, power and provide CO_2 at their facilities. The use of external CO_2, without the combustion of natural gas is growing in the Netherlands. Pure CO_2 is commercially available, however expensive. Therefore, identifying sources of suitable and affordable CO_2 for the sector can be beneficial both to reduce dependence on natural gas and accelerate the uptake of sustainable energy sources in the sector.

The current OCAP infrastructure delivers approximately 450 kilotonnes of CO_2 to around 500 greenhouses annually, representing approximately 2,000 hectares of production area (20% of total national production area). However the demand for CO_2 from greenhouses within the technically feasible delivery range of the pipeline is assumed to be much higher, at approximately 900 ktonnes per annum. It is further expected that demand for CO_2 in the provinces of North and South Holland could reach 1.2 Mt within 10 years (Ecofys, 2017). Figure 4 below shows the current extent of the OCAP pipeline, possible extensions, current and potential delivery areas and the estimated associated demand.

[2] Approximately 70% of the total greenhouse area is equipped with a CHP installation.

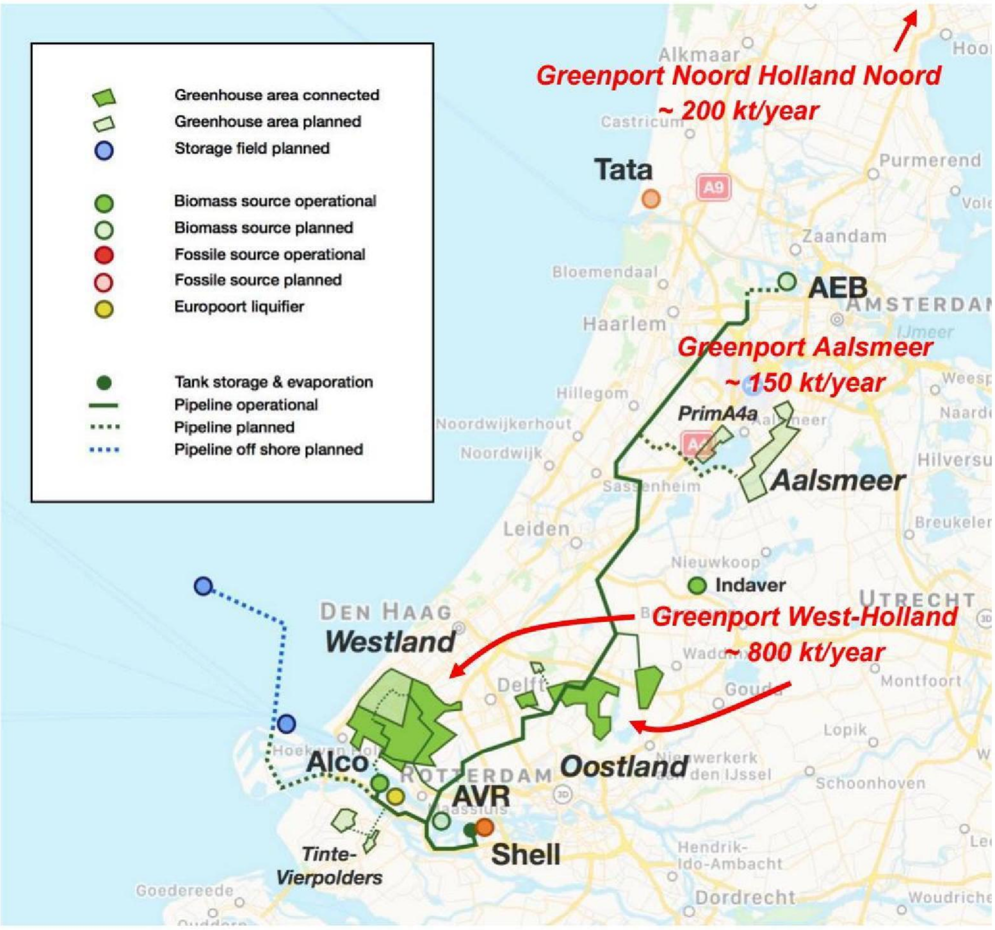

Figure 4 Current OCAP pipeline, potential expansion routes, delivery areas and associated demand Courtesy of OCAP).

4.2 Future CO_2 users

The future demand for CO_2 has been extensively assessed in the CO_2 Smart Grid Pre-feasibility Assessment (Ecofys, 2017). The report identifies a number of potential process that could require demand for CO_2 in the future (see Table 2). Although additional demand could arise, it's impossible to identify in which locations the demand will occur. With regards to polymer process and methanol production, it would be sensible to assume that such activities may occur within the considerable chemical complex situated around the Rotterdam harbour. Given that the OCAP pipeline is also situated in this region, supplying these new process with CO_2 from the Smart Grid is unlikely to warrant major investments. For carbonate mineralisation, which is generally associated with cement and concrete production, the potential location for such new processes are far less certain, as these activities are not currently found within the vicinity of the OCAP pipeline.

Table 2 CCU technologies potential for the Netherlands between 2017 and 2027 (Ecofys, 2017)

CCU technology	TRL	Current 2017 kt CO_2	Near term (5 years) kt CO_2	Long term (10 years) kt CO_2
Horticulture	9	400-500	850-1000	1200
Carbonate mineralization	4-8	0	100-200	100-300
Polymer processing	8	-	12-23	30-45
Concrete curing	7-8	-	-	30
Synthetic methanol (including methane)[3]	8	-	-	220
Methanol yield boosting[4]	9	630	900	1250
Rounded total[5]		**~400**	**~1000**	**~1700**

1: See appendix C for a discussion on biogenic CO_2
2: These estimates are produced keeping the UK market potential as reference from an earlier Ecofys study for BEIS UK (Not published yet).
3: Potential of synthetic methanol is highly uncertain, see appendix B
4: This potential usually represents on-site captive CO2 from flue gases of reformer, percentage of non-captive CO_2 is very small. If CO_2 is used through an external CO_2 source then high volumes of CO2 can be supplied as indicated.
5: Excluding methanol yield boosting, as these CO_2 can be recycled in internal methanol production processes.

5 Physical extent and requirements of the CO_2 Smart Grid

5.1 The role and basic operating principles of the CO_2 Smart Grid

During an expert workshop as part of the development of this technical assessment, a number of key operating principles of the CO_2 Smart Grid were discussed and agreed upon. These key principles are outlined below:

- The CO_2 smart grid should be designed to link current and future CO_2 emitters, with current and future CO_2 users.
- The current demand for CO_2 from the horticultural sector should be a catalyst for broader deployment of a CO_2 delivery grid for future applications.
- A 'smart grid' should have the capability to balance supply and demand.
- The smart grid should be able to manage daily demand, as well as seasonal demand.
- The smart grid should be able to improve the security of supply for CO_2 users, but also open new markets for CO_2 suppliers.
- Geological CO_2 storage/buffering should be used when CO_2 demand is low.

5.2 Current extent and capabilities of the OCAP CO_2 Network

The OCAP pipeline is expected to be the foundation, or 'backbone', for the future development of the CO_2 Smart Grid. The OCAP pipeline has a total annual transport capacity of 3-3.5 $MtCO_2$ at the standard operation pressure of 21 bar, and therefore sufficient to transport the amounts of CO_2 potentially becoming available for the Smart Grid towards 2030.

The OCAP pipeline is in good condition and can certainly operate for a further 20 years without significant renovation work. The pipeline could operate at higher pressures of up to 60 bar, which would increase the total capacity, however this would require additional investment to allow the infrastructure to operate at higher pressures.

5.3 Basic planning and identification of required extensions to supply and demand

In the phase towards 2024, there are three potential extensions of the OCAP pipeline to establish the CO_2 Smart Grid:

Pipeline connection	Length	To be realised by
OCAP pipeline Amsterdam Westpoort to TATA Steel – Velsen-Noord	~ 30 km	2020
OCAP pipeline Amsterdam Westpoort to AEB Amsterdam	~ 1.5 km	2020
OCAP pipeline inlet station in Botlek Rotterdam to AVR Botlek	< 1 km	2021

It important to note that there is also an existing disused oil pipeline that has been used to transport oil from the Q1 field in the North Sea to the Amsterdam oil terminals in Amsterdam Westpoort. The pipeline section near the oil terminals is within 2 km of the current OCAP pipeline. On it way to the coast, the trajectory of the pipeline passes to the East of the town of Beverwijk, which is within approximately 5 km of the TATA Steel site in Velsen-Noord. OCAP have investigated the suitability of reusing this pipeline for the purposes of transporting CO_2 and have found limited technical barriers for doing so. Therefore although the distance between the OCAP end station in Amsterdam Westpoort and TATA Steel in Velsen-Noord is approximately 30 km, the bulk of this distance for the transportation of CO_2 could be bridged by the reuse of this existing pipeline. This opportunity can therefore reduce the costs of extending the OCAP pipeline to TATA Steel considerably.

With regards to the supply of CO_2, particularly for the horticultural sector in Greenport West-Holland, the infrastructure is largely in place to supply the approximate 800 kt CO_2 needed per year. OCAP is also expanding its distribution network to Greenport Aalsmeer, and expects to be able to start delivering CO_2 to part of the area by 2018, with further expansion in the area by 2020 (Goedemorgentomaat, 2018). Beyond the horticultural sector, it is too early and uncertain to pinpoint where potential pipeline extensions may be needed to reach future CO_2 users.

5.4 Identification of engineering works that could be necessary

Based on the potential connections to future CO_2 suppliers, and assuming the OCAP pipeline would be extended towards TATA Steel partially using an existing pipeline, the following engineering works can be foreseen:

- **Pipelines**
    - Approximate 1.5 km pipeline connection from OCAP pipeline segment in Amsterdam Westpoort to AEB Amsterdam.
    - Approximate 0.5 km pipeline connection from OCAP pipeline inlet station in Botlek Rotterdam to AVR Botlek
    - Approximate 2 km pipeline connection from OCAP pipeline segment in Amsterdam Westpoort to the disused Q1 pipeline.
    - Pipeline connection from Q1 pipeline segment to the East of Beverwijk, to the TATA Steel premises in Velsen Noord (distance may be between ~5-15 km dependent on route of new pipeline)
- **Other equipment**
    - Compressor stations may be need at the new CO_2 sources of AVR, AEB and TATA Steel. The size and type of compression units will be dependent on the amount of CO_2 to be captured, but also the type of CO_2 capture unit chosen at each site. Some capture units result in high pressure CO_2 streams.
    - There is also an opportunity to supply the Greenpoort NoordHollandNoord in the Dutch province of West Friesland, with CO_2 from the Smart Grid. However a pipeline will be too costly, to in this instance, a CO_2 liquefaction installation with buffering tanks would be needed to facilitate CO_2 transport by truck and trailer.
- **Geological storage**

- Suitable CO_2 storage sites can be identified for the advanced stages of the CO_2 Smart Grid, should it become part of a national CCUS infrastructure in the Netherlands.

In realising the above engineering works, no technical showstoppers have been identified. All technology needed to expand the OCAP pipeline to a CO_2 Smart Grid is commercially available from companies operating in the Netherlands.

5.5 Provide high-level estimates of investment requirements for the infrastructure development

Its currently not feasible to provide investment costs for the necessary infrastructure development. Such cost estimates are dependent on, amongst other things, pipeline routing, pipeline dimensioning, material use, operating pressures and capacity utilisation. The potential reuse of an existing pipeline further complicates matters.

However from the infrastructure needed to realise the initial phase of the Smart Grid, it can be confirmed that the largest investment is related to the realisation of the pipeline link between the OCAP pipeline in Amsterdam, and the TATA Steel plant in Velsen-Noord. The two shorter pipelines to AEB and AVR from the OCAP pipeline are not expected to incur high investment costs.

Once more information can be made available by the CO_2 Smart Grid Steering Committee regarding some of the issues listed above, cost estimates be derived.

6 Conclusions

From this initial Technical Concept Assessment of the CO_2 Smart Grid, a number of key conclusions can be drawn:

- The development of a CO_2 Smart Grid is technically feasible and no engineering showstoppers have been identified. All technology to realise the infrastructure needed for the concept is commercially available.
- The greatest technical challenges are associated with the emergence of new and innovative processes to valorise CO_2 to produce low-carbon, market-driven products.
- Should the CO_2 Smart Grid expand to include geological CO_2 storage, effort will be needed to identify the most suitable and efficient CO_2 storage sites in the North Sea.
- The greatest investment cost of realising the initial phase of the CO_2 Smart Grid are associated with the realisation of the pipeline link between the OCAP pipeline in Amsterdam, and the TATA Steel plant in Velsen-Noord. This conclusion is valid regardless of the re-use of existing pipeline infrastructure.
- The two shorter pipelines to AEB and AVR from the OCAP pipeline are not expected to incur high investment costs.

6.1 Recommendations

It is recommended that within the CO_2 Smart Grid consortium, an engineering working group is established to further discuss the required infrastructure needed to realise the initial phase of the project. In particular, the link between the OCAP pipeline and TATA Steel will require frequent dialogue given the technical, spatial, societal and economic aspects of this piece of infrastructure. It is recommended that this group meets on a quarterly basis.

More generally, it is also recommended that this document is used as a basis for discussion in identifying concrete plans for the realisation of a CO_2 Smart Grid, and once further details are made available to TNO by consortium members, the document can be supplemented with further technical analysis and cost estimates.

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To: [redacted] [[redacted]@rijswijk.nl]; [redacted] [[redacted]@pzh.nl]; [redacted] [[redacted]@pzh.nl]; [redacted] [[redacted]@rijswijk.nl]; [redacted]@shell.com' [[redacted]@shell.com]; [redacted] [[redacted]@denhaag.nl]; [redacted]; [redacted]@delft.nl' [[redacted]@delft.nl]; [redacted]; [redacted] [[redacted]@denhaag.nl]; [redacted]
Cc: [redacted] [[redacted]@mrdh.nl]
From: [redacted]
Sent: Fri 2/23/2018 12:04:20 PM
Subject: FW: Kernpunten Bestuurlijk Overleg Shell Rijswijk
Received: Fri 2/23/2018 12:04:25 PM
18 02 15 CONCEPT - Kernpunten bestuurlijk overleg Shell Rijswijk.docx

Beste mensen,
Hierbij ontvangen jullie de kernpunten van het bestuurlijk overleg.
Groet,
[redacted]

Van: [redacted]
Verzonden: vrijdag 23 februari 2018 08:58
Aan: 'Gemeente Rijswijk [redacted]; [redacted]@rijswijk.nl'; 'gedeputeerde Bom'; [redacted]@shell.com'; [redacted]; [redacted]@shell.com'; [redacted]@shell.com'
Onderwerp: Kernpunten Bestuurlijk Overleg Shell Rijswijk

Geachte deelnemer van het Bestuurlijk Overleg Shell,
In de bijlage de (concept) kernpunten uit het Bestuurlijk Overleg Shell Rijswijk van 15 februari jl.
Het volgende overleg vindt plaats op **maandag 23 april 2018, 9.30 uur** op het *Hoofdkantoor Shell Nederland B.V, Carel van Bylandtlaan 16 – Brent zaal*
De bijlagen voor dit overleg ontvangt u uiterlijk 18 april a.s. Hierin zijn we afhankelijk van de snelheid waarmee de bureaus de input zullen aanleveren.
Met vriendelijke groet,

[redacted]

MRDH
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Postbus 21012 | 3001 AA | Rotterdam
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Screening LCA for CCU routes connected to CO_2 Smart Grid

CE Delft

Committed to the Environment

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Screening LCA for CCU routes connected to CO_2 Smart Grid

This report is prepared by:
[redacted]

Delft, CE Delft, 26 February 2018

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Carbon dioxide / Sources / Capture / Technology / Utilization / LCA

Client: Ministry of Infrastructure & Water Affairs

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Further information on this study can be obtained from the contact person [redacted] (CE Delft)

CE Delft
Committed to the Environment

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Content

Summary

[redacted] agreement requires significant steps in order to achieve reduction of greenhouse gases of 90-95% CO_2 eq. compared to 1990 levels. One of the possible steps is the application of novel technologies like the reuse of CO_2 in a value chain. This is attractive if can cover the cost of the capture of CO_2, while the ETS-price level is still very low. In the two Dutch provinces of North- and South-Holland, a consortium of more than 20 public and private parties is launching an initiative (CO_2 Smart Grid) aimed at utilizing CO_2 as a raw material for a circular economy (Carbon Capture and Utilization, or shortly CCU). To this end, a network will be developed in which CO_2 from different sources can be made available to different users. The proposed backbone of this network is the existing OCAP CO_2 pipeline, which already provides CO_2 from Shell in Pernis and ethanol producer [redacted] to the horticulture sector in the Westland region for growth promotion of crops.

This study focusses on the Life Cycle Assessment (LCA) of different CCU routes applicable in the CO_2 Smart Grid. The results of this study can serve as input for a to-be conducted Social Cost Benefit Analysis.

CCU routes

This study compares the environmental impact of nine different CCU routes on the basis of '1 tonne of CO_2 captured in 2030 and subsequent utilization'. The nine routes are a combination of CO_2 capture options from three different sources and utilization of the CO_2 in three different applications. Table 1 gives an overview of the CCU routes considered in this LCA. Furthermore these nine different CCU routes are compared with Carbon Capture and Storage (CCS) as a reference.

Table 1 – CCU routes

CO_2 source |Utilization	Horticulture	Mineralisation	Methanol production
Waste incineration	Route 1	Route 2	Route 3
Blast furnace process and blast furnace gas	Route 4	Route 5	Route 6
Fossil oil refining	Route 7	Route 8	Route 9

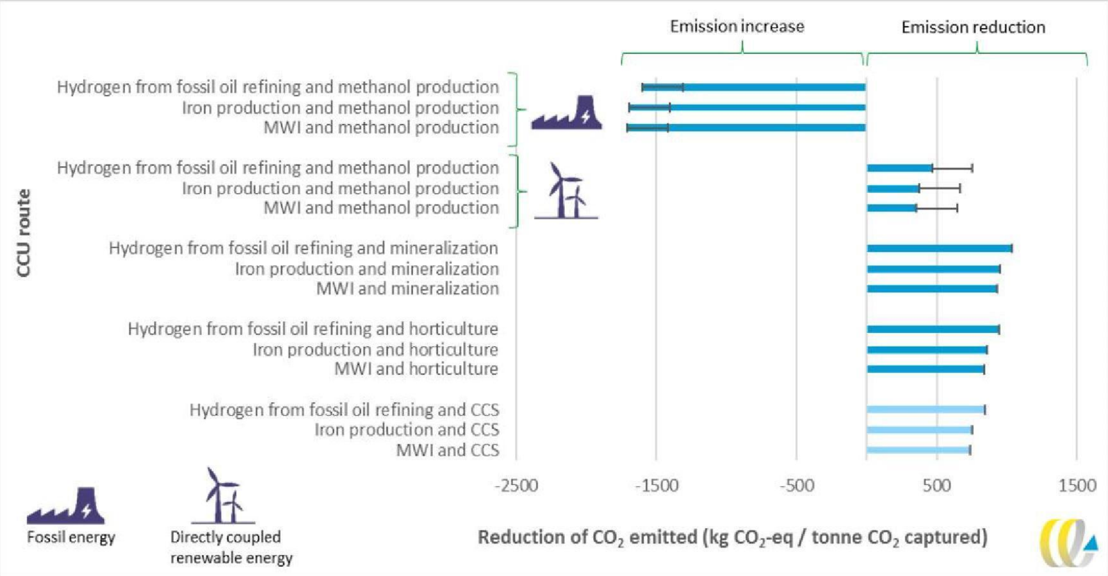
Of course there are many more CCU routes possible in the Netherlands, but this study has been limited to nine different routes which are considered relevant for the region of North-Holland (Tata Steel) and South-Holland (Rotterdam Harbour Industrial Complex).

