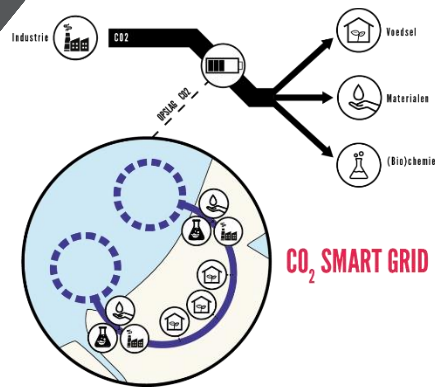
PREFEASIBILITY STUDY CO_2 SMART GRID

THE POTENTIAL OF CARBON CAPTURE, TRANSPORT, USAGE AND STORAGE

27 JULY 2017 – FINAL VERSION

OUR REFERENCE: SISNL17760



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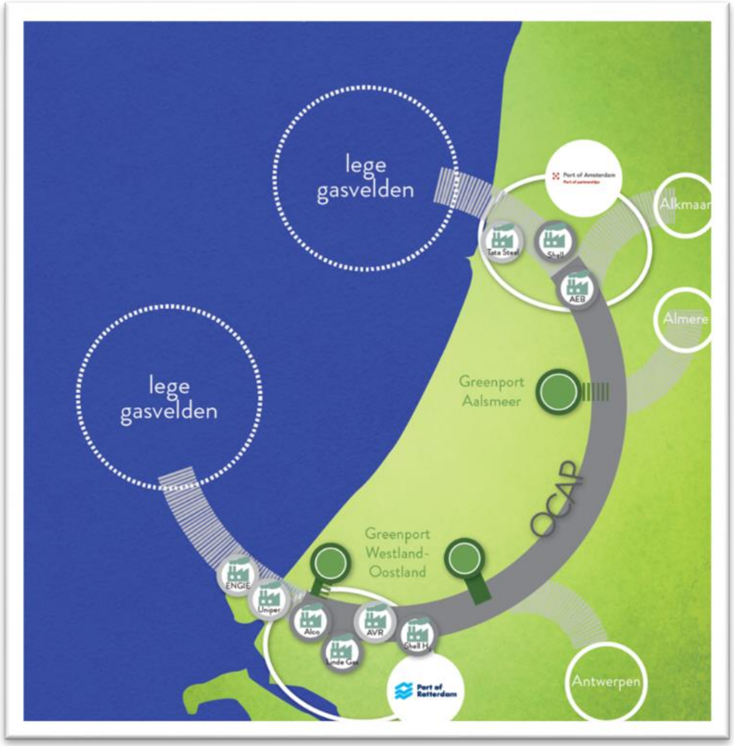
CHAPTER

INTRODUCTION
Q: WHY IS THIS PRE-FEASIBILITY STUDY NEEDED?

- As commissioned by the consortium around the CO_2 Smart Grid and financed by the Dutch Ministry of Infrastructure & Environment, Ecofys has performed an objective, high-level assessment of the feasibility of their CO_2 smart grid (CO_2 SG) initiative as a starting point for a more in-depth feasibility assessment.
- The CO_2 SG concept consist of carbon capture & usage (CCU) with the possibility to include storage (CCS)
- This pre-feasibility assessment yields insight in whether the initiative provides sufficient potential in terms of technology, business potential, societal and climate impact and whether there is a regulatory and policy match.
- To assess this potential, we take a stepwise approach to provide a high-level answer to the following questions:
  - What climate benefits can be realised by a CO_2 SG?
  - What is the potential for the re-use of CO_2 in the Netherlands (provinces North and South Holland) on the short term (<5 years) and longer term (10 years)
  - What are the key success factors or barriers for the development of a CO_2 SG?
- This report aims to provide scoping guidance, actionable recommendations and follow-up questions for the full feasibility study that will look at much greater detail into the above described topics.

Vision BLOC

CO_2: building block for the Dutch Economy



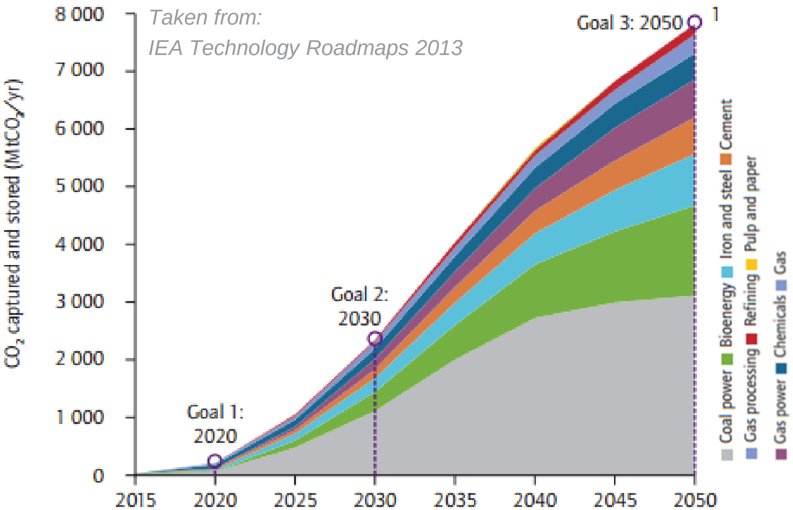
BLOC, 2017

sustainable energy for everyone

INTRODUCTION
Q: WHAT ARE DRIVERS FOR CONSIDERING A CO2 SMART GRID?

- The Paris (COP21) agreement demonstrated the political will to prevent catastrophic climate change globally by setting a target to allow at most 2°C global warming
- Most scenarios that depict what is needed to remain in this ‘2 degree world’ illustrate **a large role for Carbon Capture and Storage (CCS)** and, **to a lesser extend, Carbon Capture and Usage (CCU)**
- The Netherlands have a relatively large carbon-heavy industry and is very much dependant on these activities, in terms of required products and economic activity
- Turning this into a strength, unlocking CO_2 as a feedstock leverages available technological expertise as well as the accessibility to relatively cheap streams of CO_2, the Dutch are in a good position to get CCU to work
- Especially the **large and densely organised Dutch horticulture** provides an interesting opportunity for CCU application, or perhaps even a precondition to sustainable horticulture
- This is even more relevant since CCU is in general accepted to be a stepping stone to larger scale CCS[1]; using and expanding existing CO_2 infrastructure will not only help the transition of industry but also provide additional expertise and trained workforce
- Global CCU potential volumes however, are dwarfed by the large future volumes that are expected for CCS application, with the exception for enhanced oil recovery (EOR)

CCS in the power and industrial sectors in the 2-degrees scenario

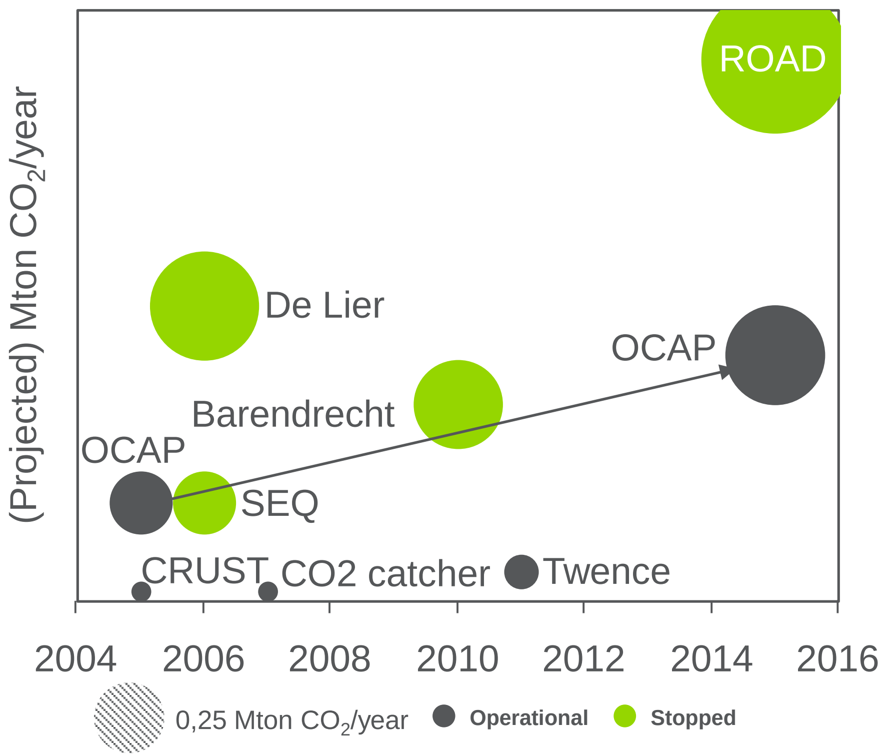


1: Mac Dowell et al., The role of CO2 capture and utilization in mitigating climate change, Nature Climate Change 2017

INTRODUCTION
Q: WHAT IS THE DUTCH EXPERIENCE WITH CCU AND CCS?

- Interest in CCS in the Netherlands started in the early nineties, culminating in the First International Conference on Carbon Dioxide Removal in Amsterdam, 1992[1].
- CCS gradually gained importance as **one of the main climate change mitigation options**. With the *Green Paper Climate Policy*, proposing a pilot project, CCS became policy relevant. The pilot project CRUST, stored an annual 20 kton of CO_2, captured from natural gas and stored in the same field; K12-B in the North Sea.
- In 2004, the Dutch startup CATO started with a € 25 mln budget by government and industry, and quickly opened the CO_2 Catcher, a pilot plant capturing flue gases.
- Other projects planned around this time were SEQ, combining oxyfuel, CO_2 storage and Enhanced Gas Recovery and De Lier, developed by NAM to store CO_2 from a Shell refinery in the De Lier field.
- 2010 marked the end of a CCUS project in Barendrecht following serious public opposition, eventually leading to a **moratorium for onshore CO_2 storage**.
- This shifted attention offshore; the ROAD project intended to use **offshore storage opportunity** and received funding from government. All environmental permits were in place but the project has recently stopped as partners Engie and Uniper have announced to exit the project.[2]

Selected Dutch CCS/CCU projects[3]



[1] http://ccs-roadmap.ecofys.com/index.php/CCS_timeline

[2] https://www.portofrotterdam.com/en/news-and-press-releases/road-project-to-be-cancelled-ccs-to-continue

[3] See Ecofys, CATO3 CCS positioning paper (2015) for an overview of international CCUS projects

INTRODUCTION
APPROACH AND OUTCOMES

- The Dutch Ministry of Infrastructure and Environment and BLOC, on behalf of a consortium of 28 partners, want to have an objective high-level assessment of the feasibility of their CO_2 smart grid (CO_2 SG) initiative as a starting point for a more in-depth feasibility assessment.
- The pre-feasibility assessment gives them insight in whether the initiative provides sufficient potential in terms of technology, business potential, societal and climate impact and regulatory and policy match.
- To assess this potential, we propose a stepped project approach to provide a high-level answer to the following questions:
  - What climate benefits can be realised by a CO_2 SG?
  - What is the potential for the re-use of CO_2 in the Netherlands (provinces North and South Holland) on the short term (<5 years) and longer term (10 years)
  - What are the key success factors or barriers for the development of a CO_2 SG?
- The reporting will provide scoping guidance, actionable recommendations and follow-up questions for the full feasibility study that will look at much greater detail into the above topics. This phase is not the in scope for this proposal.
- This study focuses mostly on CCU applications, for CCS we refer to the extensive documentation that has been published already under the CATO2 programme

Kick-off session

TAKING STOCK
- Develop a CO_2 SG partner survey
- Insight in existing CO_2 supply/demand developments and required quality levels

FACT FINDING
- Analysis and conclusions required to establish high level feasibility assessment
- Insight in key barriers, opportunities and uncertainties

REPORTING
- Concise and to-the-point report
- Actionable recommendations for way forward

Feasibility study (out of scope)

KEY CONCLUSIONS (1/2) THREE POSSIBLE STRATEGIES FOR DEVELOPING THE CO2 SG ARE IDENTIFIED

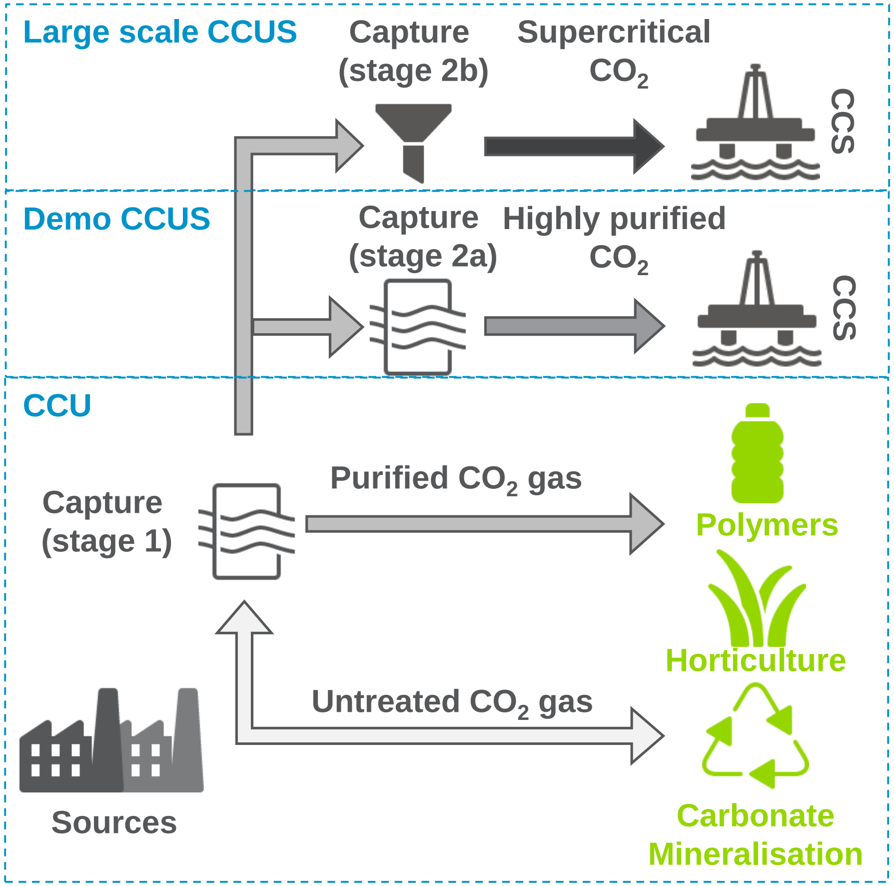
We envisage three strategies for a CO_2 smart grid to develop. These strategies differ in the grid scope and annual transported CO_2 volumes.