Climate change impact of CCU routes

Reduction of climate change impact

All of the routes considered lead to a reduction of climate change impact compared to non-capture, as can be seen in Figure 1.

Figure 1 - Reduction of climate change impact per CCU route in comparison to non-capture



Note: The black bar for methanol production indicates use of methanol for fuel (lowest reduction) and methanol use as chemical where CO_2 is stored for more than 100 years (highest reduction).

The extent to which this is the case is dependent on:

- the duration of carbon storage in the produced products (e.g. permanent storage in case of mineralisation of CO_2 in mineral construction materials);
- the quantity of energy used by the capture technology;
- the quantity of energy used by the utilization technology;
- the carbon footprint of the product that is replaced (e.g. avoidance of natural gas burner to supply Dutch horticulture with CO_2 for increased plant growth).

Utilization in mineralisation

Utilization of CO_2 for mineralisation, the production of one type of mineral material (compensatie-steen), leads to net avoided CO_2 emissions of around 1 tonne of CO_2 per tonne of CO_2 captured. Despite the carbon footprint of the capture technologies, the produced Compensatiesteen avoids production of conventional sand-lime brick. When the capture technologies have a lower carbon footprint (e.g. when in the future renewable electricity mix is used), utilization in mineralisation could even lead to net negative CO_2 emissions. This means that more CO_2 emission is prevented than CO_2 captured.

Utilization in horticulture

The utilization of CO_2 in horticulture leads to net avoided CO_2 emissions of around 900 kg CO_2 per tonne of CO_2 captured. This is a comparable or better performance than CCS (see Figure 1). The net avoided CO_2 emission is caused by the avoided use of natural gas for the production of CO_2 in horticulture. This conclusion is valid until the horticulture sector made a transition to a renewable heat source (e.g. geothermal heat).

The possible sources for CO_2 supply in horticulture (the reference) in towards 2040-2050 is unknown because the future benchmark for heat supply in greenhouses has yet to be determined. A possibility is the use of biomass in CHP for both heat and CO_2 production, but also geothermal heat supply without associated CO_2 emissions is an option. The geothermal scenario would fully depend on an external source of CO_2, which can be delivered by the CO_2 Smart Grid. Whether or not the application of captured CO_2 aids the shift towards renewable energy and what would be the appropriate reference CO_2 source to consider in the future is a topic that needs further discussion. Therefore the exact carbon footprint reduction after a switch to a fully renewable heat source in the horticulture sector is uncertain and depends on the outcome of different scenario's.

Utilization in methanol production

Utilization in methanol production will lead to net avoided CO_2 emissions when 100% renewable energy is used for methanol and hydrogen production. If fossil-based electricity is used in the process, more CO_2 is emitted than captured. The net avoided CO_2 emissions will increase when the CO_2 is used in durable products. 'Durable' in this context implies that CO_2 is sequestered for more than 100 years. In that case, this utilization method could reach net avoided CO_2 emissions of around 700 kg CO_2 per tonne of CO_2 captured. This is comparable to CCS (see Figure 1). A lot of renewable electricity is required to produce hydrogen for methanol production on a large scale. We assume additional renewable electricity supply (e.g. directly linked windfarms), ample availability of this renewable electricity for producing hydrogen, and that the use of this electricity does not compete with utilization in applications leading to lower net CO_2 emissions.

It must be noted that methanol production is not the only possible application of CO_2 in the chemical industry. The reason that methanol was selected is, apart from the availability of data from the demonstration plant in Iceland, that it is a so called platform chemical with a wide range of products which are currently based on fossil oil and gas. Other possible CO_2 utilization routes in the chemical industry include the production of polyols for the production of polyurethanes. Conclusions drawn on methanol production should thus not been seen as exemplary for CO_2 utilization in the chemical industry.

Other environmental benefits

For several reasons, no conclusions could be drawn on other environmental impacts:

- additional benefits caused by the additional cleaning of CO_2 containing (flue) gas during the capture process are unknown;
- emissions from degradation of absorbents are unknown.

Interpretation of the conclusions

The orders of magnitude of CCS and CCU applicability in 2030 are expected to be incomparable. E.g. the potential storage by means of CCS is expected to be much higher than the potential for use of CO_2 in mineralization in the Netherlands. Results must therefore only be seen on a per tonne basis and cannot be extrapolated. The spatial application of the technologies also differ, e.g. CCS can be applied the whole year round while the peak of CO_2 utilization in horticulture is during the growing season and less so in winter.

Because the study carried out is a screening LCA, the drawn conclusions should be seen as indicative figures; they offer an order of magnitude estimation and cannot be seen as representative for individual (industrial) plants present in the Netherlands. Furthermore the results are not appropriate for national carbon accounting. This means that when calculating the emissions of the Netherlands as a whole the presented reduction in CO_2 emissions cannot be taken into consideration. The same holds for using the outcomes for corporate carbon accounting practices.

To make the results applicable to individual CCU routes e.g. CO_2 capture at the AEB MWI in Amsterdam and application of the CO_2 in horticulture in Aalsmeer, a full scale LCA study will need to be conducted based on the actual variables chosen for the specific installations.

1 Introduction

In the two Dutch provinces of North- and South-Holland, a consortium of more than twenty public and private parties is launching an initiative - CO_2 Smart Grid - aimed at utilizing CO_2 as a raw material for a circular economy (Carbon Capture and Utilization, or shortly CCU). To this end, a network will be developed in which CO_2 from different sources can be made available to different users. The proposed backbone of this network is the existing OCAP CO_2 pipeline, which already provides CO_2 from Shell in Pernis and ethanol producer [redacted] to the horticulture in the Westland region for growth promotion of crops.

Ecofys has conducted a pre-feasibility study in which they identified in which applications CO_2 could be utilized in North- and South-Holland in the short term (5-10 years) (Ecofys, 2017) Table 2 shows the results of the pre-feasibility study. In this pre-feasibility study, Ecofys did not analyse the source of the used CO_2.

Table 2 - Overview of identified prospective utilization application of CO_2 as raw material

CCU technology	TRL	Current (2017) (kt CO_2)	Near term (5 years) (kt CO_2)	Long term (10 years) (ktCO_2)
Horticulture	9	400-500	850-1,000	1,200
Carbonate mineralization	4-8	0	100-200	100-300
Polymer processing	8	-	12-23	30-45
Concrete curing	7-8	-	-	30
Synthetic methanol (including methane)	8	-	-	220
Methanol yield boosting	9	630	900	1,250
Rounded total		**~400**	**~1,000**	**~1,700**

Source: Table from (Ecofys, 2017). 'Methanol yield boosting' is specifically related to methanol production at BIOMCN in Delfzijl.

According to studies of Ecofys and CE Delft the various capture and application routes are not profitable under current market conditions. The various capture and application routes could have a social advantage, in particular because they could lead to a CO_2 emission reduction, and application might therefore provide a benefit from a societal perspective. This potential benefit can be made explicit by means of a Social Cost Benefit Analysis (SCBA). The basis of such a SCBA is a Life Cycle Analysis (LCA) in which environmental impacts are quantified. The LCA is commissioned by the Ministry of Infrastructure & Water Affairs, the MKBA will be commissioned by BLOC, both on behalf of the CO_2 Smart Grid consortium.

This study focusses on the LCA of different CCU routes applicable in the CO_2 Smart Grid. The results of this study can serve as input for the later SCBA. The study is conducted under supervision of the client, process supervisor BLOC and the core working group of the consortium.

2 Methodology

The Life Cycle Assessment (LCA) methodology is used to determine the environmental impact of a product or service throughout the entire life cycle. It can be used to compare the environmental impact of different products or services. Because the different CCU routes do not provide the same product, although CO_2 is captured in all CCU routes, a substitution approach is used. See Section 2.3.

The reporting methodology for LCA is set by the ISO14040 and ISO14044 guidelines for Life Cycle Assessment. The main lines of these methodological guidelines are followed with the important note that this study is a screening LCA, and not a full scale Life Cycle Assessment. A screening LCA aims to give an indication of the comparative environmental impact and recognizes the uncertainties because of the short span in which this study is carried out.

A number of important methodological choices are described in this chapter.

2.1 Goal and scope definition

2.1.1 Goal of the study

The main goal of the study is to identify the environmental hotspots in the different CCU routes, and make a comparison of the different routes.

The main goal is reached by:
- examining the net avoided CO_2 emission for the CCU routes;
- examining the implication of the different storage times during which the CO_2 is utilized in the intended applications;
- examining possible other environmental impacts of the CCU routes.

2.1.2 Scope of the study

In order to make a comparison, a unit of comparison needs to be defined. This unit of comparison is called the **functional unit**. The functional unit is defined as:

1 tonne of CO_2 captured in 2030 and subsequent utilization.

Different utilization-routes produce different products/services. CCU is a multifunctional system generating both the service of capturing of CO_2 as well as utilizing the CO_2 in a product/service. Since the aim of this study is to provide insight into the environmental benefit of the entire CCU process, and not into a single product, the functional unit has been set in such a way that it follows one tonne of captured CO_2 through the entire process.

There are many CCU routes possible in the Netherlands of which nine different CCU routes are compared in this study. These nine routes are based on CO_2 capture options from three different sources and utilization of the CO_2 in three different applications. A selection of routes has been made based on expected availability of CO_2 in 2030, technology readiness level and the compatibility with current industry. Table 3 gives an overview of the nine different CCU routes that are considered in this

LCA. Furthermore these nine different CCU routes are compared with Carbon Capture and Storage (CCS) as a reference.

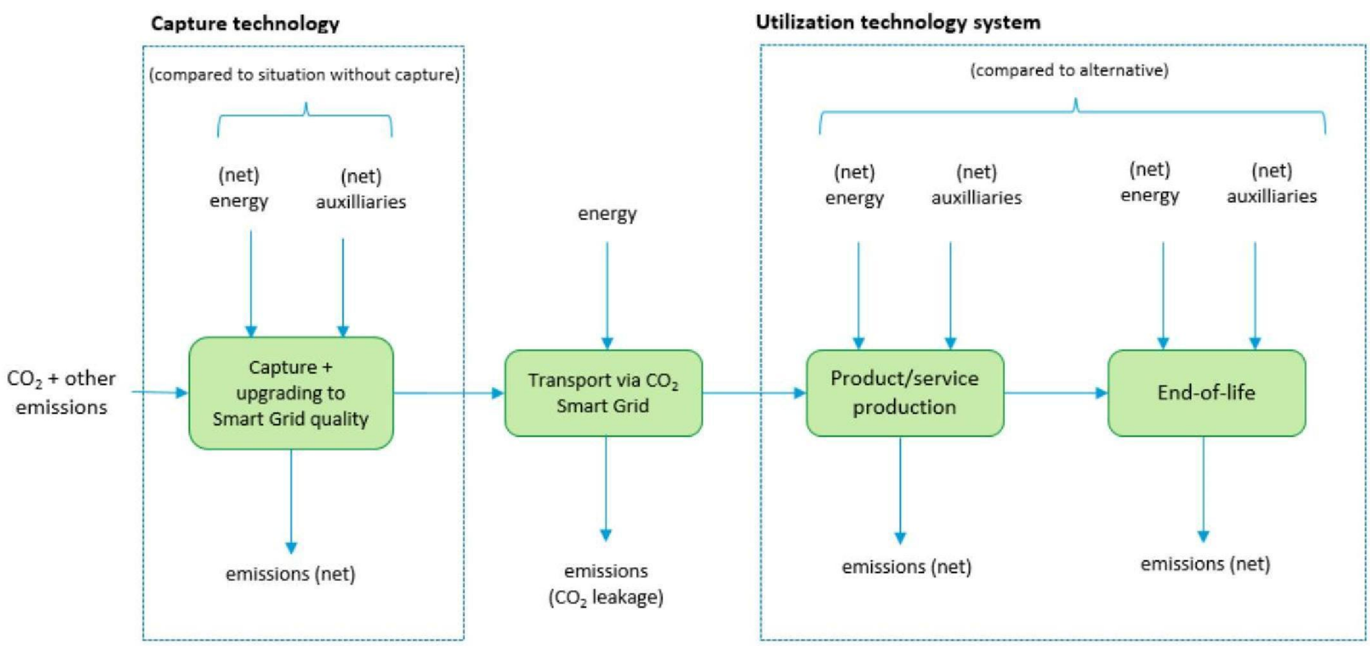
Table 3 – CCU routes

CO_2 source |Utilization	Horticulture	Mineralisation	Methanol production
Waste incineration	Route 1	Route 2	Route 3
Blast furnace process and blast furnace gas	Route 4	Route 5	Route 6
Fossil oil refining	Route 7	Route 8	Route 9

This study compares the fulfilment of the functional unit of these nine CCU routes within the **system boundaries** as shown in Figure 2. All green filled boxes represent life cycle phases that are taken into consideration in this study.

For every life cycle phase, material and energy use are taken into consideration as well as all environmental emissions relevant to the environmental impact categories considered in this study (see Section 2.2). Figure 2 shows the general system boundaries. The exact capture technology and utilization system differ per CCU route. The product or service produced because of the utilization of CO_2 also differs per utilization method. For the system description per CCU route see Chapter 3.
The CO_2 source is outside of the system boundaries this means that e.g. the production of iron is considered to occur whether or not CCU is applied. The systems of iron production and CCU are therefore seen as two different production systems.

Figure 2 - System boundaries of CCU



Note: All life cycle phases with a green filling are taken into consideration in this study, including energy and auxiliary use as well as emissions.

2.2 Environmental impact categories

This study uses the ReCiPe2016 methodology to examine the environmental impact of the different CCU routes[1]. The ReCiPe2016 Midpoint Hierarchist Approach (v.1) has been chosen as it is included in the SimaPro Software (v.8.4). A wide range of different environmental impacts are included in the ReCiPe-methodology and can be studied with LCA. Within the limited time frame of the study only global warming potential (CO_2 eq. emissions) are quantified. Qualitative statements will be made on other relevant environmental impacts such as fine particulate matter formation and acidification.

2.3 Dealing with a multifunctional system

As described earlier the different utilization-routes produce different products/services. CCU is a multifunctional system generating both the service of capturing of CO_2 as well as utilizing the CO_2 in one or multiple products.

The choice of functional unit leaves us with the issue of how to show the benefit of the produced product/service per utilization method. According to ISO14044, there are different approaches if a system under study has multiple functions. The preferred approach according to ISO14044 is to prevent needing to allocate environmental burdens between the different products/services delivered by a CCU route. Allocation of environmental burdens based on economic or physical relationships introduces uncertainties into an LCA study. In the case of the produced product/service we therefore opt for preventing allocation.

Different approaches can be taken to prevent allocation, the most common ones being system expansion and substitution. The different CO_2 utilization routes produce different products/services. Using system expansion would require that all possible products are accounted for in all different options, creating very large systems that make the comparison of the actual CO_2 utilization options complex. We therefore apply substitution by assuming prevention of the currently applied production method for the product or service. The products/services prevented are described per utilization method in Chapter 3.

2.4 Fossil and biogenic CO_2

LCA convention such as e.g. the EN 16760 norm states that to assess climate change impact, all biogenic and fossil CO_2 emissions and removals should be considered. In this study not all life cycle stages are included for the CO_2 sources. For example the biogenic CO_2 uptake (removal) in biogenic products that are eventually treated as waste in an MWI are not taken into consideration in this study.

This means that no comparison can be made of the difference in impact over the entire life cycle of the biobased material and e.g. the fossil-based material in case of the coal-fired power plant. That is also not the purpose of this study. Therefore no environmental distinction is made in this study on the environmental impact of the emission of biogenic and fossil-based CO_2. In the case future studies are carried out in which the production phase of the CO_2 source is taken into consideration, the emission of the two types of CO_2 is distinguished in the figures and tables in this study.

[1] For the full methodological report see (Huijbregts, et al., n.d.).

2.5 CO_2 storage period

CO_2 is stored for different time periods in the different products considered in this study. The ILCD-guidelines (JRC European Commission, 2010) state that:
"temporary carbon storage and the equivalent delayed emissions and delayed reuse/recycling/recovery within the first 100 years from the time of the study shall not be considered quantitatively."

We therefore only consider only two different CO_2 storage periods:
- 100 years or less, not leading to CO_2 emission reduction;
- more than 100 years, leading to CO_2 emission reduction.

In reality also a temporary storage of CO_2 (e.g. for 40 years) can have an environmental impact. Considering those differences is outside of the scope of this study, and not (yet) common in carbon accounting.

2.6 Electricity use: changes in energy demand and energy production

Changes in the energy demand and energy production are compensated for by extra production of fossil energy (Agentschap NL, CBS, ECN, PBL, 2012). This method ('de referentiepark-methode') is used in the monitoring and evaluation of energy- and climate policies in the Netherlands. In this study we use this marginal approach to the energy system in line with Dutch convention.

Per year ECN determines a CO_2 emission factor for the exact energy production facilities being used to compensate for the increased energy demand or decreased energy production. ECN has also determined a projection for this CO_2 emission factor for the years 2020, 2023 and 2030.
The CO_2 emission factor is 0.67 kg CO_2/ kWh in each of these years (ECN, 2017). Since this study looks at CCU options in the year 2030, we use this emission factor.

3 CCU routes & system boundaries

The CO_2 sources and the technologies used for carbon capture from the three different CO_2 sources are further described in Section 3.1, purification and compression is described in Section 3.2 and the utilization technologies are described in Section 3.3. Combining the three sources with the three utilization technologies leads to nine CCU routes that are examined in this study.

3.1 CO_2 sources and carbon capture

Three different industrial processes are considered as source for CO_2 capture:
- waste incineration;
- blast furnace gas from the blast furnace process (iron production);
- fossil oil refining.

These different CO_2 sources were selected based on the expectation that these sources will still be available in 2030 and beyond and because these sources emit significant amounts of CO_2 annually and can hence supply a relevant amount of CO_2 to a CCU grid. Furthermore, these sources are through individual plants already connected to the OCAP infrastructure, which forms the basis of the CO_2 Smart Grid, or can in the near future be connected without large (technological) obstacles.
Each of these sources and the technology used to capture the CO_2 are discussed per source below. For each source the carbon capture is assumed to be an addition to the current practice (tailpipe capture of CO_2) and no more amendments are assumed to be made to the current business of an industrial plant except the accommodation CO_2 capture.