1. **CCU grid**, connecting CO_2 sources to CO_2 usage. The capacity of the grid and transported volumes are determined by commercial opportunities. Excess CO_2 supply is emitted to the air, CO_2 shortage is accepted by clients and sourced in an alternative way. Dedicated, local networks can exist for different CO_2 quality grades.

2. **A demonstration-size CCUS grid**, delivering CO_2 throughout the year, with any excess supply being sequestered in the subsurface through a smart connection with a nearby offshore reservoir. Depending on storage-site characteristics, the CO_2 will require a 2nd capture/purification step. Typical CCU oversupply of 0.5-1 Mtons, preferably from multiple sources for security of supply, fits well with CCS demonstration-size projects.

3. **A large-scale CCUS grid** that mostly involves fully developed offshore CCS, handling large volumes and requiring considerable compression, pipeline and storage infrastructure. CCU can benefit from the CCS grid through offered demand-supply flexibility. Techno-economic feasibility of this flexibility should be assessed in the full feasibility study

Scope of the CO_2 Smart Grid



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KEY CONCLUSIONS (2/2) WE ASSESS A ***CCU GRID*** AND **DEMO CCUS** GRID TO BE FEASIBLE, OFFERING OPPORTUNITIES FOR R&D AND EXPORT

A CCU grid, or a demonstration-sized CCUS grid transports has the right dimension to use CCU business cases to make CCS more attractive, while offering CCS back-up volumes to support seasonal CCU peak demand

Current CO_2 demand in horticulture and other potential applications, results in an annual CCU potential of 1000 ktons growing to 1.7 Mtons in 10 years in the Dutch provinces of South- and North-Holland.

The CO_2 smart grid is globally unique in its size and scope and could offer additional benefits in establishing a leading CCUS R&D climate, stimulate CCS developments in terms of workforce and low-cost capture and storage technologies and improve Dutch export potential

RECOMMENDATIONS (1/3)
GENERAL PROJECT DEVELOPMENT RECOMMENDATIONS

Infrastructure development

1. Considering the volumes relevant for CCU between now and ten years, **large infrastructure investments decisions should be solely based on horticulture demand and CO_2 sourcing**

2. **Additional CCU opportunities can be pursued on *ad hoc* basis.** Uncertainties over projected volumes and limited size do not qualify them for a near term active grid investment strategy

CO2 sources and usage development

1. To facilitate smooth integration of CCU and CCS functionality, **CCU applications should be made *CCS ready***. This involves being able to match e.g. quality, pressure and monitoring demands

2. Development of additional sources should be done in parallel with **flexibility solutions to overcome seasonal demand pattern**. A **CCS demonstration-size project**, such as ROAD, offers matching volumes for CCU flexibility, short-term deployment and a supporting policy and financial environment.

Project development timing

1. Large uncertainties in CCS development speed and far-future CCU potential asks for an **opportunistic development approach with flexibility in planning and business development**.

2. A limited number of CCS demonstration-size projects will emerge. **Connecting to these demonstrations on the short term is essential for CO_2 SG development**.

3. Focus on the sources and applications that are relevant now and **pick the relevant partners to realize successful growth on the short term**.

Policy development

1. For many applications CCU climate impact is difficult to assess. New **CCU policies should include full life-cycle assessment** when developing support schemes

2. **CCS development requires a national vision, strategy and roadmap**. We recommend these elements to be embedded in relevant energy and climate policies to facilitate market development.

RECOMMENDATIONS (2/3)
RECOMMENDATIONS AND SCOPING GUIDANCE FOR THE PLANNED FEASIBILITY STUDY

The ambition of CO_2 SG is encompassing many applications, industries and a large geographical area. At the same time the pre-feasibility study reveals that many future developments are still uncertain.

For the next steps to be effective we recommend **scoping the upcoming feasibility study to four elements**:

1. Short term (<5years) CCU applications in horticulture
2. High potential CO_2 sources (capture and purification costs, proximity to grid-connection, availability of biogenic CO_2, continuity of supply, etc.)
3. Potential for CCS demonstration project connection (e.g. ROAD)
4. *Low hanging fruits* in short term additional CCU applications, linked to CCU demonstration-size projects in industries

Development of scenario's and use cases will make required choices more specific and give required insight into risks, investments, societal benefits and required policies.

Concrete elements we see for the full feasibility study:

- Assessment of the chance of success in connecting CO_2 sources with high potential and next steps
- Assessment of the opportunity to revive the ROAD CCS project using existing and high potential CO_2 sources in combination with value streams from horticulture and other CCU applications
- Volume and price scenario analysis of use cases with different CO_2 source, usage and storage options
- Life-cycle assessment (LCA) of the source to user CO_2 chain to assess net abatement potential (see next slide)
- Societal cost-benefit analysis on CCU and CCS in comparison to other abatement measures (partially based on the LCA)
- Techno-economical assessments of the feasibility to retrieve stored CO_2 from the subsurface and the flexibility potential to use a large scale supercritical CO_2 infrastructure as a buffer for a CCU grid[1]
- Analysis of drivers for future high impact CCU opportunities and a list of indicators for opportunity monitoring (e.g. (bio-)methanol, CO_2 efficiency in horticulture, carbonate mineralization, see appendix D)

[1] See slide 19 for details of this aspect

RECOMMENDATIONS (3/3) A CCU *LIFE-CYCLE* AND *SOCIETAL COST-BENEFIT ANALYSIS* IS REQUIRED TO SHOW CO_2 SG BENEFITS PER TON AVOIDED

- In terms of investment and operation costs, capturing CO_2 is a large cost factor in both CCU and CCS application. Currently for most sources CO_2 prices are too low to make up for these costs.
- A **societal cost-benefit analysis (SCBA)** as part of the follow-up feasibility assessment may however show that the **indirect benefits of CO_2 capturing, reuse and storage has positive societal benefits and business development potential that could outweigh the direct costs** and/or be more effective than other abatement measures.
- In order to assess the impact of a CCU technology as part of the SCBA, **a full Life-Cycle Analysis (LCA) for selected CCU options is required.** The LCA will allow comparison between the carbon footprint of the primary products produced in the traditional production pathway with the primary products produced through the CCU pathway
- In performing these LCAs, **it is important to distinct the Greenhouse Gas emissions abatement effects per CCU technology;** some applications result in long-term sequestration, like carbonate mineralisation. Others, like horticulture, merely replace the use of fossil fuels, see chart on the right.

The following steps are needed to asses the actual abatement impact:

1. **Define a baseline**: calculate the carbon footprint and energy use of the traditional production route and any potential changes expected in the future
2. **Analyse alternative production pathways**: analyse the carbon footprint and energy use of the CCU production route
3. **Estimate other environmental impacts**

For CCU business cases it is critical to assess:

- CO_2 storage duration (e.g. short for horticulture, long for carbonate mineralisation
- Allocation of GHG emissions and reductions along the full value chain, i.e.: amongst the producer of CO_2 and the producer that uses the CO_2

Abatement effect for several CCU technologies (indicative)

CCU application	Baseline replacement	Storage duration	Allocation
Horticulture	Gas burning	short	Emitters vs farmers
Polymers	Traditional	Short/medium	Internal
Carbonate mineralisation	n/a	>100 years	Value-based
…			

ADDITIONAL FINDINGS (1/2) WE ASSESS A *CCU GRID* TO BE FEASIBLE, GROWTH REQUIRES CLOSING THE FINANCIAL GAP OF 5-35 €/TON

Current OCAP grid is technically suited and economically feasible for several relevant CCU applications. Additional CO_2 sources will need to be connected to realise growth in CCU applications.

- **Current CO_2 demand** in horticulture and other potential applications, results in an annual **CCU potential of 700 ktons growing to 1.7 Mtons in 10 years** in the Dutch provinces of South- and North-Holland
  - Slide 16, Appendix A
- A CCU grid can be economically feasible on the short term focusing on horticulture and chemical CCU applications
  - Slides 23-26, Appendix E
- Quality demand of some CCU applications require additional purification steps. For these cases **CCU volumes should be large enough to justify potential additional purification investments**.
- Most prominent barrier to CCU grid growth is **shortage of current supply capacity, especially during summertime peak demand**, combined **with security of supply from the current two CO_2 sources**.
- **CO_2 container storage** to exclusively manage seasonal peak demand we consider to be **not economically feasible,** with associated costs of over 100 to 150 €/ton CO_2 stored.
  - Slide 19
- **Sufficient technical potential** available to source from additional CO_2 suppliers; involves closing a financial gap of 5-35 €/ton CO_2. Future CCU **volumes are small enough to have long-term security of sourcing,** even when considering future CO_2 emission reductions in industries
  - Slides 16-21, slide 18 on capture cost levels for sources
- Security of supply can also be delivered by connecting the smart CCU grid to a future CCS grid (see next slide).
- There are **limited societal and regulatory barriers** related to the CCU grid
  - Slides 28-31
- Development of a CCU grid has a **positive impact on CO2 emissions at the user location**. Net CO_2 reduction per use case, and relative abatement costs should be assessed through a more detailed **life-cycle assessment** and a **societal cost-benefit analysis**

ADDITIONAL FINDINGS (2/2)
CCU VOLUMES MATCH WITH DEMONSTRATION-SIZE CCS, DEVELOPMENT INTO LARGE SCALE CCS IS NOT SUITABLE

Because of economy of scale, **large capacity transport grids are required for mature CCS application**, possibly using supercritical transport of CO2 for additional cost effectiveness.

Current OCAP grid is not suited for these large CCS volumes. Development of the current **CCU grid can have benefits to early CCS development and demonstration-size projects**.

- **Expected CCU volumes are a factor 20-40 smaller than the required Dutch CCS volumes** to meet climate goals
  - Slides 15-21

- **Current OCAP infrastructure has a transport capacity of 2.6-3 Mtons annually.** This is enough for CCU applications, but limited for handling multiple large CCS sources.

- **Large scale CCS infrastructure will be dimensioned on required storage volumes**, with large capacity (supercritical) CCS transport pipelines and probably higher CO2 purity criteria than in the current OCAP grid.

- Although some future forecasts predict large CCU potential for e.g. methanol production, we emphasize the strong assumptions and uncertainties in underlying forecasts
  - Appendix B

- **The OCAP grid can however act as an accelerator for CCS demonstration projects** and in the future operate as a branch of a large scale CCS grid. If, after 2030, large CCU volumes do develop, the CCS grid and CCU grid can be fully integrated

- The development of a CCS grid provides an opportunity for CCU through **offering CO2 peak capacity** for the large CO2 summer demand in horticulture. Recent developments in the ROAD CCS project offer the opportunity for CO2 SG to restart using existing and additional OCAP CO2 suppliers.

- Development of a CCUS grid has benefits for large scale CCS development related to **CCS workforce development**, **lower costs for capture technologies and improved Dutch export potential**
  - Slides 29-30

CHAPTER

TECHNOLOGY ASSESSMENT
Q: WHAT ARE THE CURRENT SOURCES OF CO2 EMISSIONS AND HOW ARE EMISSIONS GOING TO DEVELOP?

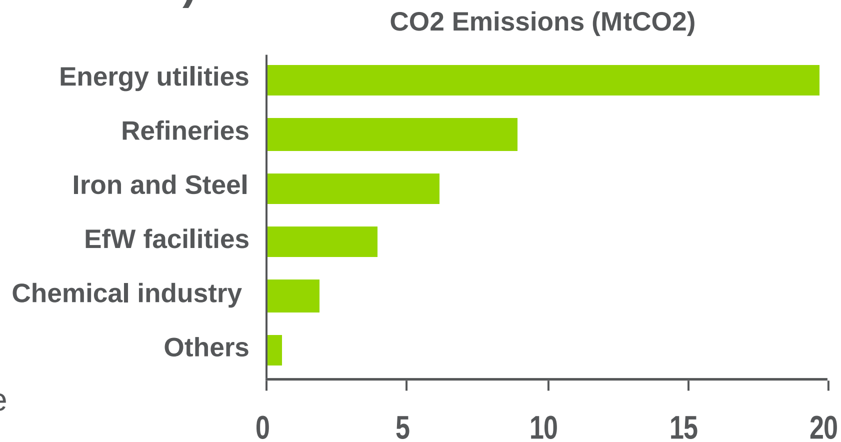
There is an annual potential of 42 Mton CO_2 that can be captured from different point sources in NH/ZH

- Largest individual emitters are **energy utilities, iron and steel producer Tata Steel and the refineries of Shell, BP and Esso**. These large emitters together contribute to nearly 80% of the total CO_2 supply in the North and South Holland.
- Typically plants contain multiple CO_2 point sources with different emission specifications and related capture costs.