3.1.1 Municipal waste incineration plants (MWI)

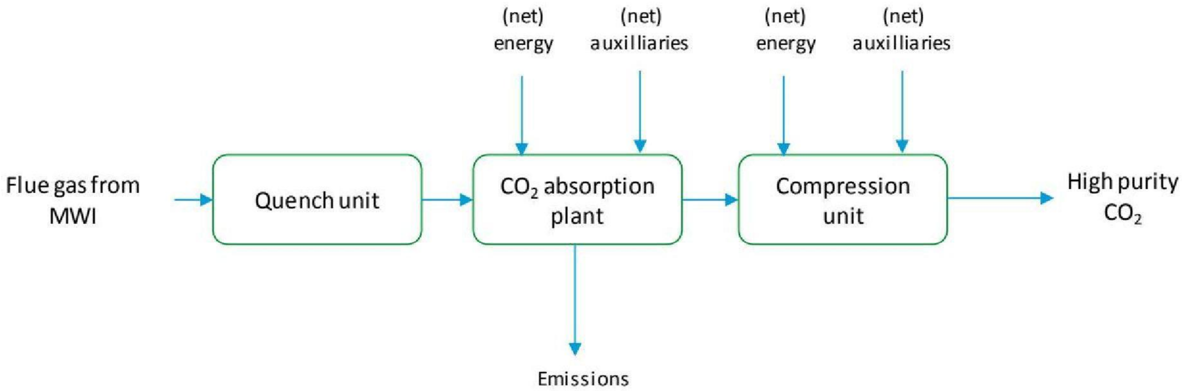
The Dutch circular economy policies aim to reduce the quantity of waste being used for energy recovery and instead to increase recycling of waste streams. We expect, however, that considering the speed at which the circular economy is taking shape in the Netherlands, waste incineration still has a role in 2030. Waste incineration plants are therefore considered to be a relevant source for CO_2 capture. Other reasons for their relevance as CO_2 source include:
- Flue gas of MWI is a point CO_2 source.
- There is an incentive for reducing waste production from the circular economy policies and the public opinion of MWI-plants is that they are not as favourable as recycling of material. The application of carbon capture at an MWI will therefore not lead to continued waste incineration when this would not be the case without CO_2 capture (no lock-in is created).
- A part of the CO_2 emissions from MWI are biogenic, since the MWI incinerates biogenic material such as garden and kitchen waste.

CO_2 emissions at MWIs are assumed to be captured by an innovative absorption technology in a CO_2 absorption plant. This technology has been developed by Procede Gas Treating, and is selected for its high Technology Readiness Level. The technology is currently applied in Delta (British Columbia) and at Twence in the Netherlands.

This technology uses Bilisol as an absorbent. This is a biodegradable solvent developed by Procede with a low degradation rate and very low volatility. A schematic representation of the processes is given in Figure 3. The hot flue gases are cooled to approximately 50°C and cleaned in a quench. CO_2 is next captured by scrubbing the flue gas with a Bilisol solution, after which Bilisol is regenerated in a separate reactor vessel heated with low-pressure steam from the MWI. Recovered high purity CO_2 (≥ 99.95 vol%) is next dehydrated and compressed to the necessary pressure for the CO_2 Smart Grid.

The use of low-pressure steam from the MWI leads to a reduction of the production of electricity. The reduction in electricity production is approximately 0.25 MWe per MW heat extracted[2].
As described in Section 2.6 the reduction in electricity production is compensated by extra production of fossil electricity.

Figure 3 - Schematic representation of carbon capture at MWIs



The capture of CO_2 emissions at MWIs is a special case, as the input, and therefore CO_2 emissions, are partly of biogenic origin. The biogenic content of the waste incinerated at MWIs is approximately 64%.[3]. As described in Section 2.4, we present the biogenic CO_2 emissions but do not make a distinction between the environmental impact of biogenic and fossil-based CO_2 emissions.

For the LCI of this capture technology see Annex A.

3.1.2 Blast furnace gas from the blast furnace process

Even in a circular economy there will be demand for primary, ore based high-grade flat steel as used in e.g. car manufacturing, due to losses and downgrading in quality of materials. Such high-grade steel can only be produced by way of the blast furnace production route for iron, as utilized at e.g. Tata IJmuiden. Tata IJmuiden is globally one of the most technologically advanced producers of such high-grade steel and is also one of the few producers operating competitively (Tata Steel, 2016) in a market plagued by overcapacity. It would hence be likely that Tata IJmuiden is still operational in 2030 and beyond. Based on this perspective, CO_2 capture from blast furnace gas at Tata IJmuiden is proposed as one of the options as feedstock for the CO_2 Smart Grid.

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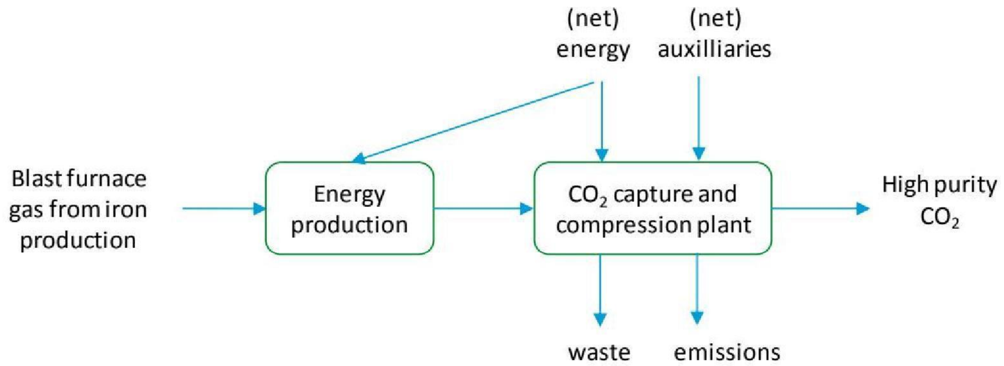
2 Personal communication AVR, December 2017. Als reported by (ECN, DNV-GL, 2014).

3 Based on data from (RIVM, 2017). Number applicable to 2015.

The blast furnace gas from Tata IJmuiden is currently fed into two different power plants (Velsen 25 and IJmond 1) where it is being incinerated to produce electricity. In case these two plants are not operational, a third plant (Velsen 24) will be used. Velsen 25 has the largest capacity of the three plants (375 MW). Therefore, this study looks at an amine-based capture method for the blast furnace process at the Velsen 25-plant. This technology is listed by the IEA as one of the primary technologies for CO_2 capture in iron production (IEA, 2013). For capture of CO_2 from blast furnace gas the amine considered is methyldiethanolamine (MDEA). After capture the CO_2 is compressed to the necessary pressure for the CO_2 Smart Grid.

Figure 4 shows a schematic representation of carbon capture from blast furnace gas from iron production for the iron production at Tata IJmuiden.

Figure 4 - Schematic representation of carbon capture from blast furnace gas from iron production



The CO_2 capture at the Velsen 25-plant leads to a reduction in electricity production of the plant. As described in Section 2.6, the reduction in electricity production is compensated by extra production of fossil electricity. An additional benefit of CO_2 capture in this way is that the heating value of the blast furnace gas increases (Zhang, et al., 2013). It has not been possible to quantify the impact of the increased heating value on the Velsen 25-plant, and the possible environmental benefit due to this is therefore not included. For the LCI of this capture technology see Annex A.

3.1.3 Fossil oil refining

The timeframe of realization of the large scale implementation of alternatives for conventional fuels (NH_3, biobased), especially for shipping, is still unclear. There are several risks that pose serious barriers to the development and implementation of e.g. biofuels. The most important risks are related to strong fluctuations in oil price, which has recently negatively impacted bioenergy manufacturers (World Energy Council, 2016). This is also acknowledged by the European Commission, stating that, in 2030, 'fossil fuels continue to be by far the dominant energy source' (GAIN, 2017). Therefore, we assume in this study that fossil oil refining is likely to remain in place until 2030. However, it should be noted that fossil oil refining is likely to lose some market share to other fuel types. The International Maritime Organization (IMO), for instance, will introduce regulations on CO_2 emissions from shipping by 2023 (IMO, 2016).

For fossil oil refineries, there are several different CO_2 emissions sources, such cracking reactors and hydrogen plants. For this sector we will consider CO_2 capture at the hydrogen plant. For capture at a hydrogen plant several different technologies are being applied commercially or demonstrated at

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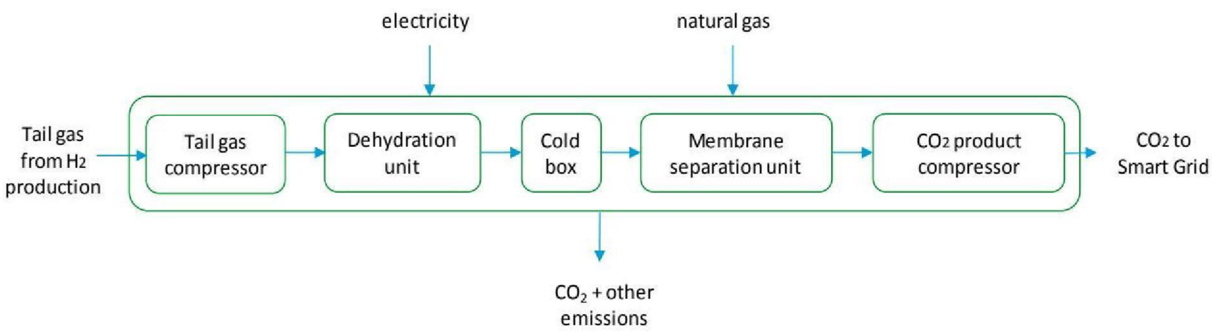
commercial scale[4]. In this case, cryogenic capture of the tail gas released during H_2 production will be considered. Benefits of this technology compared with alternative capture technologies include a very high purity CO_2 product.

Cryogenic capture (or 'low temperature separation') is based on separation principles involving the partial condensation of CO_2 and separating it from the gas phase in a distillation- or flash column (IEA, 2013). The selected specific technology is based on case 2B from IEA (2017), and includes the use of membranes in the setup of the CO_2 purification and compression unit. While not going into detail on its technological specifics, we briefly describe its components (see Figure 5):

- tail gas compressor: compresses tail gas to the required pressure of the cold box (see below);
- dehydration unit (dryers): dries compressed tail gas and lowers its temperature to below -55°C;
- cold box: contains coupled flash columns to separate the partially condensed CO_2 from the gas phase;
- membrane separation unit: recovers additional CO_2 from the output of the cold box;
- CO_2 product compressor: compresses the CO_2 to 110 bar(a).

Figure 5 - Carbon capture at H_2 production (cryogenic technology and membranes)



For the LCI of this capture technology see Annex A.

3.2 CO_2 upgrading: purification and compression

For utilization and for transport by means of the OCAP-pipeline system the captured CO_2 will have to meet specification requirements (see Table 4). In case specifications of the captured CO_2 do not meet requirements for utilization and/or transport, the CO_2 will have to be upgraded.

Table 4 - Specification requirements for applications and transportation

	Horticulture*	Mineralisation (Compensatiesteen)	MeOH production	CCS
CO_2 (vol%)	≥ 99.3%	60%	≥ 99.9%	≥ 99.9%
Pressure (bar(a))	≥ 21	unknown	50 - 100	130

* Specifications as currently met in the OCAP pipeline.

[4] These include VPSA, amine based capture (BASF MDEA, Shell ADIP X), cryogenic capture and a combination of cryogenic separation and cold methanol (see e.g. (Zero Emissions Platform [redacted] 2017).

The current OCAP-pipeline pressure is standardized at 21 bar(a). For a doubling of capacity, when realising the CO_2 Smart Grid, the pressure will need to be higher. We assume a necessity of approx. 40 bar(a) in pressure. This assumption was agreed on in the project meeting of December 5th 2017. For the CO_2 Smart Grid the purity of the CO_2 will need to be 99.9 vol% to meet the requirements of all the three studied applications.

For CCS an extra compression step until 130 bar(a) is required before injection in supercritical state.

Efficient compression to the required high pressure level of the CO_2 gas takes place in several stages. Based on polytropic efficiency in an electrically driven compressor the work per ton of CO_2 is calculated per stage using the following input variables:
- mass flow in kg/s;
- input pressure;
- output pressure;
- input temperature;
- gas compressibility;
- molar weight of the gas;
- polytropic efficiency of the compressor stage;
- electric motor efficiency.

The output pressure of the previous stage is used as the input pressure of the next stage. The next stage input temperature is after intercooling when applied. When the required pressure is reached no more stages are added. This results in the work of compression per stage which are added to deliver the total work of compression in kJ/kg CO_2 compressed.

3.3 CO_2 utilization

3.3.1 Horticulture

Enhanced CO_2 levels in horticulture in greenhouses are essential for creating optimal growing conditions for commercial crops. The CO_2 used in Dutch greenhouses is currently supplied either by CO_2 produced from the combustion of natural gas in a gas burner, a CHP-unit or delivered from the OCAP-pipeline network. This latter network is a network in South-Holland currently supplying CO_2 from [redacted] and Shell to horticulture in South-Holland.

The horticulture sector is strongly committed to sustainability, and has the ambition to become carbon neutral by 2040. A boundary condition for realizing this goal is an abundance of externally available CO_2. The availability of external CO_2 is seen by the sector as a key enabling factor in realizing this transition. Under these developments, application of captured CO_2 in horticulture provides one of most interesting and well-developed opportunities for CCU application (Ecofys, 2017).
In the provinces North-Holland and South-Holland (i.e. roughly the area around the OCAP pipeline), horticulture is said to provide a CCU potential of 500 ktonnes at the moment, with the potential to increase to 1.2 Mtonne in 10 years. For the Netherlands, this potential is estimated at 2.1 Mtonne in 2030 due to the creation of new CCU projects (Berenschot ; EEI ; MEC, 2013).

Description of utilization technology

For this utilization system we present two figures:

1. figure that shows the utilization system of the application of CO_2 from the CO_2 Smart Grid as plant growth enhancer in horticulture;
2. figure of the reference case (the alternative): using a gas burner for the generation of (useless) heat and CO_2.

The dotted line indicates the elements of the system that are taken into account in assessing the environmental benefits of using captured CO_2 in this application.

In the reference case system, natural gas is burned to generate CO_2. The heat that is unwanted in the greenhouse is released to the air. When using CO_2 from the CO_2 Smart Grid or OCAP-pipeline, the burning of natural gas is summer is no longer needed. The quantity of natural gas incinerated that can be replaced by CO_2 from the CO_2 Smart Grid is determined based on the current incineration of natural gas in the summer, when the heat is not necessary for plant growth. The choice for this approach is in line with previous research by CE Delft (CE Delft, 2017).

Figure 6 - System boundaries of utilization in horticulture – case A (current situation)

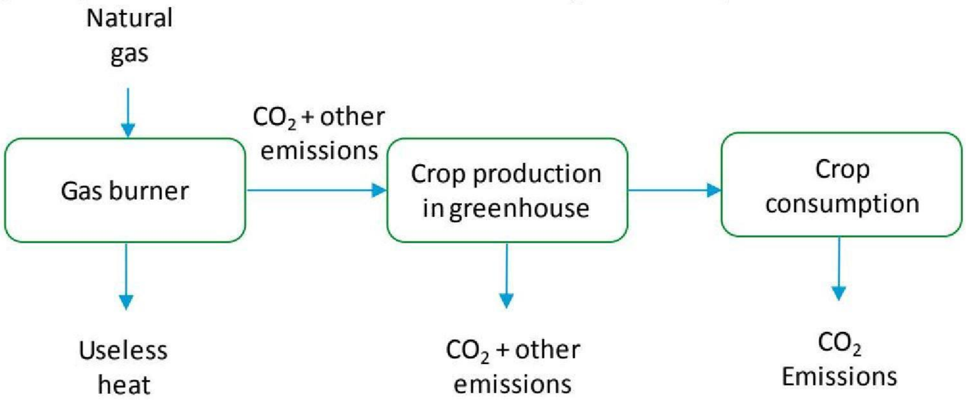
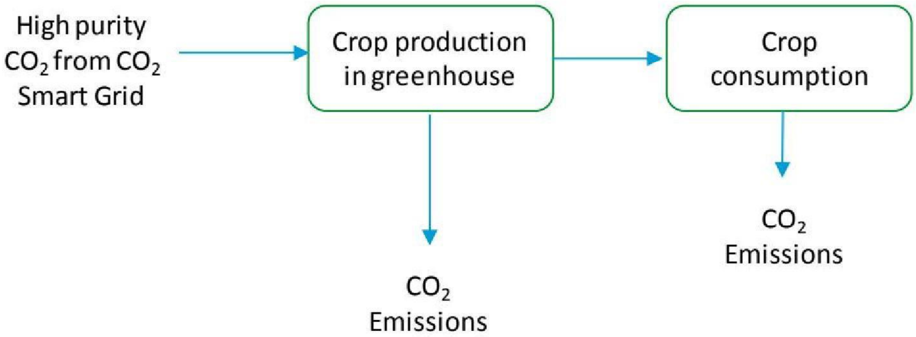


Figure 7 - System boundaries of utilization in horticulture – case B



Produced products/services

All CCU routes that include utilization in horticulture produce the following products/services:
- capture of one tonne of CO_2;
- increased plant growth.

CO_2 storage time

The CO_2 that is sequestered in plants is released back into the atmosphere relatively quickly. Therefore, the storage of CO_2 in agricultural and horticultural crops is short-cyclical. In line with conventional CO_2 accounting practices, short-cyclical CO_2 is in this study not accounted for as a reduction in CO_2 emissions.

Excluded: increased plant growth

A side effect of using a gas burner or combined heat and power (CHP) generator in summer to generate CO_2 for use in horticulture is that the production of CO_2 is limited by the production of heat. After all, crops are only able to grow properly at a certain maximum temperature. Therefore, when no heat is produced in the process of generating CO_2, i.e. by using external CO_2, the used amount of CO_2 per m^2 can be larger. This is likely to have a positive effect on the production efficiency of greenhouses (energy used per weight of crop produced) (Dieleman, et al., 2009). However, since no quantitative data is available on this issue, it has not been taken into account in this study.

Excluded: alternative CO_2 source makes energy transition possible

Currently most greenhouses in North- and South-Holland are heated by means of a combined heat and power (CHP) unit. These CHPs use natural gas to produce three products: heat, electricity (also supplied to the grid) and CO_2 used as plant growth enhancer. This means that the supply of an alternative affordable CO_2 for use as plant growth enhancer can have the effect of making a transition towards a different heating technology for greenhouses possible. This is a situation in which the abundance of external CO_2 and its application in horticulture has enabled a transition to carbon-neutral heat. Carbon-neutral heat could for example be geothermal heat, residual heat, or a combination of these and other options. Since the exact impact that using an external CO_2 source has on the energy supply is unknown, this is not included in the LCA.

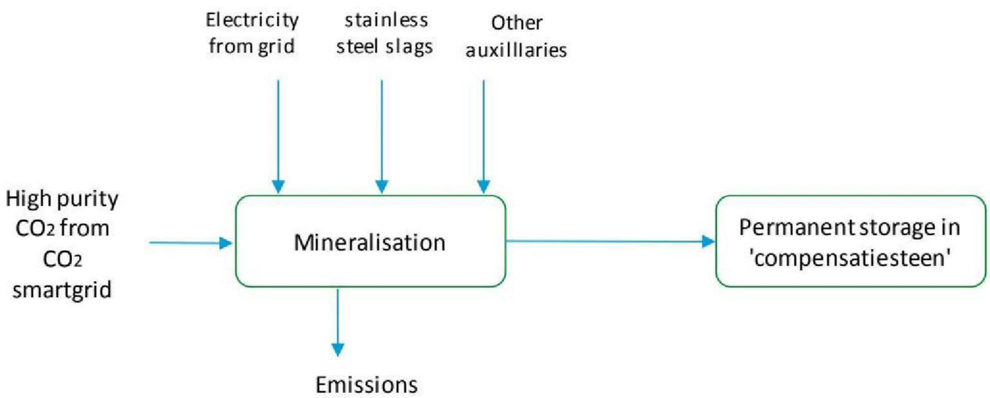
3.3.2 Mineralisation

In this application route, a mineral feedstock reacts with captured CO_2 to form an inert carbonate rock. Hereby, the carbon is chemically trapped and permanently sequestered. According to Ecofys, the market potential for carbonate mineralisation is somewhere between 100 and 300 ktonnes per year within ten years (Ecofys, 2017).
There are several technologies possible for carbonate mineralisation these include reaction of several waste products with CO_2 as well as the reaction of olivine (a mineral) with CO_2. In this study, we consider the Carbstone-process, as developed by the Belgium research institute 5.1.2e as an example for mineralisation. This process has been amended and is commercially applied (TRL 9) by the RuwBouw Groep, who sells a 'compensation stone' (compensatiesteen) made through this technology. The RuwBouw Groep uses slags from stainless steel production, sand and CO_2 and converts this into a stone that can be used as a substitution for sand-lime bricks.