Over the next decades, current emissions will see a strong decline, however annual volumes of tens of Mtons remain

- **Renewable energy sources** provide a growing share of the energy mix, pushing out fossil based plants. Omitting coal fired plants translates to a total emission reduction of nearly 7 Mton.
- **Enhanced recycling of waste and transition to circular economy** will lower waste volumes and associated Energy from waste (EfW) emissions. Large scale international import of waste could reduce the emission reduction speed.
- **Lower dependency on fossil fuels** will result in reduction of the size of the refinery sector and associated emissions.
- After **energy efficiency measures in industries**, over half of the industrial emissions are expected to remain. These are more difficult to replace and are a potential source for CCUS.
- CO_2 with a **biogenic origin** is an especially attractive source as it results jn zero/limited net emissions for CCU and negative emissions in CCS, see appendix C for details.

CO_2 Emissions from Major Sources (>100 kton) in the North and South Holland



Ecofys EUTL database 2016

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TECHNOLOGY ASSESSMENT
Q: WHAT IS THE POTENTIAL FOR CCU APPLICATIONS?

- **Total potential for promising CCU applications is around 1 Mton and estimated to increase to 1.7 Mtons in 10 years**. Additional potential might arise from other CCU technologies, see appendix A.
- **Horticulture provides a CCU potential of 500 ktons at the moment, with the potential to increase to 1.2 Mton** in 10 years (assuming 100% market penetration in NH/ZH). We expect this CCU volume to drop on the longer term: the sector has the ambition to become climate neutral by 2050. Realising the sectors climate neutral ambition, CO_2 will have to be from biogenic origin[1] or emissions prevented, amounting to 150-300 ktons/year of CO_2 demand.
- **Carbonate mineralization potential** can change based on the availability of waste streams especially the **steel slag and fly ash**. Based on constant historic steel production volumes we expect the amount of steel slag to be constant in the future. Fly ash may decrease if coal plants are shut down. Therefore, this CO_2 use potential may decrease to 200 ktons in the long term. The decrease could be off-set by a developing market for other construction materials that capture CO_2, such as Olivine.
- **There is no CO_2-based polymer processing in the Netherlands at the moment.** However, the polyols may replace 5-10% and 10-15% of the conventional polyols in the near and long term, respectively. Potential from polycarbonates is expected to be 30% of the polyols demand. This translates into CO_2 potential of 12-23 ktons and 30-45 ktons in the near and long term, respectively. **Beyond 2030, rigid polycarbonates and isocyanates may mature and offer an additional few ktons of CO_2 use.**
- **Concrete curing**: with this technology fully developed we may expect a potential of 70k tons for the Dutch market. If 40% of this technology is deployed in the North and South Holland then CO_2 use potential would be around 30 ktons.
- **Methanol yield boosting[1]** is a commercial technology. Around 47% of the CO_2 used for methanol production is meant for yield boosting. Roughly 0.54 tons of CO_2 are used for one ton of conventional methanol production.

CCU Technologies Potential[2]

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.

TECHNOLOGY ASSESSMENT
Q: IS THERE SUFFICIENT STORAGE CAPACITY FOR CCS?

- The is plenty of subsurface storage potential for large scale CCUS. A high-level overview in the form of known oil and gas fields shown in the table on the right.
- The cheapest option would be onshore storage. West Netherlands has some 110 Mton storage potential in depleted oil and gas fields, but with the Barendrecht project halted due to public opposition, we do not foresee this being a viable option in the near term.
- Offshore storage meets less public opposition and with infrastructure to offshore already available, **most relevant to the CO_2 Smart Grid would be the offshore potential of around 1200 Mton**.
- Assuming annual Dutch CCS volumes of around 40-90 Mtons[1], this will equate to **13-30 years of offshore storage**. After that period additional storage locations should be found, or further CO2 emission reduction is required
- More specifically, the Dutch ROAD project, a CCS pilot, looked at using gas fields in block P18 from TAQA, located 3.5 km from the Maasvlakte with a combined storage potential estimated to be 35-42 Mton.
- The original ROAD pilot aimed to capture at a rate of 1.1 Mton CO_2 annually. Prolonging this pilot, this equates to over 30 years of storage.

Storage capacity

Location	Potential ($Mt\ CO_2$)
Groningen gas field (not valid)	9000
Onshore excl. Groningen	1500-2000
of which West Netherlands	110
Offshore (*see below*)	1200
Total excl Groningen	2700-3200

Cluster	Storage capacity ($Mt\ CO_2$)
L10	159
K6-CC	73
Nogat	133
L7-CC	91
G17d-A	40
D15-A	58
L8-Golf/L8-P4	55
K14-FA	303
K5-CC	112
Local	79
J06-A	61
P18	42
Q08	10
Total capacity	**1215**

[1] *Scenario predictions range from 40 – 90 Mtons a year for The Netherlands, McKinsey, Large scale roll-out scenario's for CCS in The Netherlands 2020-2050, 2009*

Sources: EBN & Gasunie, CO2 transport- en opslagstrategie, 2010
Rijksoverheid, Policy Document on the North Sea 2016-2021

TECHNOLOGY ASSESSMENT
Q: CAN CO_2 BE CAPTURED AND AT WHAT COST?

- Several technologies exist that can capture CO_2 from various CO2 sources, as listed in the figure.
- Capture costs, therefore, represents the cost of reducing CO_2 emissions to the atmosphere while producing the same amount of product from a reference plant. The capture costs differ based on the industrial process to which a capture technology is applied to, the capture technology used, CO_2 source size and the concentration of CO_2 at the point source. Cost ranges are displayed in € per ton of CO_2 avoided.
- CO_2 capture sources relevant for CO_2 SG from a cost perspective are **production of hydrogen, methanol and ethanol**. These sources provide relatively pure CO_2 stream and also fall in the low capture cost category of 12-33 €/ton.
- CO_2 capture costs from **coal and gas fired plants, EfW facilities and blast furnaces** is 10-30 euros more expensive than the low cost category CO_2 sources. These sources, however can provide **high volumes of CO_2** for the CO_2 SG.
- The **(fossil or biogenic) origin of CO_2** is a relevant selection criterion for CCUS (see appendix C for details) which may favour CO_2 from EfW as up to 60% the associated CO_2 can be of biogenic origin.
- Apart from capture costs, also costs are associated with transport infrastructure and

CO_2 Capture Cost from Different Point Sources

Industry	Sub-category	Typical plant size (Mt CO2/yr)	CO2 source size (Mt CO2/yr)	Cost EUR (2015)/t CO2 avoided
Refinery	Hydrogen production	~4.9	0.25-1	12-33
	Process heaters/CHP		0.2-1	33-104
	FCC		1-2.5	66-104
Iron and Steel	Blast furnace	~4.5		21-62
	Hot stoves			58-71
	Coke oven			75-79
Chemical	Ethylene oxide	~3.3		12
	Hydrogen (ammonia/methanol)		0.1-1	17-33
	Ethylene/Propylene			58
	Process heaters/CHP		0.2-1	33-104
Cement	Precalciner	~0.9	0.5	17-37
Paper and pulp	Craft mill	~1	1	25-58
Gas processing		~2	2	8
Ethanol production		~0.5	0.5	12
Aluminium smelter		~0.25	0.25	12
Electricity sector	Coal fired plant	~5	5	36-48
	Gas fired palnt	~3	3	66
Waste incineration				43

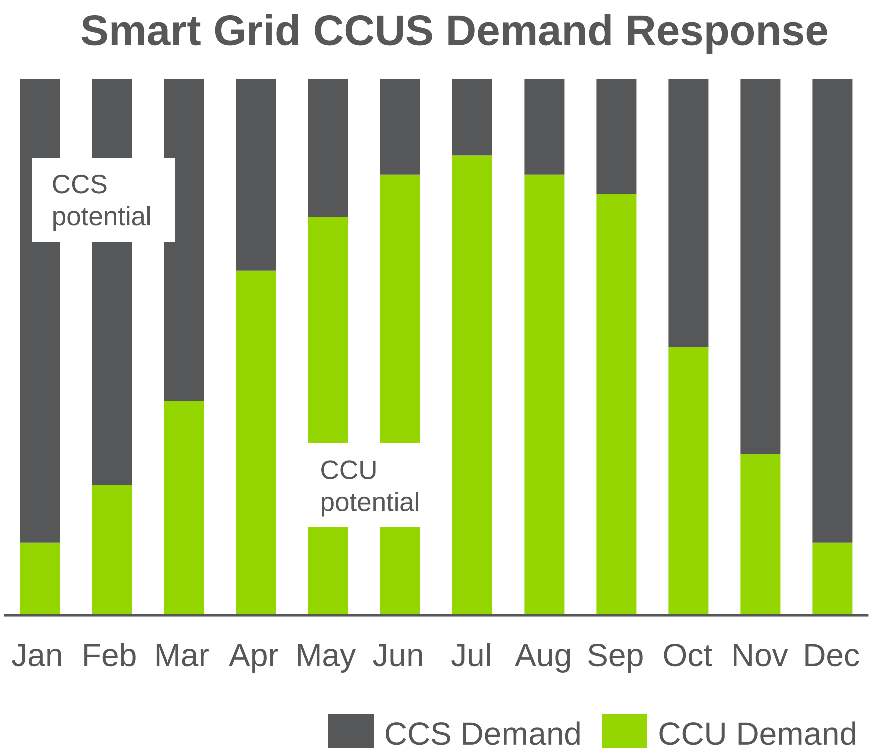
Low: Less than 33 **Medium: Less than 66** **High: Greater than 66**

Grey-out industries are outside the geographical scope of the CO2 smart grid and this pre-feasibility study

1: IEA Technology Roadmap CCS 2013
2: ZEP CCS for Industry 2015
3: ZEP CCS in Energy-Intensive Industries 2013
4:TNO A secure and affordable CO2supply for the Dutch greenhouse sector 2015
5: Carbon Counts CCS Roadmap for Industry: High-purity CO2sources 2010

TECHNOLOGY ASSESSMENT
Q: CAN WE RETRIEVE CO_2 FROM STORAGE LOCATIONS AND TRANSPORT IT TO CO_2 USERS?

- Technically gas stored in reservoirs can be retrieved as also demonstrated in Bergermeer or Grijpskerk Underground Gas Storage (UGS) for natural gas. For CO_2 this is technically not very different. The infrastructure should be designed to be capable of dealing with two flow directions.
- However, retrieved CO_2 will be contaminated with residual hydrocarbons from the reservoir or even more harmful substances like H_2S or mercury
- To our knowledge no subsurface CO_2 storage and retrieval demonstrations exist. **Additional R&D would be required to assess technical and economic feasibility.**
- Additionally, the revenue from CCS (i.e. EU ETS) would somehow need to be discounted for in retrieval, rendering it a potentially costly undertaking.
- Considering a projected CCU horticulture volume of 1.2 Mton/year, 250 ton/hour should be supplied to match seasonal peak demand, without need for storage retrieval. The capacity of the OCAP backbone is sufficient for this[1]. In addition to CCU an annual CCS volume of 0.7 Mton can be realized. This mechanism is indicated on the right.
- Apart from subsurface storage to manage seasonal fluctuations, cryogenic tanks may provide large scale (>100kton) storage, but cost estimates (including liquefaction, cooling and write-off) yield a € 100-150 / t CO_2 price range, rendering this solution expensive to manage peak demand



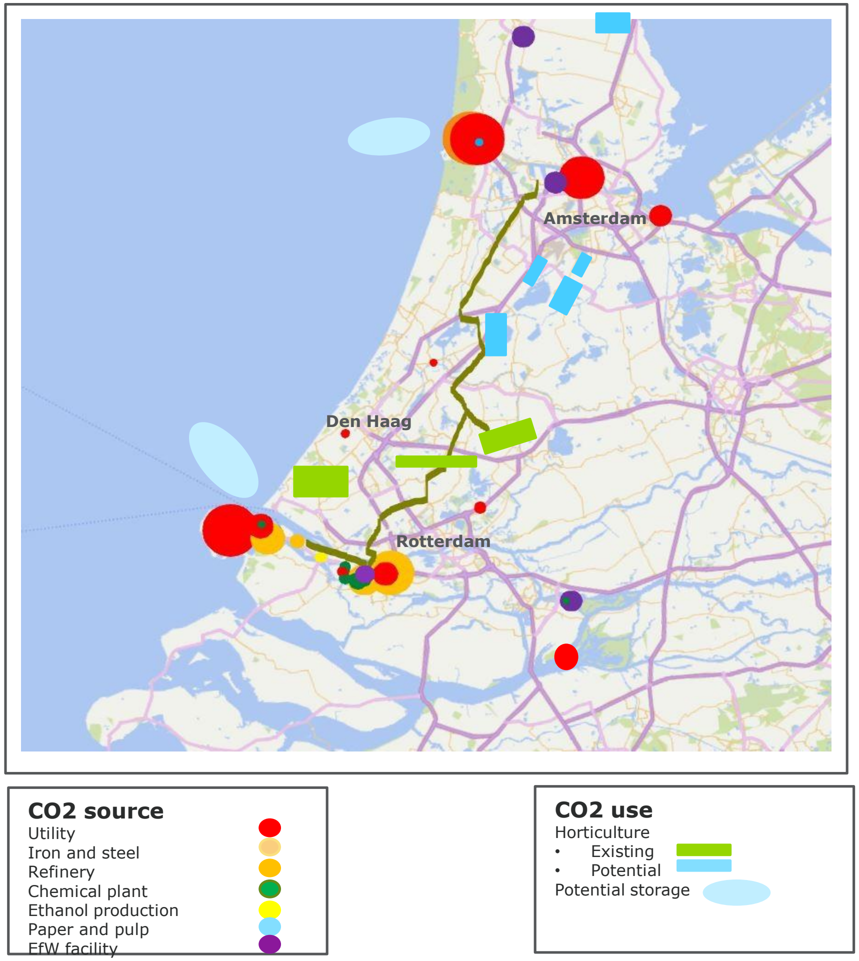
Ecofys, based on OCAP seasonal demand pattern