Description of utilization technology

The current pilot plant of the RuwBouw Groep produces 3,000 m^3 of compensatiesteen per year. The organisation is investigating the possibilities for setting up a full-scale production plant with a capacity of sequestering 80 ktonnes of CO_2, equivalent to the production of 164,000 m^3 compensatie-steen. Compensatiesteen is produced by means of a hydraulic press, which uses little electricity. The stone is then cured in a CO_2 rich environment until it is fully saturated. Figure 8 shows the production and end-of-life of compensatiesteen. For a full life cycle inventory see Annex A.

Figure 8 - System boundaries of utilization in carbonate mineralisation



Produced products/services

All CCU routes that include utilization of CO_2 for mineralisation in compensatiesteen produce the following products/services:

- capture of one tonne of CO_2;
- compensatiesteen.

CO_2 storage time

The CO_2 used in mineralisation is permanently stored, and will only come free again with continuous weathering of rock or when treated in an industrial process.

Prevention of sand-lime brick production

Compensatiesteen is a hard, stone-like material that is currently used in construction applications where originally sand-lime bricks would be used. RuwBouw Groep expects that the stone can also be used in conventional non-constructive concrete applications if the permit procedure for this application has been completed. Non-constructive applications include concrete parts which, with the exception of any transport and auxiliary reinforcement, do not contain any structural reinforcement. In this LCA we consider the prevention of sand-lime brick production.

Conventional use stainless steel slags

Stainless steel slags are currently treated and used as aggregates or sand in road construction[5]. If the stainless steel slags are used to produce compensatiesteen, the aggregate will need to come from elsewhere. The environmental impact of aggregate production elsewhere is taken into consideration in this study.

Excluded: cleaning stainless steel slags

The stainless steel slags used by the RuwBouw Group are cleaned before being used in the compensatiesteen. However, it is currently unclear where the cleaning process takes place, and whether this process requires a large amount of associated energy use and/or other inputs. We expect that in comparison to the conventional application of stainless steel slags as granulate or sand in road construction, no extra treatment is needed.

3.3.3 Methanol

According to Ecofys, the Dutch market potential for CO_2 based methanol amounts to 220 ktonnes/year within ten years (Ecofys, 2017). In methanol production the captured CO_2 is hydrogenated with separately produced hydrogen. This hydrogen in the studied CCU route is produced through electrolysis: the process of using electricity to split water into hydrogen and oxygen. We study the production of methanol and the electrolysis based on a fossil fuel mix (as described in Section 2.6) as well as based on directly coupled renewable energy.

Description of utilization technology

We consider the process as it is currently applied by Carbon Recycling International (CRI). CRI runs a demonstration installation with a 4,000 tonnes/year production capacity of 'Vulcanol' which has been operational since 2012[6]. CRI aims at a commercial scale of 35-40 ktonnes/year. The TRL level of this technology is estimated to be TRL 7-8. Vulcanol is fuel grade methanol which can be blended with gasoline for automobiles and used in the production of biodiesel or fuel ether. In addition, Vulcanol can be used in the production of several synthetic materials.

Figure 9 shows the utilization system of CO_2 from the CO_2 Smart Grid as feedstock for the production of methanol production based on this technology. The process yields methanol and water and some combustible by-products, which may be marketed/supplied to external customers. The heat of the exothermic CO_2 hydrogenation reaction is partially used to heat feed streams and for distillation of the raw product.

We study this CCU in the following four cases:
- complete renewable electricity use, short term sequestration of CO_2 (e.g. fuel);
- complete renewable electricity use, long term sequestration of CO_2 (e.g. chemical);
- complete fossil electricity use, short term sequestration of CO_2 (e.g. fuel);
- complete fossil electricity use, long term sequestration of CO_2 (e.g. chemical).

In the case of production with completely renewable energy use, the hydrogen is considered to be produced with renewable energy with a direct connection to the hydrogen plant, e.g. hydrogen produced by water electrolysis with electricity from *directly coupled* wind power or photovoltaic power. Hydrogen production by way of electrolysis and methanol production need not take place at

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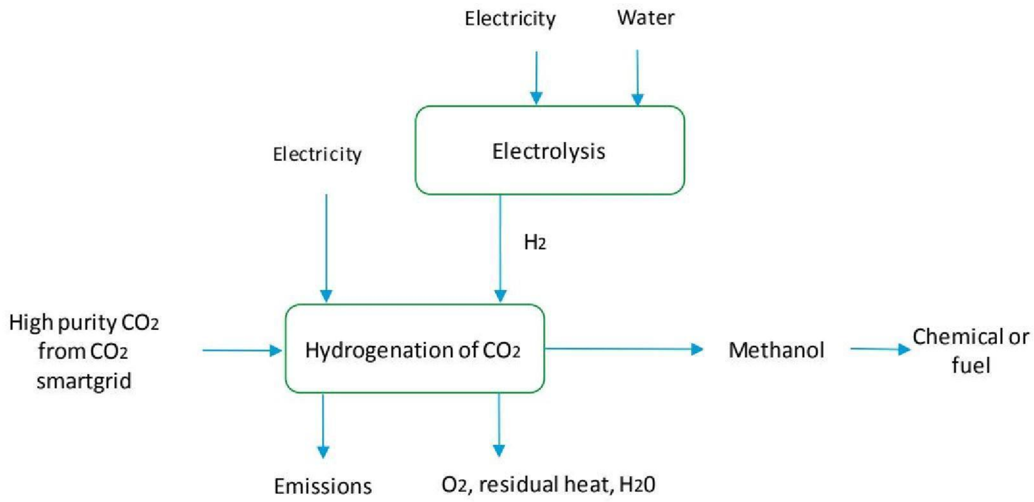
5 See for example the products sold by Orbix: www.orbix.be/nl/materialen

6 A second technology-provider is Japanese company Mitsui Chemicals Inc., but their technology seems less evolved.

the same location if hydrogen production can be connected with methanol production by way of a pipeline, e.g. the existing Air Liquide North-western high pressure H_2 network. Such a high pressure system may act or be utilized as a H_2 buffer by way of the 'line pack[7]' of the system.

In the case of production based in fossil electricity mix we use the carbon footprint of electricity as given in Section 2.6.

Figure 9 - System boundaries of production of methanol from CO_2 through hydrogenation



Produced products/services

All CCU routes that include utilization of CO_2 for methanol production produce the following products/services:

- capture of one tonne of CO_2;
- methanol.

The combustible by-products, residual heat and O_2 could be marketed as products but are not considered to be so in the base case modelling because not enough data has been obtained to do so.

CO_2 storage time

Given the wide range of applications for methanol it is undoable in this project to consider each of them. We will therefore indicate the time period during which the CO_2 utilized in methanol production is 'sequestered' in these applications. This will be done for two extremes in terms of duration:

- use in fuels (e.g. as oxygenate or as a component in biodiesel methyl esters or MTBE/TAME);
- use as chemical for use as a component in technical plastics.

[7] The intrinsic volume of the pipeline system.

In the case of use in fuels the carbon storage is short-cyclical, as the fuel is relatively quickly burned. In line with conventional CO_2 accounting practices, short-cyclical CO_2 is in this study not accounted for as a reduction in CO_2 emissions (see Section 2.4). In the case of use as chemical we assume CO_2 storage time of more than 100 years when used for technical plastic production that can be recycled several times.

Prevention of diesel production and use (application as fuel)

The reference technology for CO_2-based methanol production used as fuel is the production and use of conventional diesel for transportation.

Prevention of conventional methanol production (application as chemical)

The reference technology for CO_2-based methanol production is conventional methanol production in world scale units, utilizing stranded gas.

4 Reference technology: CCS

4.1 Introduction

One of the main questions to be considered and evaluated in this report is whether it is worthwhile in terms of CO_2 sequestration and/or other environmental aspects to utilize captured CO_2 for each of the considered applications instead of immediate geological storage in offshore abandoned gas fields or in offshore deep aquifers. Therefore an introduction is given into the carbon capture and storage (CCS) technology.

4.2 Background

CCS deposits captured carbon from large point sources to storage sites such that it will not enter the atmosphere, normally deposition occurs in underground geological formation such as abandoned gas fields or offshore deep aquifers. The CO_2 is captured, compressed, transport and subsequently injected.

For CCS as a reference case to this study, the injection step is that only step that differs from the CCU routes. The capture and transportation of CO_2 is also included for all CCU cases. For the injection, a compressor is used, which compresses the captured CO_2 into a supercritical fluid. The CO_2 is then injected under pressure into the geological formation, where it is trapped under an impermeable layer of rock. In this study, the electricity that is needed to inject the captured CO_2 into the geological formation is taken into account, as well as (possible) carbon leakage from the compressor.

4.3 Literature review

Several studies have assessed the carbon footprint of CCS technologies. In addition, a number of meta-studies that critically compare a variety of LCAs involved with this topic have been published.

(Cuéllar-France & Azapagic, 2015) published a well-cited comprehensive article in which numerous LCAs of CCS and CCU technologies are compared. The authors conclude that, on average, the Global Warming Potential (GWP) of CCS is significantly lower than that of CCU options. However, other environmental impacts, such as acidification potential and human toxicity potential might be higher compared to CCU. A number of CCS studies specifically address lowering the GWP of power plants. In this case, the GWP is reduced by 63-82%.

Another well-cited article describes the LCA of a pulverized coal power plant with post-combustion capture, transport and storage of CO_2 (Koornneef, et al., 2008). While the study is slightly older, it is situated in the Netherlands, and therefore relevant to this study. The authors show that GHG-emissions per kWh produced are reduced by 71-78%, depending on the technological advancement of the power plant. The International Energy Agency published a synthesis report of LCAs of CCS technologies in 2010 (Marx, et al., 2011). The results of the LCAs of the coal power generation systems with CCS clearly indicate a substantial reduction in GWP of around 80%. Similar results are shown for application of CCS at lignite power plants.

A [redacted] study from 2007 presents an LCA and cost assessment of CCS technologies at hard coal-fired power plants and compares this to renewable energy solutions (Viebahn, et al., 2007).

The conclusion of the study is that CO_2 emissions per kWh for CCS technologies are 72-90% lower than for coal-fired power plants without CCS.

A more recent Norwegian study assesses the environmental impact of carbon capture in the context of a natural gas combined cycle electricity generation plant (Singh & Hertwichm, 2011). The authors show that, when sequestrating 90% CO_2 from the flue gas, 70% of CO_2 emissions per kWh are avoided. The Global Warming Potential is reduced by 64%. However, a number of environmental impact on midpoint level are influenced conversely: for example, both acidification (43%) and eutrophication (35%) increase. This is a similar result as (Cuéllar-France & Azapagic, 2015).

4.4 Conclusion

The consulted peer-reviewed academic references present that the reduction in carbon dioxide emissions from power plants range between 63-90%, strongly depending on the carbon capture technology and carbon source. This means that between 630 and 900 kg of CO_2 is sequestered per tonne of captured CO_2 for more than 100 years in a CO_2 storage location. The carbons sources studied in this study are different than those looked at in the literature, but the literature gives a good insight in the order of magnitude of sequestered CO_2. Some studies indicate that trade-offs might occur on other environmental effects. This points towards the importance of, in further studies, also taking into account e.g. acidification and eutrophication effects.

5 Results: Global warming

The results for this screening LCA of CCU routes are presented in two ways: per carbon capture technology/carbon source and per utilization technology. Subsequently, different forms of utilization can be more easily compared, whereas it also enables us to draw more attention to the environmental performance of the different capture methods.

Global warming, CO_2 and CO_2 eq.
Global warming is caused by greenhouse gasses. The most commonly known greenhouse gas is carbon dioxide (CO_2). This is, however, not the only greenhouse gas, other such gasses include methane and dinitrogen monoxide. All other greenhouse gasses can be expressed in CO_2 eq.; the global warming potential of a greenhouse gas compared to carbon dioxide. In this chapter we look at the impact of the CCU routes on global warming. We have not only looked at CO_2 emissions, but also other greenhouse gas emissions. *When referring to CO_2 emissions or reduction of CO_2 emissions we are therefore technically speaking about CO_2 eq. and not only CO_2.*

5.1 Results per carbon capture technology/carbon source

In this section, the results are shown separately for each the three carbon capture technologies/ carbon sources.

5.1.1 Carbon capture at a MWI

Table 5 shows the emitted CO_2 and the net avoided CO_2 emission of the different utilization-routes for CO_2 captured at an MWI in comparison with not capturing CO_2 at a municipal waste incinerator, including a breakdown. Figure 10 shows the emitted CO_2 of the different utilization-routes for CO_2 captured at an MWI.

Table 5 - Net avoided CO_2-emission per CCU/CCS route compared to non-capture

	Capture from MWI and utilization in horticulture	**Capture from MWI and utilization for mineralisation**	**Capture from MWI and utilization for methanol production*** 100% renewable energy	**Capture from MWI and utilization for methanol production*** 100% fossil-based energy	**Capture from MWI and storage (CCS)**
CO_2 emission capture technology (kg/tonne captured)	239 kg	239 kg	239 kg	239 kg	239 kg
CO_2 emission product/service production (kg/tonne captured)	0 kg	116 kg	568 kg	2634 kg	24 kg
CO_2 emission end-of-life (within 100 years) (kg/tonne captured)	1,000 kg, of which: 361 kg fossil based 639 kg biogenic	0 kg	1,000 kg, of which: 361 kg fossil based 639 kg biogenic	1,000 kg, of which: 361 kg fossil based 639 kg biogenic	0 kg

	Capture from MWI and utilization in horticulture	Capture from MWI and utilization for mineralisation	Capture from MWI and utilization for methanol production* 100% renewable energy	Capture from MWI and utilization for methanol production* 100% fossil-based energy	Capture from MWI and storage (CCS)
CO_2 emission reduction replacement (kg/tonne captured)	-1,076 kg	-286 kg	-1,163 kg	-1,163 kg	0 kg
Total CO_2 emitted (kg/tonne captured)	162 kg	69 kg	644 kg	2710 kg	262 kg
CO_2 emitted without CO_2 capture at MWI	- 1,000 kg	- 1,000 kg	- 1,000 kg	- 1,000 kg	- 1,000 kg
Reduction of CO_2 emission in comparison to current situation (kg/tonne captured)	- 838 kg	- 931 kg	-356 kg	1710 kg (emission increase)	- 738 kg

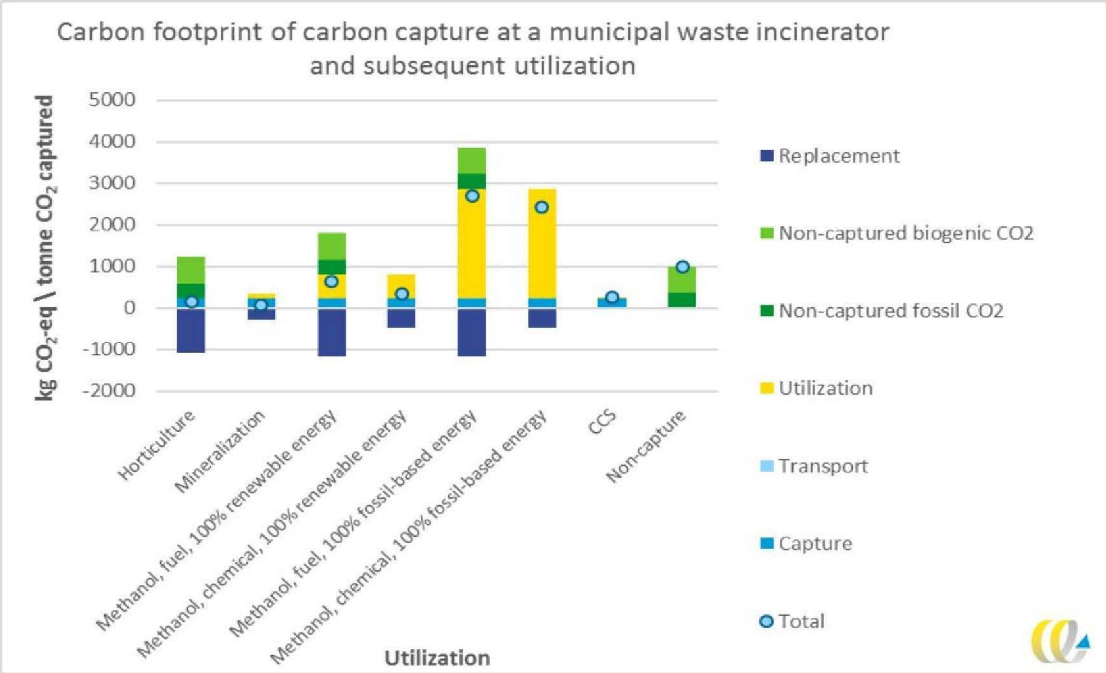
* Results for methanol production are based utilization of methanol used as fuel. For more methanol-results see Section 5.2.3.

Table 5 and Figure 10 show that the utilization-route of methanol is the least preferable option also when renewable energy is used in all the production processes. There are several reasons for this. Firstly, all captured CO_2 is emitted very rapidly again if the methanol is applied in an application that sequesters the CO_2 shorter than 100 years, for example when the methanol is used as a fuel. In addition, the current available production technique for methanol from CO_2 is not so efficient, which is reflected in the relatively high value for the emissions associated with utilization. When methanol is used for the production of a chemical for an application where the CO_2 is sequestered for more than 100 years, the methanol utilization-route comes closer to CCS.

Another striking result is that the carbon footprint of utilization of CO_2 in horticulture is the same order of magnitude as that of CCS. This is mostly linked to the large benefit associated with the avoided incineration of natural gas in the summer months. It is, in this case, the question whether this situation will still be relevant in the (near) future, and especially towards 2050, when heat production in the horticulture sector in the Netherlands will become carbon neutral. The in that case reference is no longer necessarily natural gas incineration but CO_2 could also be supplied by e.g. a wood burner.

For the mineralisation-route, the results indicate that long-term sequestration of captured carbon could be a good option. In addition, the replacement of sand-lime brick is relatively certain, and still quite a conservative (i.e. simple) avoided product. The energy use of the utilization of this route is also modest in terms of carbon footprint. There are however some uncertainties surrounding the energy use for utilization, since the modelling has been based completely on data supplied by the producer of compensatiesteen. In the sensitivity analysis we will delve further into this uncertainty (see Chapter 7).

Figure 10 - Carbon footprint of carbon capture at a MWI and subsequent utilization per tonne captured CO_2



5.1.2 Carbon capture from blast furnace gas from iron production

Table 6 shows the emitted CO_2 and the net avoided CO_2 emissions of the different utilization-routes for CO_2 captured from blast furnace gas from iron production in comparison with not capturing the CO_2, including a breakdown. Figure 11 shows a breakdown of the emitted CO_2 of the different utilization-routes for CO_2 captured from blast furnace gas.