1: backbone capacity: 300-350 ton/hour, OCAP private discussion

TECHNOLOGY ASSESSMENT
Q: WHAT INFRASTRUCTURE WOULD BE NEEDED FOR A CO_2 SMART GRID? (1/2)

- Potential CO_2 sources are in the figure. The size of a balloon represents the volume of CO_2 available at the source.
- For all potential sources **costs for additional pipeline infrastructure** to connect to the OCAP grid have been calculated. We did not take into account costs reduction by re-utilization of existing pipelines for oil or gas.
- For most of the sources (75%) the **estimated infrastructure CAPEX per ton of CO_2 supplied is negligible** (less than 1 EUR/t CO_2 supplied). This is due to very low distance to CO_2 emissions ratio. For the remaining 25% there will be additional costs ranging from 2-25 EUR/ tCO_2 supplied. See table on next slide.
- For the use of CO_2, **most of the potential CCU sites are located close to or at the CO_2 source**:
  - **Polymers CCU demand will most likely be located at chemical plants**; little pipeline infrastructure is expected
  - For efficiency purposes, we expect **demand for carbonate mineralization to be concentrated at sources of both CO_2 and waste materials**, e.g. coal plants, steel plants and EfW; little pipeline infrastructure is expected
  - Demand from horticulture is projected to increase. Existing and potential locations are displayed as light green and sky blue rectangles in the map, respectively. Pipeline costs for the planned sites would be sensitive to the CO_2 volumes used against unit length of the distribution pipeline. We recommend volume projections and business cases to be developed per specific location.

CO_2 Pipeline Infrastructure



  7-9-2017 sustainable energy for everyone

TECHNOLOGY ASSESSMENT
Q: WHAT INFRASTRUCTURE WOULD BE NEEDED FOR A CO_2 SMART GRID? (2/2)

- Pipeline costs range from almost nothing to 25 EUR/tCO_2, depending on distances, volumes transported.
- OCAP is currently supplying ~500 ktons (through Shell refinery and Alco ethanol plant) to roughly 500 greenhouses annually. The **additional supply** required for market growth could potentially come **from refineries and chemical plants** as they have negligible infrastructure costs and can provide cheap and pure supply of CO_2.
- Air Products Nederland and Air Liquide are generating around 1 Mton of pure CO_2 stream at their hydrogen production facilities in Botlek-Rotterdam. These can be relatively low cost options to meet the short term needs of the OCAP grid.
- Considering only cost, other potential CO_2 sources could be EfWs,(AVR, Rotterdam; AEB, Amsterdam) followed by coal plants (E.ON, Maasvlakte; Engie, Maasvlakte) and gas plants (Enecogen, Europoort-Rotterdam; Eurogen, Botlek-Rotterdam; Nuon, Velsen, etc.)
- However, a more detailed assessment is needed to select suitable sources to meet the short and long term requirements of the OCAP grid. Apart from costs, security of supply, CO_2 quality and technical feasibility of connecting a particular point source should be explored properly. Depending on the specifics of the CO_2 source considerable additional costs can be required.

CO_2 Sources Suitable for Meeting CCU Requirements

CO2 source	City	Emissions (kt CO2)	Distance (km)	Total cost (EUR/tCO2)
Air Products Nederland B.V.	Botlek-Rotterdam	907	**< 1**	12-33
Air Liquide Nederland B.V.	Rozenburg	141	**< 1**	12-33
AVR	Rozenburg	1,510	**< 1**	43
AEB	Amsterdam	1,180	**~6**	43
Uniper Benelux N.V.	Maasvlakte-Rotterdam	5,950	**~10**	36-48
Nuon Power Generation B.V.	Velsen	5,783	**~12**	66
Tata Steel IJmuiden B.V.	Veslen-Noord	6,212	**~15**	21-79

Note:
1: Total costs only represent capture costs as our high level estimates suggest that all these sources have negligible (less than 1 EUR/tCO_2) pipeline infrastructure costs. CAPEX: 1000 EUR/m, OPEX 3% of the initial CAPEX.
2: Most listed sources have different processes and locations in the plants where CO_2 can be captured. Total costs listed describe the typical cost range for all these capture locations.

CHAPTER

BUSINESS ASSESSMENT
WHAT ARE CONSIDERATIONS THAT DRIVE COSTS?

Infrastructure dimensioning

- Transport costs depend on dimensioning of the grid. We envisage three different scenarios for a CO_2 smart grid, with different physical requirements
  - CCU grid; an extension of the current OCAP pipeline to connect more sources and applications
  - Demo CCUS; an extension of the current OCAP pipeline to connect more sources and applications including offshore storage, where potentially additional purification and compression will need to take place prior to injection, depending on the storage site.
  - Large scale CCUS; a very large and extensive CO_2 grid where the CCU applications will form the smaller onshore offtake point of a large offshore infrastructure
- The first two scenarios are natural next steps from the current situation, possible even in consecutive order
- The last scenario requires considerably more investment and a clear role for government is foreseen to enable the development of infrastructure at this scale. Both on compression, pipeline dimensions and distribution a step change is needed compared to the current infrastructure
- In this last scenario, a more utility-style of smart grid operator would be needed, guaranteeing quality, integrity, stability and security of supply