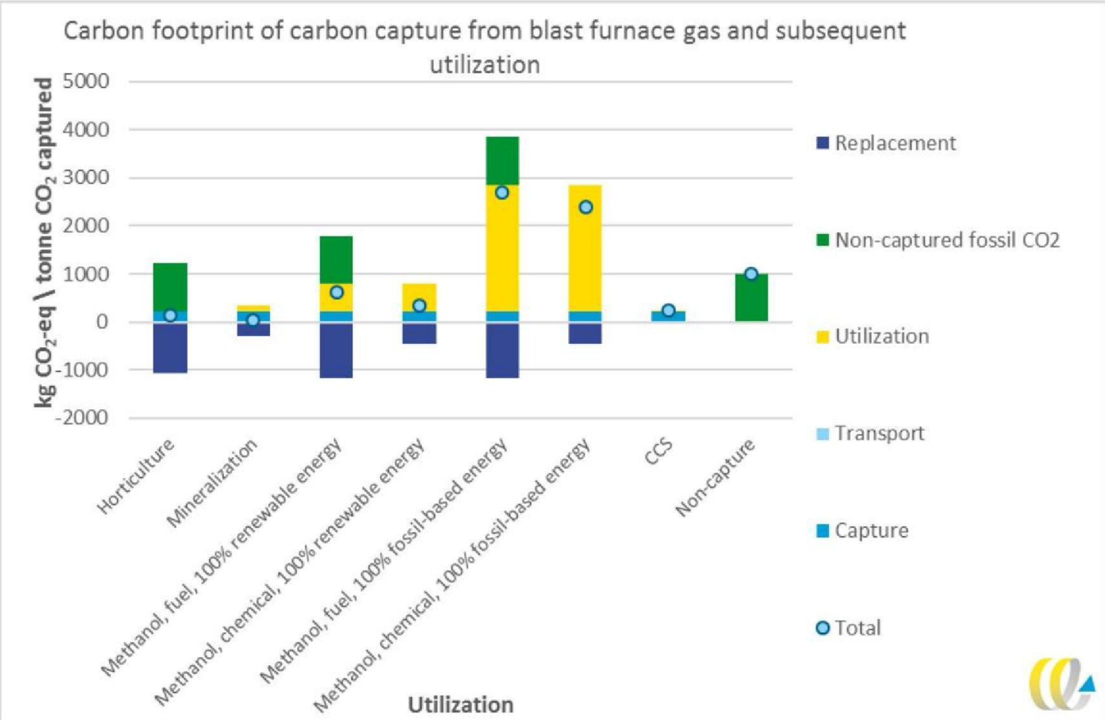
Table 6 - Net avoided CO_2 emission per CCU/CCS route compared to non-capture

	Capture from blast furnace gas and utilization in horticulture	**Capture from blast furnace gas and utilization for mineralisation**	**Capture from blast furnace gas and utilization for methanol production*** 100% renewable energy	**Capture from blast furnace gas and utilization for methanol production*** 100% fossil-based energy	**Capture from blast furnace gas and storage (CCS)**
CO_2 emission capture technology (kg/tonne captured)	220 kg	220 kg	220 kg	220 kg	220 kg
CO_2 emission product/service production (kg/tonne captured)	0 kg	116 kg	568 kg	2,634 kg	24 kg
CO_2 emission end-of-life (within 100 years) (kg/tonne captured)	1,000 kg	0 kg	1,000 kg	1,000 kg	0 kg
CO_2 emission reduction replacement (kg/tonne captured)	- 1,076 kg	- 286 kg	- 1,163 kg	- 1,163 kg	0 kg
Total CO_2 emitted (kg/tonne captured)	144 kg	50 kg	625 kg	2,691 kg	244 kg
CO_2 emitted without CO_2 capture from blast furnace gas	*- 1,000 kg*	*- 1,000 kg*	*- 1,000 kg*	*- 1,000 kg*	*- 1,000 kg*
Reduction of CO_2 emission in comparison to current situation (kg/tonne captured)	- 856 kg	- 950 kg	- 375 kg	1,691 kg (emission increase)	- 756 kg

* Results for methanol production are based utilization of methanol used as fuel. For more methanol-results see Section 5.2.3.

For the case of carbon capture from blast furnace gas, Figure 11 shows that the carbon footprint of the capture technique is comparable to that of capture at an MWI. The methanol-route, where the methanol is used in application where the CO_2 is stored for less than 100 years, is again the least favourable option.

Figure 11 - Carbon footprint of carbon capture from blast furnace gas and subsequent utilization per tonne captured CO_2



Note: Results for methanol production based on 100% renewable electricity.

5.1.3 Carbon capture at hydrogen plant (from fossil oil refining)

Table 7 shows the emitted CO_2 and the net avoided CO_2 emissions of the different utilization-routes for CO_2 captured at a hydrogen plant (from fossil oil refining) in comparison with not capturing the CO_2, including a breakdown. Figure 12 shows a breakdown of the emitted CO_2 of the different utilization-routes for CO_2 captured at a hydrogen plant.

Table 7 - Net avoided CO_2 emission per CCU/CCS route compared to non-capture

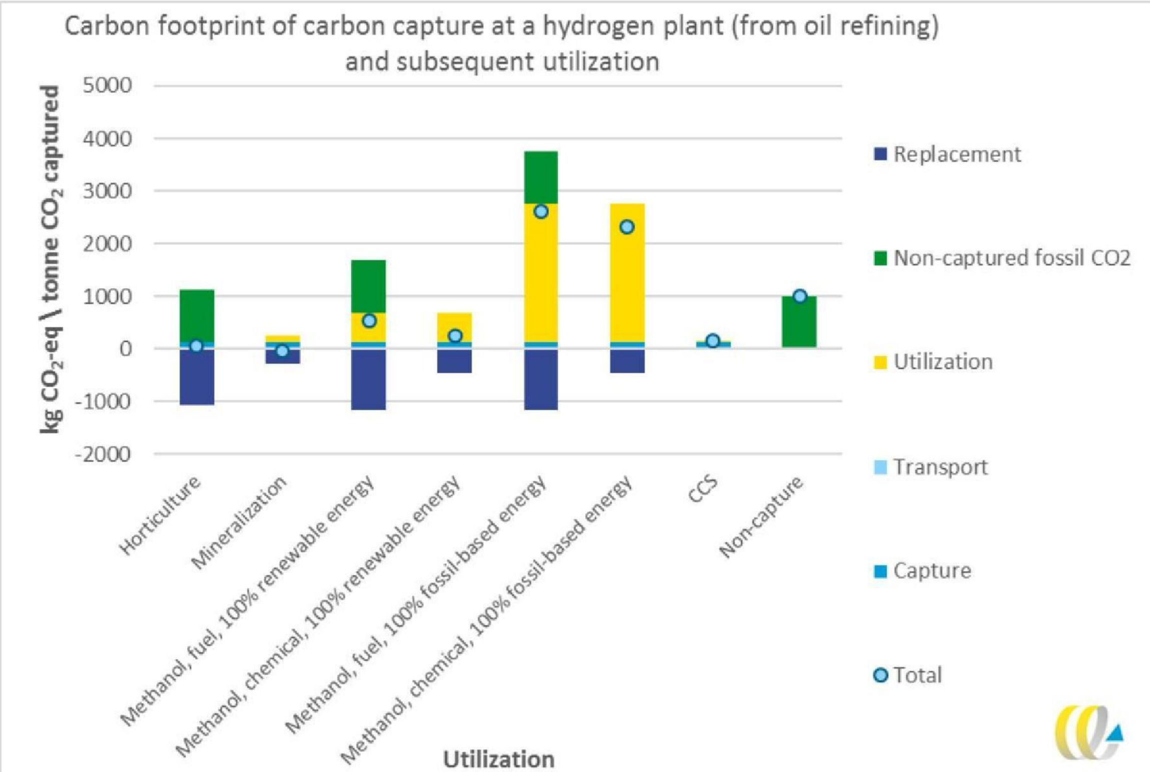
	Capture at a hydrogen plant and utilization in horticulture	**Capture at a hydrogen plant and utilization for mineralisation**	**Capture at a hydrogen plant and utilization for methanol production*** 100% renewable energy	**Capture at a hydrogen plant and utilization for methanol production*** 100% fossil-based energy	**Capture at a hydrogen plant and storage (CCS)**
CO_2 emission capture technology (kg/tonne captured)	129 kg	129 kg	129 kg	129 kg	129 kg
CO_2 emission product/service production (kg/tonne captured)	0 kg	116 kg	568 kg	2,634 kg	24 kg
CO_2 emission end-of-life (within 100 years) (kg/tonne captured)	1,000 kg	0 kg	1,000 kg	1,000 kg	0 kg

CO_2 emission reduction replacement (kg/tonne captured)	- 1,076 kg	- 286 kg	- 1,163 kg	- 1,163 kg	0 kg
Total CO_2 emitted (kg/tonne captured)	53 kg	-41 kg	535 kg	2,600 kg	153 kg
CO_2 emitted without CO_2 capture at a hydrogen plant	- 1,000 kg	- 1,000 kg	- 1,000 kg	- 1,000 kg	- 1,000 kg
Reduction of CO_2 emission in comparison to current situation (kg/tonne captured)	947 kg	1,041 kg	465 kg	1,600 kg (emission increase)	847 kg

* Results for methanol production are based utilization of methanol used as fuel. For more methanol-results see Section 5.2.3.

Since the carbon footprint of the capture of CO_2 at fossil oil refining is comparable to that of capture from blast furnace gas as described in Section 5.1.2, the results of the different utilization technologies combined with capture do not differ much. Again mineralisation leads to a negative carbon dioxide emission (more carbon dioxide being captured than emitted), application in horticulture is comparable to CCS and the production of methanol for an application where CO_2 is stored for less than 100 years is the least preferable option, even when renewable energy is used.

Figure 12 - Carbon footprint of carbon capture at a hydrogen plant (from fossil oil refining) and subsequent utilization per tonne captured CO_2



Note: Results for methanol production based on 100% renewable.

5.2 Results per utilization technology

In this section, we present the estimated carbon footprint per utilization technology.

5.2.1 Utilization in horticulture

Table 8 shows the emitted CO_2 and the net avoided CO_2 emission of the different CO_2 sources/capture technologies and utilization of CO_2 in horticulture in comparison with not capturing the CO_2, including a breakdown. Figure 13 shows a breakdown of the emitted CO_2.

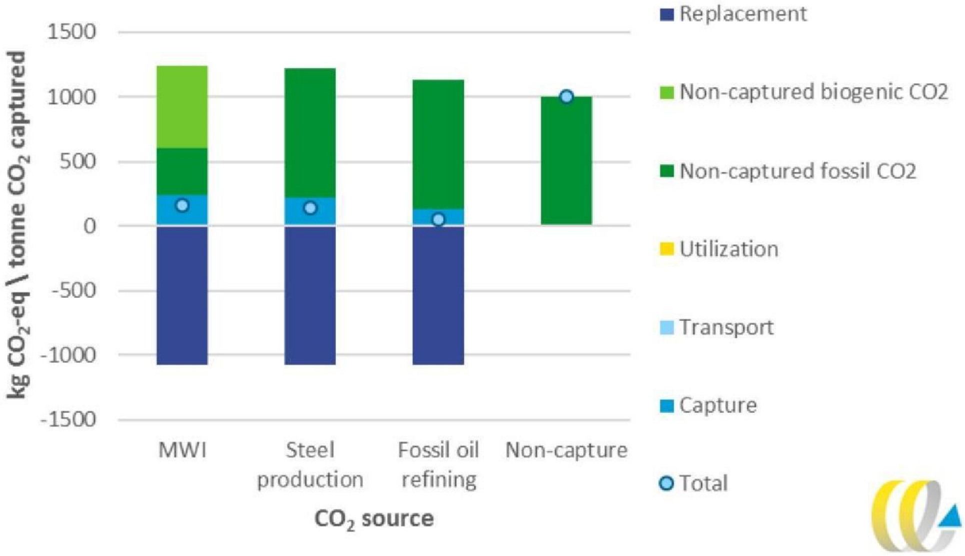
Table 8 - Net avoided CO_2 emission per CCU route compared to non-capture

	Capture at MWI plant and utilization in horticulture	**Capture at iron production and utilization in horticulture**	**Capture at hydrogen plant and utilization in horticulture**
CO_2 emission capture technology (kg/tonne captured)	239 kg	220 kg	129 kg
CO_2 emission product/service production (kg/tonne captured)	0 kg	0 kg	0 kg
CO_2 emission end-of-life (within 100 years) (kg/tonne captured)	1,000 kg, of which: 361 kg fossil based 639 kg biogenic	1,000 kg	1,000 kg
CO_2 emission reduction replacement (kg/tonne captured)	- 1,076 kg	- 1,076 kg	- 1,076 kg
Total CO_2 emitted (kg/tonne captured)	162 kg	144 kg	53 kg
CO_2 emitted without CO_2 capture	- 1,000 kg	- 1,000 kg	- 1,000 kg
Reduction of CO_2 emission in comparison to current situation (kg/tonne captured)	838 kg	856 kg	947 kg

Note: These are indicative figures, and serve to give an order-of-magnitude-estimation.

Table 8 and Figure 13 shows that for all three carbon capture technologies the utilization of the captured carbon in horticulture leads to net CO_2 emissions and that net more than 800 kg of CO_2 emission avoided per tonne of CO_2 captured. This is because currently the CO_2 used in greenhouses in the Netherlands largely originate from natural gas combustion, the prevention of natural gas use (the replacement) compensates for a large part of the CO_2 emissions.

Figure 13 - Carbon footprint of carbon capture and utilization in horticulture per tonne of captured CO_2



Future energy supply horticulture

When the incineration of natural gas is no longer the most logical supply for CO_2, i.e. when the heat supply will become carbon-neutral, it can be argued that the application of captured CO_2 in horticulture no longer needs to lead to the prevention of natural gas use. In that case the CO_2 could also be supplied by e.g. a wood burner. If that is the case the CO_2 emissions from utilizing captured CO_2 in horticulture will be higher than the quantity of CO_2 captured because of the energy demand for the capturing technology.

5.2.2 Utilization in mineralisation (compensatiesteen)

Figure 9 shows the emitted CO_2 and the net avoided CO_2 emissions of the different CO_2 sources/capture technologies and utilization of CO_2 for mineralisation in comparison with not capturing the CO_2, including a breakdown. Figure 14 shows a breakdown of the emitted CO_2.

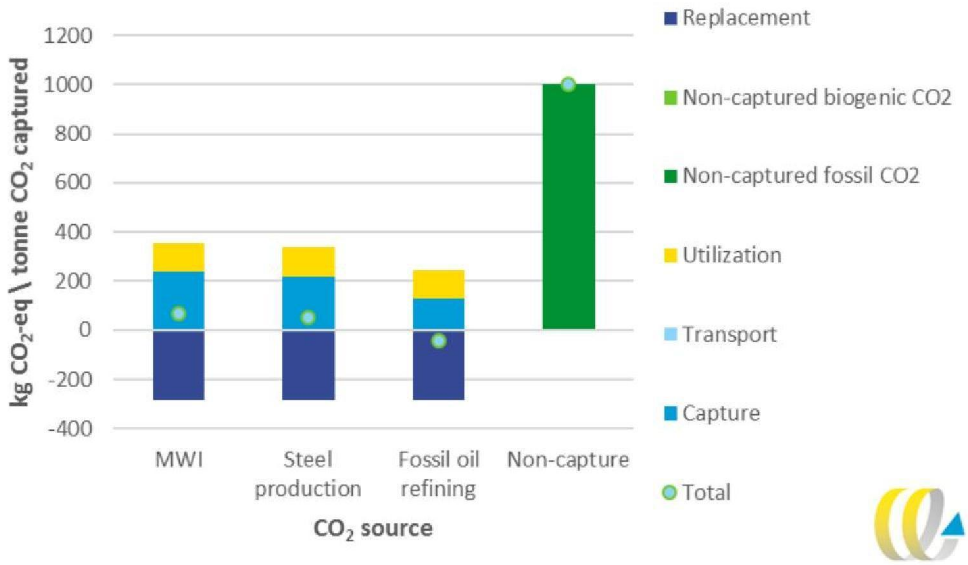
Table 9 - Net avoided CO_2 emission per CCU route compared to non-capture

	Capture at MWI plant and utilization for mineralisation	Capture at iron production and utilization for mineralisation	Capture at hydrogen plant and utilization for mineralisation
CO_2 emission capture technology (kg/tonne captured)	239 kg	220 kg	129 kg
CO_2 emission product/service production (kg/tonne captured)	116 kg	116 kg	116 kg
CO_2 emission end-of-life (within 100 years) (kg/tonne captured)	0 kg	0 kg	0 kg
CO_2 emission reduction replacement (kg/tonne captured)	- 286 kg	- 286 kg	- 286 kg
Total CO_2 emitted (kg/tonne captured)	69 kg	50 kg	-41 kg
CO_2 emitted without CO_2 capture	- 1,000 kg	- 1,000 kg	- 1,000 kg
Reduction of CO_2 emission in comparison to current situation (kg/tonne captured)	931 kg	950 kg	1,041 kg

Note: These are indicative figures, and serve to give an order of magnitude estimation.

Table 9 and Figure 14 show that the lower the carbon footprint of the capture technology is, the more likely that mineralisation of CO_2 in compensatiesteen will lead to a net negative CO_2 emission.
The figure also shows that, even in the case of a relatively high carbon footprint of the capture technology, such as capture at the MWI, there is a reduction of more than 90% of the CO_2 emissions compared to non-capture.

Figure 14 - Carbon footprint of carbon capture and utilization for mineralisation (compensatiesteen) per tonne of captured CO_2



5.2.3 Utilization in methanol production

We study this CCU route in the following four cases:

1. Complete renewable electricity use, short term sequestration of CO_2 (e.g. fuel).
2. Complete renewable electricity use, long term sequestration of CO_2 (e.g. chemical).
3. Complete fossil electricity use, short term sequestration of CO_2 (e.g. fuel).
4. Complete fossil electricity use, long term sequestration of CO_2 (e.g. chemical).

To make the comparison as easy as possible the range of values for the four cases with the three studied capture methods/CO_2 sources is shown.

Table 10 shows the emitted CO_2 and the net avoided CO_2 emission of the different cases in comparison with not capturing the CO_2, including a breakdown. Figure 15 shows a breakdown of the emitted CO_2.

Table 10 - Net avoided CO_2 emission for capture and utilization for methanol production compared to non-capture

	Renewable electricity CO_2-storage <100 years	Renewable electricity CO_2-storage >100 years	Fossil electricity CO_2-storage <100 years	Fossil electricity CO_2-storage >100 years
CO_2 emission capture technology (kg/tonne captured)*	129 – 239 kg	129 – 239 kg	129 – 239 kg	129 – 239 kg
CO_2 emission product/service production (kg/tonne captured)	568 kg	568 kg	2,634 kg	2,634 kg
CO_2 emission end-of-life (within 100 years) (kg/tonne captured)	1,000 kg	0 kg	0 kg	0 kg
CO_2 emission reduction replacement (kg/tonne captured)	- 1,163 kg	- 451kg	- 1,163 kg	- 451 kg

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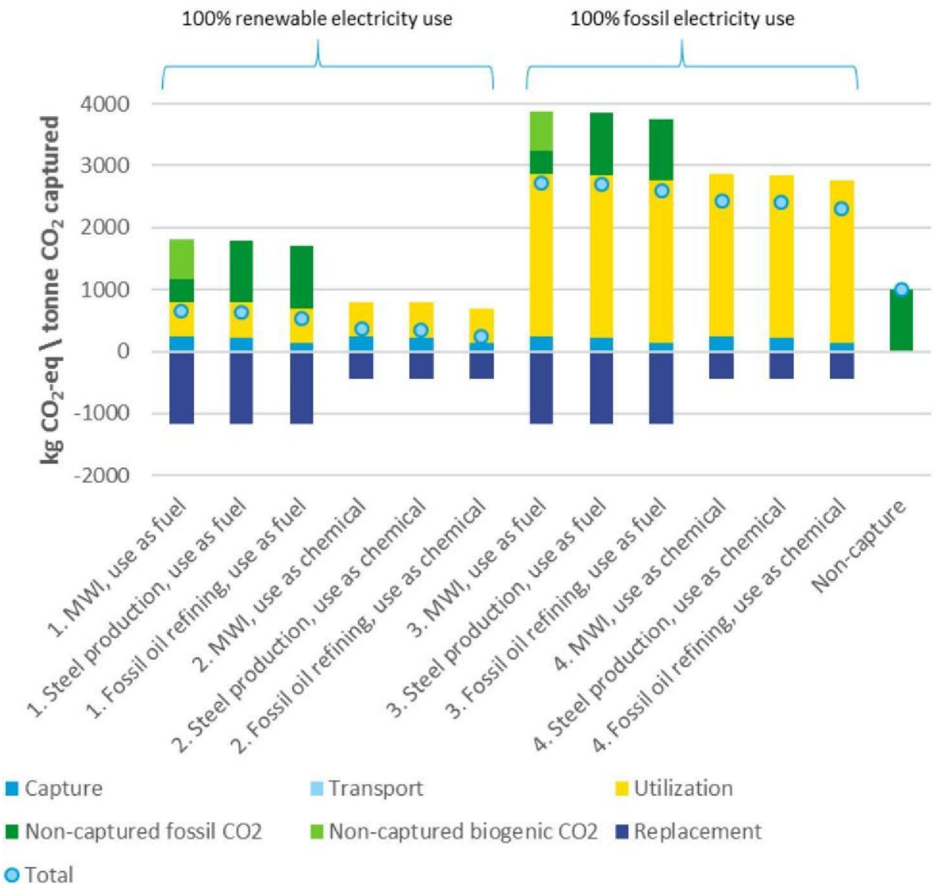
	Renewable electricity CO_2-storage <100 years	Renewable electricity CO_2-storage >100 years	Fossil electricity CO_2-storage <100 years	Fossil electricity CO_2-storage >100 years
Total CO_2 emitted (kg/tonne captured)	535 – 644 kg	246 – 355 kg	2,600 – 2,710 kg	2,312 – 2,421 kg
CO_2 emitted without CO_2 capture	- 1,000 kg	- 1,000 kg	- 1,000 kg	- 1,000 kg
Reduction of CO_2 emission in comparison to current situation (kg/tonne captured)	- 356 – - 465 kg	- 645 – - 754 kg	1,600 – 1,710 kg	1,312 – 1,421 kg

* This table gives a range of values for all three capture technologies studied.

In case of production of methanol from CO_2 with non-renewable electricity there will be no reduction in CO_2 emissions in comparison to non-capture. In the case of 100% renewable electricity use for the hydrogen and methanol production a net reduction of CO_2 emission can be achieved ranging between 350 kg and 750 kg per tonne of CO_2 captured. The higher end of this spectrum can be reached with a capture technology with low CO_2 footprint, and utilization of the methanol in an application where the CO_2 is stored for more than 100 years.

Figure 15 - Carbon footprint of carbon capture and utilization for methanol production



Note: The methanol routes consider 100% renewable energy use, and applications where the CO_2 is stored for less than 100 years (e.g. fuels).

Discussion: renewable energy in methanol production

The utilization of 100% renewable electricity in the production of methanol using captured CO_2 might naturally lead to a discussion regarding the administration of the environmental benefits of this electricity. In the Netherlands, renewable electricity is largely made possible through the SDE+ subsidy scheme, introduced to accelerate the large-scale implementation of renewable energy technologies. The subsidy itself is made possible by the Dutch government, and mainly Dutch consumers who pay an extra fee for their electricity.

When strictly interpreting LCA rules, the environmental benefits of the renewable energy produced through the SDE+ system should therefore be rewarded to the government and consumers. Parties that make the realization of additional renewable energy possible through e.g. additional funding could make the decision to use the renewable energy for the production of 'green' methanol. However, in this case, it is important to stress that in the coming years, the net CO_2 reduction of this this application of renewable electricity will be lower than when it will be used directly to replace fossil electricity.

6 Results: Other environmental impacts

Environmental benefit additional cleaning of CO_2 containing gas

For coal-fired power plants, the deployment of carbon capture results in an additional environmental advantage: additional cleaning of the produced flue gases. This advantage results in lower emissions of e.g. SO_2 and particulate matter of coal-fired power plants: see (Royal Haskoning, 2011). For the three CO_2 sources considered in this study, any possible additional cleaning of CO_2-containing gases has not been described in detail in literature. Therefore the additional advantages of this additional cleaning are not expressed in the results of this study.

For example, the emissions associated with blast furnace gas include hydrogen sulphide, fine particulate matter and carbonyl sulphide (COS). It is likely, in line with what occurs at coal-fired plants when applying capture, that some hydrogen sulphide and fine particulate matter will be captured along with CO_2. COS is unlikely to be captured.

Capture from blast furnace gas and MWI: environmental costs of additional emissions

Furthermore additional emissions from capture associated with the application of absorbent have not been taken into consideration because of a lack of data. It is however known that the use of [redacted] as an absorbent has in the past led to the production of aerosols. The MDEA absorbent is less prone to degeneration than [redacted] is but the exact emissions because of the use of this absorbent are unknown. Additionally, engineering measures to prevent the emissions of these aerosols can mitigate this. Also, whether or not Bilisol (the absorbent used for capture from the MWI) degenerates is not known.

Environmental impacts of utilization technology system

Because of the lack of data described on the possible environmental benefits and environmental costs of the difference between capture and non-capture at the CO_2 capture location we exclusively describe the environmental impacts relevant for air quality that are related to the utilization technology. This study has considered the following environmental impact of the three utilization technology systems:

1. Fine particulate matter formation ($PM_{2.5}$ emissions).
2. Terrestrial acidification (SO_2 emissions).
3. Tropospheric ozone formation (NO_x emissions).

All utilization technology systems lead to a reduction of environmental impacts in these impact categories, even when considering fossil energy use for the capturing technologies. This means that in all cases the conventional production of product that is being replaced (natural gas combustion, sand-lime brick and methanol) has higher emissions than the emissions from the electricity used for the CCU (capture plus utilization).

Future research needed

As indicated in Chapter 4, possible trade-offs between reduction in CO_2 emissions and acidification and eutrophication exist. The acidification and eutrophication impact of the different CCU routes have not been studied. In further research it is important to take these into consideration, as well as other emissions occurring at the CO_2 capture location.

7 Sensitivity analysis

Because of the short time frame in which this screening LCA has been carried out there are uncertainties surrounding the results discussed in the previous chapter. This is partly due to the fact that the available data originates from one source, and time was too limited to verify the data.
In this chapter we describe the uncertainties that have been identified that make it possible to reach (firmer) conclusions about the studied CCU routes.

Uncertainties can arise because of several reasons. In this study, they mainly originate from a lack of available data (or time to obtain the data) and the difficulty of studying environmental impacts in the future. The most important uncertainties are briefly described below.

7.1 Uncertainties because of data availability

Uncertainties related to data availability include missing data on:
- compression energy for capture from MWI;
- carbon footprint of absorbents; carbon footprint of stainless steel slags.

Furthermore uncertainties exist in the used data, because it has not been possible to verify all data obtained from a single data source.

Capture from MWI: Compression energy

The energy needed for compression of the CO_2 captured from the MWI has been set at its most conservative because the pressure of the produced CO_2 was not mentioned in the used literature. The energy use for the compression accounts for approximately 20% of the CO_2 emissions from the capture at the MWI in the current calculations.

This uncertainty could lead to a reduction of the carbon footprint of capture at the MWI compared to the results that are presented in Chapter 5, and could make the carbon footprint of this capture technology more comparable to the carbon footprint of the other two capture technologies studied.

Capture from blast furnace gas: Carbon footprint absorbent

The carbon footprint of the MDEA-absorbent needed for the capture of CO_2 from blast furnace gas is not publically available. An approximation of the footprint has been made based on the production of methylamine. This is likely to be an underestimation of the actual carbon footprint.

This uncertainty could lead to a slight increase of the carbon footprint of the capture of CO_2 from iron production compared to the results in Chapter 5.

Capture from fossil oil refining

Because the capture technology considered for fossil oil refining does not produce CO_2 with the purity vol% required for use in the CO_2 Smart Grid an extra purification step is needed. The CATOX-technology could be used to do so. The only necessary input for this process, besides infrastructure, is pure O_2. Since very little O_2 is needed, the production of O_2 has not been taken into consideration because the exact quantity needed is unknown. An environmental burden is however associated with this production.

This uncertainty could lead to a slight increase of the carbon footprint of the capture of CO_2 from fossil oil refining compared to the results in Chapter 5. The increase can be expected to be low because of the small quantity of O_2 needed.

Utilization for mineralisation: stainless steel slags

Stainless steel slags have been modelled as having no environmental impact because of their status as a waste product. However, stainless steel slags are actually used as aggregate in road construction, and therefore, a part of the environmental emissions for the stainless steel production should be attributed to this product. Because the economic value of stainless steel slags is unknown, economic allocation has however not been applied.

This uncertainty could lead to a slight increase of the carbon footprint of the utilization of CO_2 for mineralisation. The impact can however be expected to be limited since a tonne of steel has a much higher value than a tonne of aggregate.

All CCU routes: verification of data

Because of the short time span of the study, data for several processes within the CCU route have been obtained from a single data source. This data has not been verified extensively.
Some uncertainties exist because of this, including:
- Electricity use for the production of Compensatiesteen, which is much lower than that of the Carbstone technology, of which it has been derived from[8].
- Data on capture at the MWI has been obtained from (Monteiro, et al., 2015), a study conducted by Procede, the owner of the technology. This data has not been verified except for order of magnitude verifications.
- Data on production of methanol has been based on data on a single pilot plant from (Stefansson, 2015). This data has not been verified except for order of magnitude verifications.

7.2 Uncertainties due to future development of CO_2 Smart Grid

This study looks at the implementation of a CO_2 Smart Grid in 2030. Since it is difficult to predict the future there are a number of uncertainties concerning future development of the studied CCU routes. These include:
- other applications of Compensatiesteen;
- sustainable heat supply in Dutch horticulture;
- optimization possibilities for methanol production;
- additional cleaning of CO_2 containing gas;
- exact requirements of the CO_2 for the CO_2 Smart Grid;
- uncertainty of electricity use for CCU routes.

[8] For the Carbstone technology energy use has been determined at 200 kWe per m^3 Carbstone concrete [redacted] 2014). While the Ruwbouwgroup reports electricity use that is approximately 80% lower.

Utilization for mineralisation: other applications of Compensatiesteen

Compensatiesteen has currently been tested and approved for use in applications where it prevents the use of sand-lime brick. The stone could also be applied in in applications where it replaces concrete, but has not been approved for this application. The application of Compensatiesteen instead of concrete would lead to a bigger 'replacement' of CO_2 emissions than when using it instead of sand-lime brick.

If Compensatiesteen can replace concrete in 2030, the CCU routes including mineralisation would lead to a higher net avoided CO_2 emission than shown in the results in Chapter 5.

Utilization for horticulture: sustainable heat supply

The future heat supply for Dutch horticulture is unknown, and therefore also the possible sources for CO_2 used in greenhouses. A possibility is the use of biomass for both heat and CO_2 production, but also geothermal heat supply not yielding any CO_2 emissions is an option. Whether or not the application of captured CO_2 aids the shift towards renewable energy and what would be the appropriate reference CO_2 source to consider in the future is a topic that needs further discussion.

If a sustainable heat supply is in place in 2030 in Dutch horticulture, the CCU routes including utilization for horticulture could lead to a lower net avoided CO_2 emission than shown in the results in Chapter 5.

Utilization for methanol production: marketing of by-products

In the current study we have only looked at methanol production from captured CO_2 as it is currently applied in a pilot plant in Iceland . A possible optimization of the current practice is the marketing of by-products such as residual heat and O_2 from electrolysis. The O_2 and residual heat will need to meet the specifications required by the market.

If the by-products of methanol production can be marketed, the CCU-routes including methanol would lead to a lower carbon footprint than shown in Chapter 5.

Requirements CO_2 Smart Grid: compression and purity

The requirements of the CO_2 Smart Grid are not yet known. The exact compression of CO_2 needed for transport over distance as well as the required purity of CO_2 for the utilization technologies attached to the grid remain to be determined when the exact utilization technologies are known.

When less compression and a lower vol% of CO_2 is required, the environmental impact of upgrading the CO_2 stream to the desired level will decrease. This means that the carbon footprint of all CCU routes would decrease in comparison those shown in Chapter 5.

All CCU-routes: future renewable electricity use

In CCU routes electricity is used. We have in line with LCA and Dutch policy practices used the fossil electricity type on the margin (see Section 2.6). It is possible that the different CCU routes ensure that they use renewable electricity. E.g. using directly coupled renewable electricity for the production of Compensatiesteen.

If the electricity used would be from directly coupled renewable electricity, the carbon footprint of a CCU routes would decrease in comparison those shown in Chapter 5.

8 Conclusion

Here, we summarize the results presented in Chapter 5. In addition, we formulate conclusions based on the sensitivity assessments shown in Chapter 7.

Capture technologies and carbon sources considered have comparable carbon footprints

The three different capture technologies do not differ significantly in carbon footprint. The capture of CO_2 from iron production and capture of CO_2 the MWI are particularly comparable in terms of carbon footprint. The footprint of capture from fossil oil refining (at the hydrogen plant) is slightly lower, but the difference between the technologies in the results could be due to uncertainties surrounding the data gathered.

Utilization in mineralisation

Utilization of CO_2 for mineralisation, the production of Compensatiesteen, leads to net avoided CO_2 emissions of around 1 tonne of CO_2 per tonne of CO_2 captured. Despite the carbon footprint of the capture technologies, the produced Compensatiesteen leads to the avoided production of conventional sand-lime brick. It is possible that the footprint of the utilization technology is slightly higher than portrayed in this report because of an uncertainty surrounding the energy use in the process. This requires further study but will not lead to the technology having a net CO_2 emission compared to non-capture. mineralisation

Utilization in horticulture

In the current situation, the utilization of CO_2 in horticulture leads to net avoided CO_2 emissions of around 900 kg CO_2 per tonne of CO_2 captured. This is a comparable or even better performance compared with well-functioning CCS. The net avoided CO_2 emission is caused by the avoided use of natural gas for the production of CO_2 in horticulture.

The future heat supply for Dutch horticulture is unknown, and therefore also the possible sources for CO_2 used in greenhouses. A possibility is the use of biomass for both heat and CO_2 production, but also geothermal heat supply not yielding any CO_2 emissions is an option. Whether or not the application of captured CO_2 aids the shift towards renewable energy and what would be the appropriate reference CO_2 source to consider in the future is a topic that needs further discussion. Therefore the exact carbon footprint reduction after a switch to a renewable heat source in the horticulture sector has been made is uncertain.

Utilization in methanol production

Utilization in methanol production will only lead to net avoided CO_2 emissions when renewable energy is used for methanol and hydrogen production. The net avoided CO_2 emissions will increase when the CO_2 is used in durable products. ‘Durable’ in this context implies that CO_2 is sequestered for more than 100 years. In that case, this utilization method could reach net avoided CO_2 emissions of around 700 kg CO_2 per tonne of CO_2 captured. This is comparable to the least efficient type of CCS.

It must be noted that methanol production is not the only possible application of CO_2 in the chemical industry. Other possible utilizations could include the production of polyols for the production polyurethanes.

Conclusions on other environmental impacts

For several reasons, no conclusions could yet be drawn on other environmental impacts and on emissions from the capturing technology:

- additional benefits caused by the additional cleaning of CO_2 containing gas are unknown;
- emissions from degradation of absorbents are unknown.

Because of the lack of data described on the possible environmental benefits and environmental costs of the difference between capture and non-capture at the CO_2 capture location we only describe the environmental impacts relevant for air quality that have to do with the utilization technology.

This study has considered the following environmental impact of the three utilization technology systems; Fine particulate matter formation ($PM_{2.5}$ emissions), Terrestrial acidification (SO_2 emissions) and Tropospheric ozone formation (NO_x emissions). All utilization technology systems lead to a reduction of environmental impacts in these impact categories, even when considering fossil energy use for the capturing technologies. This means that in all cases the production of product that is replaced (natural gas combustion, sand-lime brick and methanol) has higher emissions than the emissions from the electricity used for the utilization technology and in the capturing process.

Possible trade-offs between reduction in CO_2 emissions and acidification and eutrophication exist. The acidification and eutrophication impact of the different CCU routes has not been studied, and in further research it is important to take these into consideration.

Interpretation of the conclusions

The orders of magnitude of CCS and CCU applicability in 2030 are expected to be incomparable. E.g. the potential storage by means of CCS is expected to be much higher than the potential for use of CO_2 in mineralization in the Netherlands. Results must therefore only be seen on a per tonne basis and cannot be extrapolated. The spatial application of the technologies also differ, e.g. CCS can be applied the whole year round while the peak of CO_2 utilization in horticulture is during the growing season and less so in winter.

Because the study carried out is a screening LCA, the drawn conclusions should be seen as indicative figures; they offer an order of magnitude estimation and cannot be seen as representative for individual (industrial) plants present in the Netherlands. Furthermore, because a substitution methodology has been used, the results are not appropriate for consumption-based carbon accounting (see Brander & Wylie, 2011). This means that, when calculating the emissions of a country's total consumption, LCA results that are calculated through the substitution methodology cannot be included. The same holds for using the outcomes for corporate carbon accounting practices.

To make the results applicable to individual CCU routes e.g. CO_2 capture at the AEB MWI in Amsterdam and application of the CO_2 in horticulture in Aalsmeer, are full scale LCA study will need to be conducted.

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A Life cycle inventory

For this screening LCA, various reports and studies were used for collecting relevant data. This chapter summarizes the data and sources used, based on the previously described system boundaries.

A.1 Carbon capture from CO_2 source and preparation for injection into Smart CO_2 grid

Municipal waste incineration (MWI) plant

A study has been conducted on the application of the Procede Gas Treating technology for capture of CO_2 specifically for injection of CO_2 into the OCAP pipeline. This study gives a description of the consumables for the quench unit, the capture plant and the compression needed for injection. Because of the difference in compression assumed needed for the CO_2 Smart Grid, we have only used the data on the quench unit and the capture plant. See Table 11 for the overview of the inputs needed as obtained from (Monteiro, et al., 2015).

Table 11 - Net inputs for CO_2-capture and preparation for injection into the Smart CO_2-grid at a MWI

	Conventional MWI	MWI with capture	Net	Net per tonne captured CO_2
Electricity for capture	-	1,693 MWh/year	1,693 MWh/year	0.10 GJe/tonne CO_2
Steam for capture	-	57,596 MWh/year	57,596 MWh/year	3.48 GJ/tonne CO_2
Cooling water for capture	-	9,384,595 m^3/year	9,384,595 m^3/year	157 m^3/tonne CO_2
CO_2 capture		59,600 tonne/year	59,600 tonne/year	

Data source: (Monteiro, et al., 2015).

Reduction in electricity production

There is one aspect that is not included in the process described by (Monteiro, et al., 2015); a reduction in electricity production because of the steam/heat used by the capture technology. According to the AVR (MWI of Rotterdam) the reduction in electricity production is approximately 0.25 MWe per MW heat extracted. This means that per tonne CO_2 captured the electricity production decreased with approximately 0.87 GJe.

The reduction of electricity production can be seen as an electricity input needed for the CO_2 capture and is taken into consideration as electricity input from the Dutch electricity grid.

Compression

Monteiro, et al., (2015) do not mention the exact pressure of the produced CO_2 stream. We therefore assume that it is produced at a 1 bar(a) pressure. This means that the stream still needs to be compressed to 40 bar(a). Further compression has been based on the operational conditions of a compressor given in (Geological Survey of the Netherlands, 2009). Based on this source to get to 40 bar(a) from 1 bar(a) an approximate 295 MJe/tonne CO_2 captured is needed.

Monteiro, et al.,(2015) also do not mention the exact purity of the CO_2 gas stream produced. However, since their study refers to producing CO_2 to be injected in the OCAP line, the purity is likely to be 93% (see Section 3.2).

The off gas of MWIs needs to reach a high purity level; there is stringent emission regulation in the Netherlands. The CO_2 capture unit is placed after the conventional purification steps. This might lead to a further reduction in emissions, but this is not taken into consideration in this screening LCA because of a lack of data.

Blast furnace gas from the blast furnace process

This study looks at an amine-based capture method for the blast furnace process. This technology is listed by the IEA as one of the primary technologies for CO_2 capture in iron production (IEA, 2013). The net inputs for this technology are given by (IEA, 2013) and shown in Table 12.

Table 12 - Net inputs for CO_2 capture from blast furnace gas and preparation for injection into the Smart CO_2 grid

	Conventional iron production	Iron production with capture	Net	Net per tonne captured CO_2
Electricity for capture	-	572,622,619 kWh year	572,622,619 kWh/year	0.6 GJ/tonne CO_2
Steam for capture	-	8,082,495 GJ/year	8,082,495 GJ/year	2.35 GJ/tonne CO_2
MDEA make-up for capture	-	688 tonne/year	688 tonne/year	0.2 kg/tonne CO_2
MDEA disposal for capture	-	688 tonne/year	688 tonne/year	0.2 kg/tonne CO_2
Raw water for capture	-	10,557,185 m^3/year	10,557,185 m^3/year	3 m^3/year
CO_2 capture	-	3,439,360 tonne/year	3,439,360 tonne/year	-

Data source: (IEA, 2013).

Reduction in electricity production

There is one difference between the technology as described by the IEA and the likely application of the technology for Tata IJmuiden: the blast furnace gas from Tata IJmuiden is currently fed to two different power plants (Velsen 25 and IJmond 1) where it is being incinerated to produce electricity. In case these two plants are not operational a third plant (Velsen 24) is used. Of the three Velsen 25 has the largest capacity of 375 MW. Applying the CO_2 capture at the Velsen 25 plant leads to a reduction in electricity production of Velsen 25.

The reduction of electricity production can be seen as an electricity input needed for the CO_2 capture. Figure 16 shows the configuration of the Velsen 25 plant. The steam produced by the turbine is 540°C and 180 bar(a), the steam is fed into the High Pressure (HP) turbine after which it is fed back into the boiler where it is reheated to 540°C and 40 bar(a). The steam is then used in the Intermediate Pressure (IP) turbine where after which it reaches Low Pressure (LP) turbines. The condensing occurs at 24 degrees and 30 mbar(a).

Figure 17 shows the Velsen 25 plant with CO_2 capture assuming no changes in the boiler efficiency and no net change in parasitic power consumption. The steam for the MDEA reboiler (2.35 GJ/tonne CO_2 as given by (IEA, 2013)) is supplied from the outlet of the IP turbine. The outlet of the IP turbine is the

most logical place to tap steam from since it has the least influence on electricity production (latest possible stage) and still reaches the required 120°C required for the MDEA reboiler.
The loss in electricity production therefore occurs at the LP turbine.

The overall electric efficiency of the Velsen 25 plant is 43%. The HP turbine has the highest efficiency and the LP turbine the lowest efficiency. The approximate efficiency of the LP turbine is 27%. Assuming the turbine runs on full load, the reduction of efficiency is minimal due to the steam extraction. This therefore leads to a reduction in production of 0.65 GJe per tonne of CO_2 captured.

Figure 16 - Velsen 25 plant without CO_2 capture, per 0.48 tonne CO_2

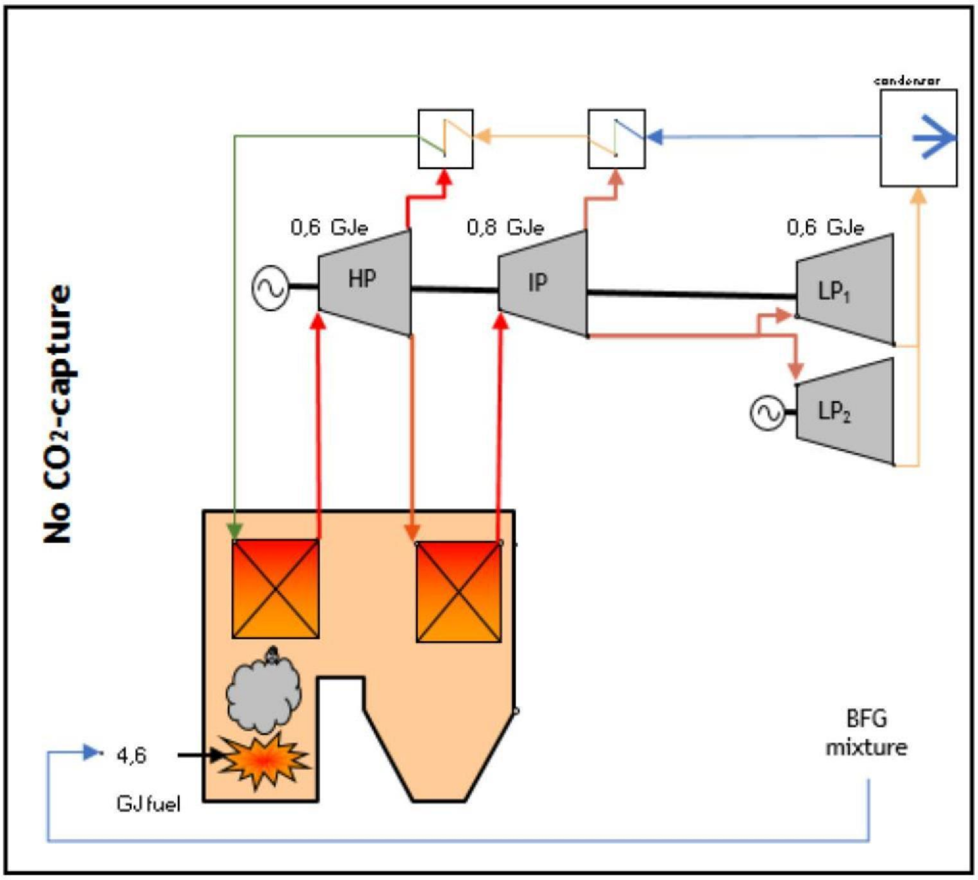

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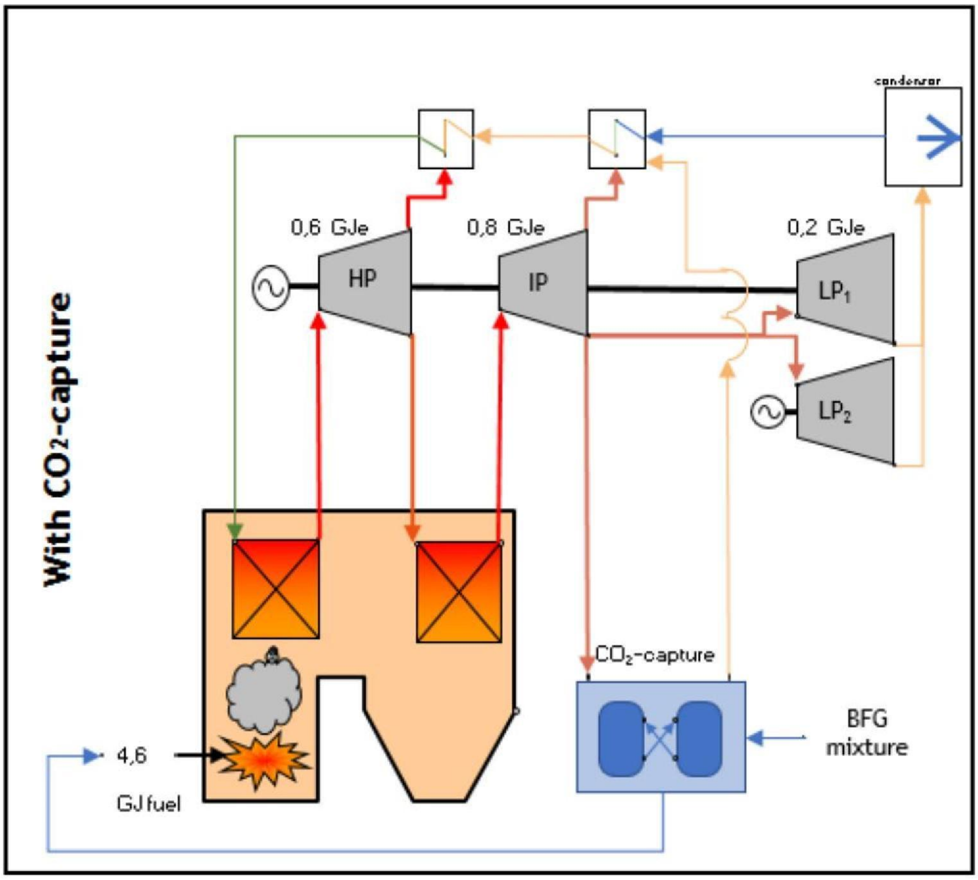
Figure 17 - Velsen 25 plant with CO_2 capture, per 0.48 tonne CO_2



Increased temperature blast furnace gas

Due to the capture technology the lower heating value of the blast furnace gas increases (Zhang, et al., 2013). This means that a higher electricity production could be achieved when supplying the blast furnace gas after CO_2 capture to the boiler. Since the exact influence of an increase in lower heating value for the Velsen 25 plant is unknown the result of the increased temperature blast furnace gas is not included in this study.

Compression

The capture technology as described by (IEA, 2013) produces CO_2 with a purity of 99.9% at a pressure of 110 bar(a). To be able to meet the specifications of 40 bar(a) for the CO_2 Smart Grid much less compression is needed. Compression energy has been estimated based on the operational conditions of a compressor given in (Geological Survey of the Netherlands, 2009). Based on this source the energy needed to get from 40 bar(a) to 110 bar(a) is approximately 100 MJe / tonne CO_2 captured. This energy use is subtracted from the total energy use for the capture at the blast furnace.

Emissions

The blast furnace gas from Tata Steel is used to produce energy from at the Velsen 23 plant. The gas is incinerated here, removing a number of harmful substances. However this plant currently still emits fine particulate matter, H_2S and COS. When adding a CO_2 capture unit after the Velsen 23 plant there is a possibility that the emissions of fine particulate matter and H_2S decrease.
Since no concrete data is available, however, on the exact impact of installing a CO_2 capture unit these possible benefits are not taken into consideration. The use of MDA as an absorbent has in the past lead to the production of aerosols. The MDEA absorbent is less prone to degeneration than MDA is but the exact emissions because of the use of this absorbent are unknown.

Fossil oil refining

The description of the CO_2 capture plant at the hydrogen facility has been obtained from (IEA, 2017). This report describes the energy balance for a conventional hydrogen facility as well as the energy balance of the plant with several different CO_2 capture technologies. We have calculated the difference between the conventional hydrogen plant and the plant using a cryogenic capture technology (including membranes) as described in case 2B to get to an energy consumption per tonne CO_2 captured (see Table 13).

Table 13 - Net inputs for CO_2 capture and preparation for injection into the Smart CO_2 grid at a hydrogen plant

	Conventional hydrogen plant	Hydrogen plant with capture	Consumption for capture	Net per tonne CO_2 captured
Electricity to grid	9.9 MWh	0.3 MWh	9.6 MWh	0.22 MWh
Natural gas consumption (Feedstock)	1,219.7 GJ/h	1,219.7 GJ/h	0 GJ/h	0 GJ/h
Natural gas consumption (Fuel)	201.4 GJ/h	198.3 GJ/h	3.2 GJ/h	- 0.075 GJ
CO_2 captured	0 tonne/h	42.89 tonne/h	-	

Note: Conventional hydrogen plant based on the base case and hydrogen plant based on case 2B from (IEA, 2017). Figures might not add up due to rounding.

The capture technology as described by (IEA, 2017) produces CO_2 with a purity of 99.64% at a pressure of 110 bar(a). Other components in the CO_2-stream include 0.27 vol% CH_4 and 0.07 vol% 5.1.2e be able to meet the specifications of 99.9% vol% for the CO_2 Smart Grid a further treatment step is needed. Further purification would naturally happen with the CATOX technology in which the CO_2 stream is combined with O_2 along a catalytic bed. No energy is needed for this process. High purity O_2 is needed, but only a small amount per tonne of CO_2. Therefore the production of O_2 is disregarded.

Compression energy has been estimated based on the operational conditions of a compressor given in (Geological Survey of the Netherlands, 2009). Based on this source the energy needed to get from 40 bar(a) to 110 bar(a) is approximately 100 MJe/tonne CO_2 captured. This energy use is subtracted from the total energy use for the capture at the hydrogen plant.

The emissions from a conventional hydrogen plant after fossil oil refining are limited to water vapour and CO_2. When capturing the CO_2 in a CO_2 capture plant therefore no other emissions are captured in the process.

A.2 CO_2 utilization

Horticulture

As explained previously, the reference case for the utilization of captured CO_2 in horticulture is using a gas burner for the generation of heat and CO_2. Little quantitative information on the reduction of CO_2 emissions through the delivery of captured CO_2 in horticulture is available. In a previous (confidential) study by CE Delft, the quantity of gas used exclusively for the production of CO_2 is said to be 7 m^3 gas/m^2.
Using a CO_2 emission factor of 2.04 kg CO_2/m^3 for the incineration of natural gas, this amounts to 14.28 kg CO_2 emission/m^3. This is equal to 490 m^3 gas avoided per tonne CO_2 added to the greenhouse.

Table 14 - Inventory horticulture case

	Amount	Reference
Gas use of greenhouses (reference case)	7 m^3/m^2 of greenhouse space.	(CE Delft, 2017); confirmed by LTO glaskracht/OCAP
Avoided burning of natural gas	490 m^3/tonne CO_2 added to greenhouse	(CE Delft, 2017); confirmed by LTO glaskracht/OCAP;

Mineralisation

For the utilization of the captured CO_2 in mineralisation in Compensatiesteen, the developer RuwBouw Group was contacted. RuwBouw Group provided data on the electricity use, the amount of Compensatiesteen per tonne CO_2 in, the input of stainless steel slags, and the amount of avoided production of sand-lime brick.

Table 15 - Inventory mineralisation case

	Amount/tonne CO_2 in	Reference
Electricity	82.05 kWh	Interview with developer
Compensatiesteen	2.05 m^3 (= 4 tonne)	Interview with developer
Input of stainless steel slag (max.)	3.75 ton	Interview with developer
Avoided production of sand-lime brick (max.)	3.75 ton	Interview with developer

The avoided sand-lime brick is modelled as [redacted] sand lime brick production. Electricity used in the process is assumed to be medium-voltage.

No data has been obtained on the cleaning of the stainless steel slags before utilization in the Compensatiesteen process.

Methanol

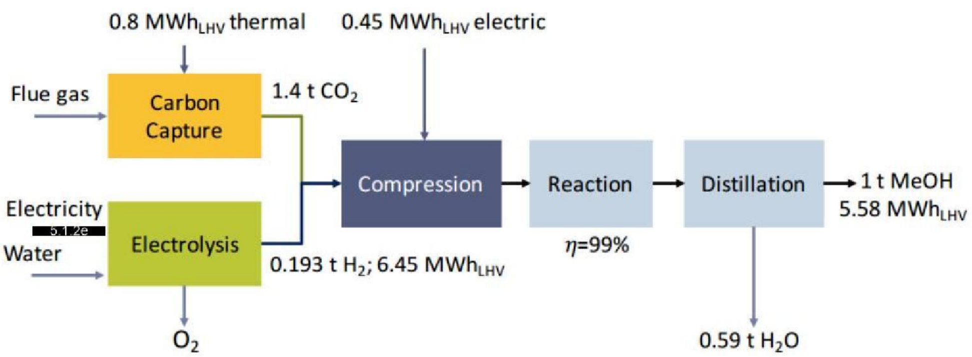
Data on the production of methanol using captured CO_2 was retrieved from a mass energy balance as presented in (Stefansson, 2015). Figure 18 shows the readily available data on the production process including the ratios of weight between raw materials and desired products. Additionally, data from (Rocha, et al., 2017) was used for the electricity use of the electrolysis step.

Table 16 - Inventory methanol case

	Amount	Reference
Electricity hydrogenation CO_2	0.32 MWh/tonne CO_2 in	(Stefansson, 2015)
Electricity electrolysis H_2	51.20 MWh/tonne H_2 produced	(Rocha, et al., 2017)
Hydrogen (in)	0.14 tonne/tonne CO_2 in	(Stefansson, 2015)
Water (out)	0.42 tonne/tonne CO_2 in	(Stefansson, 2015)
Methanol (out)	0.71 tonne/tonne CO_2 in	(Stefansson, 2015)

The hydrogen used in the process is assumed to be produced through chlor-alkali electrolysis, using a diaphragm cell. For grey electricity, medium voltage Dutch average electricity is used.
For the sensitivity case, in which green electricity is used, this is assumed to be derived from a >3MW onshore wind turbine.

Figure 18 - Mass balance and energy balance for CRI CO_2 to methanol technology



Bron: (Stefansson, 2015).

A.3 Carbon Capture and Storage (CCS)

The reference technology of CCS is mainly based on data retrieved from (Koornneef, et al., 2008). Furthermore extra compression from 40 to 130 bar(a) is determined based on (Geological Survey of the Netherlands, 2009). This case is kept very simple, and no infrastructure is taken into account.

Table 17 - Inventory CCS

	Amount/tonne CO_2 in	Reference
Electricity for compression from 40 bar(a) to 130 bar(a)	100 MJe	(Geological Survey of the Netherlands, 2009)
Electricity for injection - compression energy	7 kWh	(Koornneef, et al., 2008)
Fugitive CO_2 emissions from compressor	0.0003	(Koornneef, et al., 2008)

INNOVATIEVE AANPAK BRENGT ZUID-HOLLANDSE TOEKOMSTMAKERS VERDER

'PROVINCIE ZOEKT TOEKOMSTMAKERS', KOPTE EEN LINKEDIN-ADVERTENTIE IN HET NAJAAR VAN 2016. EN DE PROVINCIE ZUID-HOLLAND VINDT ZE: ZO'N 600 BELEIDSMAKERS, ONDERNEMERS EN WETENSCHAPPERS KWAMEN IN NOVEMBER 2016 SAMEN TIJDENS HET FESTIVAL VAN DE TOEKOMST OM TE WERKEN AAN EEN TOEKOMSTBESTENDIGE PROVINCIE.

Het deed in het begin wat fronsen: een provincie die een festival organiseert. Kan dat niet gewoon in de hal van het Provinciehuis? Met wat workshops in de zalen daaromheen? Gewoon, zoals de provincie altijd bijeenkomsten organiseert. Maar wat is 'gewoon'? De vraagstukken waarover het gaat zijn ook niet zo alledaags: duurzame mobiliteit, duurzame energie, groene groei, innovatie. Vraagstukken die niet voor 100% aan te pakken zijn met bestaand beleid, maar waarvoor we nieuwe oplossingen moeten vinden. Met nieuwe partners. En dat vraagt om een inspirerende aanpak.

Het Festival van de Toekomst

De frons werd een knik, de bijeenkomst een festival: het Festival van de Toekomst. Met als centrale vraag: hoe zorgen we ervoor dat de provincie Zuid-Holland slimmer, schoner en sterker wordt en snel en adequaat kan inspelen op de sterk veranderende maatschappelijke ontwikkelingen? Flink wat overheden, bedrijven en kennisinstellingen zijn daar op hun eigen manier mee bezig. Aan de provincie de taak hen bij elkaar te brengen en door kruisbestuiving kennis te delen en innovatie verder aan te jagen. Via een festival dus.

Inhoud en vorm in balans

Provincie Zuid-Holland legde de lat hoog. Je kunt een bijeenkomst namelijk een festival *noemen*, maar beter is het om van een bijeenkomst een festival te *maken.* Op inhoudelijk niveau, zoals bezoekers dat van de provincie gewend zijn, maar met een festivaluitstraling. Reden om een vroegtijdige samenwerking op te zetten tussen beleid, organisatie en communicatie. Dertig verschillende sessies? Prima, maar dan wel vanuit dezelfde kernboodschap. Innovaties presenteren op een *experience floor?* Oké, maar dan wel innovaties die het verhaal van Zuid-Holland vertellen. Een relatiegeschenk voor de sprekers? Vooruit, maar dan wel duurzaam, vernieuwend én uit de regio. Ook de standaard uitnodiging was niet genoeg. Zo plaatste de provincie de eerder genoemde vacature voor Toekomstmakers op LinkedIn en nodigden sprekers de deelnemers zelf uit via een persoonlijke videoboodschap. Doordat ze die via hun eigen socialmedia-kanalen verspreidden leverde dat flink meer bereik op – ook buiten het bekende relatiebestand van de provincie. Precies de bedoeling, want nieuwe gezichten leveren nieuwe contacten en samenwerkingen op.

Iedereen twittert mee

Omdat je met dertig sessies niet overal kunt zijn, kwamen er FestivalFlitsen. In journaals van ongeveer twee minuten werden workshops vastgelegd, sprekers en deelnemers ge-

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interviewd en Zuid-Hollandse innovaties in beeld gebracht. De flitsen – ongeveer iedere 1,5 uur een nieuwe – werden niet alleen ter plekke uitgezonden voor de deelnemers, maar ook via social media, waardoor ook de buitenwereld een goed beeld kreeg van wat er op het festival gebeurde.

Het bereik werd vergroot door social streams op de festivalvloer te tonen; daardoor twitterde het gros van de bezoekers er flink op los. #fvdt16 was trending topic en zorgde daarmee voor flink wat zichtbaarheid voor de provincie. De berichten op social media vertegenwoordigden een pr-waarde van ruim 110.000 euro op de dag zelf, meer dan 320.000 euro in totaal. Het verslag achteraf, via Storify, maakte het bereik nog eens goed duidelijk: een veelzijdigheid aan berichten, van zowel beleidsmakers, onderzoekers als ondernemers.

Zichtbare partner

Los van de zichtbaarheid op de dag zelf leverde het festival ook inhoudelijk iets op. De provincie is een zichtbaarder partner geworden wat betreft innovatieve projecten en de aanpak van maatschappelijke vraagstukken als energietransitie en duurzame mobiliteit. Zo zijn de provincie en het Leiden-Delft-Erasmus Centre for Sustainability na het festival een partnership aangegaan om een project over groene groei verder te brengen. Meer samenwerkingen zijn in de maak, nieuwe contacten zijn gelegd. En wie weet presenteren zij hun nieuwe innovatieve idee tijdens de volgende editie.

'JE KUNT EEN BIJEENKOMST NAMELIJK EEN FESTIVAL NOEMEN, MAAR BETER IS HET OM VAN EEN BIJEENKOMST EEN FESTIVAL TE MAKEN'

[redacted] 5.1.2e

'HET GROS VAN DE BEZOEKERS TWITTERDE ER FLINK OP LOS; #FVDT16 WAS TRENDING TOPIC'

Festival van de Toekomst

- Plenair programma met sprekers als

[redacted] 5.1.2e

- Zo'n 30 werksessies over 4 thema's: duurzame mobiliteit, groene groei, duurzame energie en kennis & innovatie.
- Experience floor met Zuid-Hollandse innovaties en vooral ruimte voor ontmoeting tussen ondernemers, wetenschappers en beleidsmakers.

Succesfactoren

- Vanuit beleid, organisatie en communicatie in vroeg stadium bij elkaar komen.
- Op alle fronten – vorm, organisatie, communicatie, inhoud – buiten de gebaande paden treden.
- De buitenwereld betrekken en regie uit handen durven geven.
- Duidelijke keuze voor communicatie via social media.

Meer weten? www.zuid-holland.nl/fvdt

To: [redacted][[redacted]@pzh.nl]
Cc: [redacted] [[redacted]@pzh.nl]
From: [redacted]
Sent: Tue 4/10/2018 10:52:57 AM
Subject: RE: letter of support SHELL vb
Received: Tue 4/10/2018 10:52:58 AM

[redacted] van [redacted] hoorde ik vanochtend dat bij een informatieve brief een mandaatnummer niet nodig is, ook niet als [redacted] wil tekenen.
Gr [redacted]

Van: [redacted]
Verzonden: maandag 9 april 2018 8:28
Aan: [redacted]
Onderwerp: RE: letter of support SHELL vb

Dankjewel. Dan heb ik nog het mandaatnummer nodig. Kan je me daaraan helpen?

Van: [redacted]
Verzonden: vrijdag 6 april 2018 15:28
Aan: [redacted]
Onderwerp: RE: letter of support SHELL vb

[redacted],
Heb navraag gedaan en de brief kan idd door [redacted] worden getekend. Gaat via de workflow middels een Informatieve brief.
Kun jij hiermee verder?
Gr [redacted]

Van: [redacted]
Verzonden: vrijdag 6 april 2018 9:33
Aan: [redacted]
Onderwerp: FW: letter of support SHELL vb
Van: [redacted]
Verzonden: dinsdag 3 april 2018 14:37
Aan: [redacted]
Onderwerp: Fwd: letter of support SHELL vb

Verstuurd vanaf mijn iPhone

Begin doorgestuurd bericht:

> **Van:** "[redacted]" <[redacted]@pzh.nl>
> **Datum:** 3 april 2018 om 11:50:28 CEST
> **Aan:** '[redacted]' <[redacted]@pzh.nl>
> **Onderwerp: letter of support SHELL vb**
>
> http://idms/otcs/llisapi.dll?func=ll&objId=579633765&objAction=browse&viewType=1
> [redacted]
> Provincie Zuid-Holland
> [redacted]

GOEDERENVERVOER OVER WATER

SLIMMER, SCHONER, STERKER

IN EEN STROOMVERSNELLING

Samen zetten we de volgende stap naar een schone en slimme binnenvaart

To: [redacted]@mrdh.nl]; [redacted]@delft.nl'[redacted]@delft.nl]; [redacted]@shell.com'[redacted]@shell.com]; [redacted]@denhaag.nl]; [redacted]@denhaag.nl]; [redacted]@pzh.nl]; [redacted]@ [redacted]@rijswijk.nl]; [redacted]@rijswijk.nl]; [redacted]@pzh.nl]; [redacted]
From: [redacted]
Sent: Thur 4/12/2018 2:40:27 PM
Subject: RE: agenda incl annotatie
Received: Thur 4/12/2018 2:40:31 PM
[180412 Agenda bestuurlijk overleg Shell incl annotatie (23-4) v2.docx]()

Nu met bijlage!

Van: [redacted]
Verzonden: donderdag 12 april 2018 16:40
Aan: [redacted]; [redacted]@delft.nl'; [redacted]@shell.com'; [redacted]; [redacted]@pzh.nl'; [redacted]; [redacted]@pzh.nl'; [redacted]@thehague.com'
Onderwerp: agenda incl annotatie

Beste allemaal,
Ter info stuur ik jullie de geannoteerde agenda voor het bestuurlijk overleg (in concept).
Als je zaken anders wilt zien dan graag een reactie voor morgen 15 uur.
Als er tav van het ecorys onderzoek nog zaken veranderen nav jullie reacties (dat bespreken [redacted] ik morgen telefonisch) dan koppelen we dat nog terug.
Groet,
[redacted]

Van: [redacted]
Verzonden: woensdag 14 maart 2018 18:14
Aan: [redacted]@delft.nl'; [redacted]@shell.com'; [redacted]; [redacted]@pzh.nl'; [redacted]; [redacted]@pzh.nl'; [redacted]
CC: [redacted]
Onderwerp: Werkgroep bijeenkomst maandag 19 maart

Beste allen
Voor komende maandag staat er weer een overleg in de planning, bij deze een voorzet voor de agenda.
Qua locatie hebben we nog niet besloten wat het meest praktische is om bijeen te komen.
Bij de MRDH in Rotterdam is altijd voldoende ruimte, maar wellicht is Den Haag makkelijker vanwege de reistijd voor velen?
Ik hoor graag wat jullie voorkeur heeft.

1. Onderzoek Ecorys, voortgang.
2. Voortgang spoor 1 en 3:
   - Economische vraag (Rijswijk,[redacted] DH, Shell).
   - Maatschappelijke vraag (Shell, [redacted].
3. Animo voor pand en bezichtigingen.
4. 10 april volgende werkgroep bijeenkomst, ter voorbereiding op bestuurlijk overleg van 23 april. Wat moet hier voor voorbereid worden?

Met vriendelijke groet,

[redacted]

Metropoolregio Rotterdam Den Haag
[redacted]

Metropoolregio Rotterdam Den Haag
Westersingel 12 | 3014 GN | Rotterdam
Postbus 21012 | 3001 AA | Rotterdam
Meer weten? Kijk op www.mrdh.nl en volg ons via Twitter op @Metropoolregio of praat mee met #MRDH.

To: [redacted] [redacted]@pzh.nl]
Cc: [redacted]
From: [redacted]
Sent: Thur 3/9/2017 12:36:45 PM
Subject: RE: verzoek tot interview t.b.v. North Sea Energy Lab
Received: Thur 3/9/2017 12:36:55 PM

OK, ik wacht even af of de datum doorgaat.
[redacted]

Van: [redacted] [[redacted]
Verzonden: donderdag 9 maart 2017 13:02
Aan: [redacted]
CC: [redacted]
Onderwerp: RE: verzoek tot interview t.b.v. North Sea Energy Lab

[redacted],
Beslis maar of je mee wilt
Van onze kant zou [redacted] eventueel kunnen als we dat deze week willen
Maar 2 is prima wat mij betreft, dus laat even weten
groet
[redacted]

[redacted]

Wijnhaven 23
3011 WH Rotterdam
The Netherlands

T [redacted]
F [redacted]
M [redacted]

[redacted]

[redacted] [[redacted]@planet.nl]
Sent: Thursday, March 9, 2017 12:31 PM
To: [redacted] <[redacted]@pzh.nl>
Cc: [redacted] <[redacted]>; [redacted] <[redacted]
Subject: RE: verzoek tot interview t.b.v. North Sea Energy Lab

[redacted],
We hebben een interview-vragenlijst opgesteld, als format.
Houd die in je achterhoofd.
Ik zou 16 maart kunnen
[redacted]

Van: [redacted] [[redacted]
Verzonden: donderdag 9 maart 2017 12:01
Aan: [redacted]
CC: [redacted] ([redacted]@planet.nl); [redacted]
Onderwerp: Re: verzoek tot interview t.b.v. North Sea Energy Lab

Dag [redacted],
Mooi!
Ik ben ook zeer benieuwd hoe ze kijken naar vormen & mogelijkheden van (financieel) participeren in de windparken door stakeholders - kustbewoners, vissers, kustgemeenten/provincies. Hoop dat je die vraag kunt meenemen.
Hartelijke groet,
[redacted]

> On 9 Mar 2017, at 09:54, [redacted] <[redacted]@pzh.nl> wrote:
> Beste [redacted],
> Fijn dat we gister al even telefonisch contact hebben gehad.
> Hier nog de begeleidend mail: Wij willen graag met jou een 'dialogue interview' houden in het kader van het Northsea Energy Lab (zie bijlage). Vanuit de provincie Zuid-Holland doe we hieraan mee, omdat we voor een enorme uitdaging staan qua energietransitie en tegengaan van klimaatverandering. We hebben hier in het recente verleden, nav ons festival van de toekomst op

10 nov jl, reeds gesprekken over gevoerd met [redacted] en [redacted].
Ik zal dit interview graag samen doen met met iemand binnen het Lab, bv [redacted]. De onderwerpen waarover we van gedachten willen wisselen, zijn: uiteraard Borssele II, maar breder ook, hoe Shell de energietransitie ziet, zowel op zee als op land. Blijft wind op zee all-electric, of gaan we ook deels energietransport vanuit zee doen via waterstof, syngas, ammoniak enz. en welke rol kunnen de bestaande boorplatformen hierbij spelen. Maar ook hoe dit dan op land eruit ziet, hoe gaan we de energie opslaan, hoe gaan we om met fluctuaties in vraag en aanbod enz. Welke transportbrandstoffen worden dominant en wat betekent dat voor de raffinages in de Rotterdamse Haven. En hoe sluit hier dan weer een eventueel warmtenetwerk op aan?
Veel vragen en we gaan uit van een dialoog, dus ook ons mag je vragen stellen, of neem een collega mee.
Aangezien we eind van de maand maart op werkbezoek in de Rotterdamse haven gaan, zouden we het fijn vinden als dit interview reeds daarvoor plaats zou kunnen vinden.
Je gaf aan dat je aan dat donderdagmiddag de 16 maart zou kunnen. Wat mij betreft ook. Graag hoor ik of dit nog steeds uitkomt. Twee uur zou ideaal zijn (volgens de officiele dialogue interview methode), maar in 1/1,5 uur zou het ook kunnen.
Mvg, [redacted]

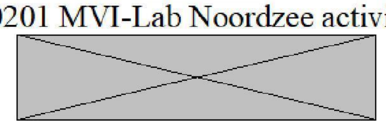
Met vriendelijke groet,
[redacted]

[redacted]

http://www.energieagendazuidholland.nl/strategieen/innoveren-in-de-delta

Afdeling Mobiliteit en Milieu
T [redacted] | **M** [redacted]
Twitter [redacted]
[redacted]@pzh.nl
[redacted]
Provincie Zuid-Holland | Zuid-Hollandplein 1
Postbus 90602 | 2509 LP Den Haag
www.zuid-holland.nl

<170201 MVI-Lab Noordzee activiteiten voorjaar 2017_pub.pdf>



[redacted]

[redacted]

To: [redacted]@pzh.nl]
Cc: [redacted]@pzh.nl]; [redacted]@pzh.nl]
From: [redacted]
Sent: Mon 11/7/2016 8:49:09 AM
Subject: RE: briefing deelname deelsessie Energietranstie tijdens Festival van de Toekomst op 10 november
Received: Mon 11/7/2016 8:49:10 AM

Hierbij een nieuwe update met 2 kleine wijzigingen.

1. Inderdaad zal [redacted] van [redacted] niet komen,
2. En het stukje bij the Green Village over het Co creation centre: eventuele deelname van Shell en [redacted] is eruit. [redacted] vind het nog te prematuur om dit te bespreken.

Geven jullie dit nog door aan [redacted]?

Met vriendelijke groet,
[redacted]

[redacted]
Afdeling Mobiliteit en Milieu
T [redacted] | **M** [redacted]
Twitter [redacted]
[redacted]@pzh.nl
[redacted]
Provincie Zuid-Holland | Zuid-Hollandplein 1
Postbus 90602 | 2509 LP Den Haag
www.zuid-holland.nl

Van: [redacted]
Verzonden: zondag 6 november 2016 20:45
Aan: [redacted]
Onderwerp: FW: briefing deelname deelsessie Energietranstie tijdens Festival van de Toekomst op 10 november

Hoi [redacted],

Is er nog een update van de briefing (zag dat de aanwezigheid van [redacted] nog niet bevestigd was)? Dan kan ik deze morgen naar [redacted] sturen. Eerdere versie is wel al verstuurd.

Groet,
[redacted]

Van: [redacted]
Verzonden: donderdag 3 november 2016 16:07
Aan: [redacted]
CC: [redacted]; [redacted]
Onderwerp: briefing deelname deelsessie Energietranstie tijdens Festival van de Toekomst op 10 november

Beste [redacted],

Hierbij de notitie voor [redacted] over zijn bijdrage voor festival van de toekomst. Ook jou deel zit hierin. Aan jou de vraag: Kan jij liefst uiterlijk volgende week woensdag 1300 uur (maar liever eerder) jou ca 4 sheets naar me mailen (of invoegen in bijgestuurde ppt). Dan ik deze nog in de doorlopende presentatie voegen! Je kijgt 5 minuten. Hopelijk lukt het je om het hierbij te laten, het programma zit echt flink vol!

Met vriendelijke groet,
[redacted]

[redacted]
Afdeling Mobiliteit en Milieu
T [redacted] | **M** [redacted]
Twitter [redacted]
[redacted]@pzh.nl
[redacted]
Provincie Zuid-Holland | Zuid-Hollandplein 1
Postbus 90602 | 2509 LP Den Haag
www.zuid-holland.nl

To: [redacted] [[redacted]@pzh.nl]
From: [redacted]@shell.com
Sent: Wed 3/15/2017 10:06:38 AM
Subject: RE: verzoek tot interview t.b.v. North Sea Energy Lab
Received: Wed 3/15/2017 10:06:54 AM

Prima, bij Carel van Bylandtlaan 16. Tot morgen, [redacted]

From: [redacted] [[redacted]@pzh.nl]
Sent: Wednesday, March 15, 2017 10:24 AM
To: [redacted], [redacted]
Cc: [redacted] ([redacted]@planet.nl)
Subject: RE: verzoek tot interview t.b.v. North Sea Energy Lab

Beste [redacted],
Graag komen ik en [redacted] naar jullie kantoor in Den Haag (als dat is waar jij zit) tussen 10-11 uur.
Kan jij aangeven waar we ons kunnen melden?
Mvg, en tot morgen.
Met vriendelijke groet,
[redacted]

provincie ZUID HOLLAND

[redacted]
Afdeling Mobiliteit en Milieu
T [redacted] | **M** [redacted]
Twitter [redacted]
[redacted]@pzh.nl
[redacted]
Provincie Zuid-Holland | Zuid-Hollandplein 1
Postbus 90602 | 2509 LP Den Haag
www.zuid-holland.nl

Van: [redacted]@shell.com [[redacted]@shell.com]
Verzonden: woensdag 15 maart 2017 10:18
Aan: [redacted]
Onderwerp: RE: verzoek tot interview t.b.v. North Sea Energy Lab

Beste [redacted],
Excuses, ik kan donderdag enkel tussen 10-11. Is dit telefonisch of op kantoor?
Groet [redacted]

From: [redacted] [[redacted]@pzh.nl]
Sent: Tuesday, March 14, 2017 11:59 AM
To: [redacted], [redacted] <[redacted]@shell.com>
Cc: [redacted] ([redacted]@planet.nl) <[redacted]@planet.nl>; [redacted] ([redacted]) <[redacted]
Subject: Re: verzoek tot interview t.b.v. North Sea Energy Lab

Beste, [redacted], wellicht aan je aandacht ontglipt, maar kan je aangeven of as donderdag lukt, of mogelijk een ander tijdstip?
Mvg, [redacted]

[redacted] onder ander document v [redacted]

[redacted]

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onder ander document verstrekt id 106610

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