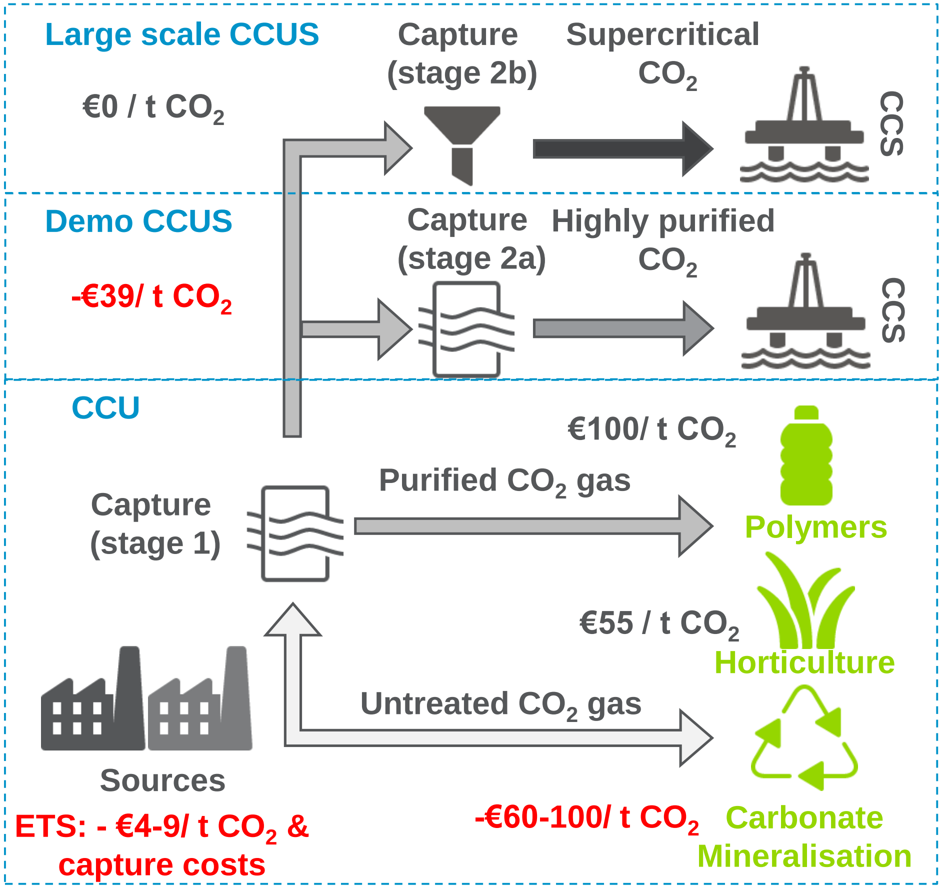
Gas quality

- Horticulture is viewed as having the largest foreseen potential for the smart grid in the near term. Combined with the fact that existing infrastructure delivers quality that meets the specs for horticulture applications, we foresee the quality of the CO_2 gas should remain as is in the main infrastructure, only to be treated further (upgraded) for potential CCS
- For a number of applications in the carbonate mineralization business case, a lower grade supply might suffice, which means that applying higher grade CO_2 might be value eroding. This means a low grade separate system would be needed, preferably small-scale, in close proximity of both source and usage.
- In most of the low-grade applications, we foresee a source of CO_2 close to application. Tata Steel emits in excess of 6 Mt CO_2 annually and produces steel slag that can potentially be carbonized. EfW facilities emit CO_2 and can apply the gas to carbonize bottom ash. These routes could be fully decoupled from the grid or CO_2 gas stream could be partially diverted before a capture stage downstream leading to the main grid

BUSINESS ASSESSMENT
Q: WHICH BUSINESS CASES EXIST OR CAN BE DEVELOPED FOR A CO_2 SMART GRID AND WHAT IS POTENTIAL VALUE?

- The viability of business cases, including CCS, are driven by a maximum asking price for CO_2 that in turn is governed by a commercial application or a policy incentive like a CO_2 price under ETS.
- These are estimated in the following slides and indicated in the schematic on the right
- Value that is associated with the CCS and CCU applications varies greatly.
- **Most value is associated with the CO_2 use for chemical processes** as this allows for an alternative feedstock compared to much more expensive fossil materials such as currently produced from crude oil
- At current ETS prices, CCS and carbonate mineralization are the options that results in **negative potential returns**. Only large scale, matured CCS is feasible at current ETS
- All the usage and storage cases considered under the three scenarios are detailed on the following slides
- The **grid operator** will need to develop a cost structure below these asking prices that enables CO_2 (capturing &) purchasing, grid operation & maintenance and investment costs. These are estimated to be **around €30-45t CO_2 for the current OCAP grid**.
- Estimates for operational costs for **new investments require more detailed analysis**. The **costs for additional CO_2 sources** is expected to be the dominant factor.

Outline of CO_2 Smart Grid



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BUSINESS ASSESSMENT
Q: WHAT ARE RELEVANT CONSIDERATIONS TO ASSESS THE VIABILITY OF A BUSINESS CASE?

Horticulture

An important consideration is the means by which potential users are supplied with heat. Today, greenhouses mostly use CHP or boilers for heat, delivering electricity and CO_2 as a (cheap) by-products. Hence, this is the key competitor for external CO_2 supply. However, more and more greenhouses look for a connection to a district heating system or geothermal as a sustainable heat supply – creating opportunities to develop bundled infrastructure for heat, CO_2 and electricity to meet (future) horticulture needs. Combining CO_2 supply with district heating development can reduce costs and enhance adoption rates for both commodities.

A smart grid will need to be able to deal with seasonal demand fluctuations through large-scale storage, smart diversion of supply surplus or integrating with CCS. This integration will increase sensitivity to carbon prices.

Carbonate mineralisation

This business case mostly focusses on the binding of CO_2 to industrial waste streams ranging from AVIs to steel plants. In developing business cases for carbonisation of these waste streams, security of waste supply becomes important. In other words: to what degree can we be certain that current waste streams will not reduce over the next decade(s)? This is believed to be most critical for fly ash from coal-fired power plants (as society may decide to speed up phasing out of this form of electricity generation) but also Municipal Solid Waste Incineration (MSWI) may reduce due to a transitioning to more circular business models and re-use of waste.

In the case of carbonate mineralisation, the largest part of future revenues is dictated by a carbon price. This business case is therefore sensitive to fluctuations in policy outlook.

Polymers

For polymers the major challenge is the risk averseness around new products of the chemical industry. This is to say that the users of polycarbonates and polyurethane manufacturers are reluctant to try a new technology that can risk changing the downstream chemical processes. Cost savings alone would not be sufficient for the polymer industry to mitigate the potential risks of a new technology. Some of the properties of CO_2-based polymers may be enhanced but for numerous applications they would still be different. The acceptability for CO_2-based polymers would likely vary between applications, and this would determine how quickly these new products are adopted by the market.

The technology, however, appears to have substantial economic gains over traditional processes as it replaces expensive fossil based raw material with relatively cheap CO_2.

BUSINESS ASSESSMENT
Q: WHAT WOULD BE A REALISTIC AND FEASIBLE BUSINESS MODEL FOR A CO_2 GRID OPERATOR?

The business model for a CO_2 grid resembles that of a utility infrastructure operator:

- Current business model, as deployed by OCAP, is to buy, transport and sell CO_2 to users.
- CO_2 that is not directly used for CCU is supplied to a small peak demand buffer and the remainder is vented.
- Currently used *cost plus* pricing model, is a common pricing method as used by utilities with long term infrastructure investments as it provides the operator with contracts that have an assured profit margin.
- The service OCAP provides would potentially become more valuable once the supply of CO_2 is guaranteed throughout the year, overcoming supply shortage during summer peak demand
- As not all CO_2 users assign the same value to security of supply and some may have more flexibility is shifting CO_2 demand, there may be some additional value in offering demand-response services when flexibility is required.
- Additional examples of potential demand-response services can be found in the electricity and gas markets.
- Venting of surplus CO_2 can be avoided by using CCS. However the current ETS price of 4-9 €/ton alone is insufficient to allow for development of CCS infrastructure. Additional financing could come from R&D funds, government subsidies or companies' CSR or strategy budgets

- The feasibility of the business model can improve by realizing synergies in:
  - **Infrastructure operation synergy**: service provision in multi-commodity grids (heat, CO_2, gas, water, electricity)
  - **User service offering portfolio**: develop behind the CO_2 meter services, such as CO_2 level monitoring automation, horticulture CO_2 capture technology, closed greenhouse technology

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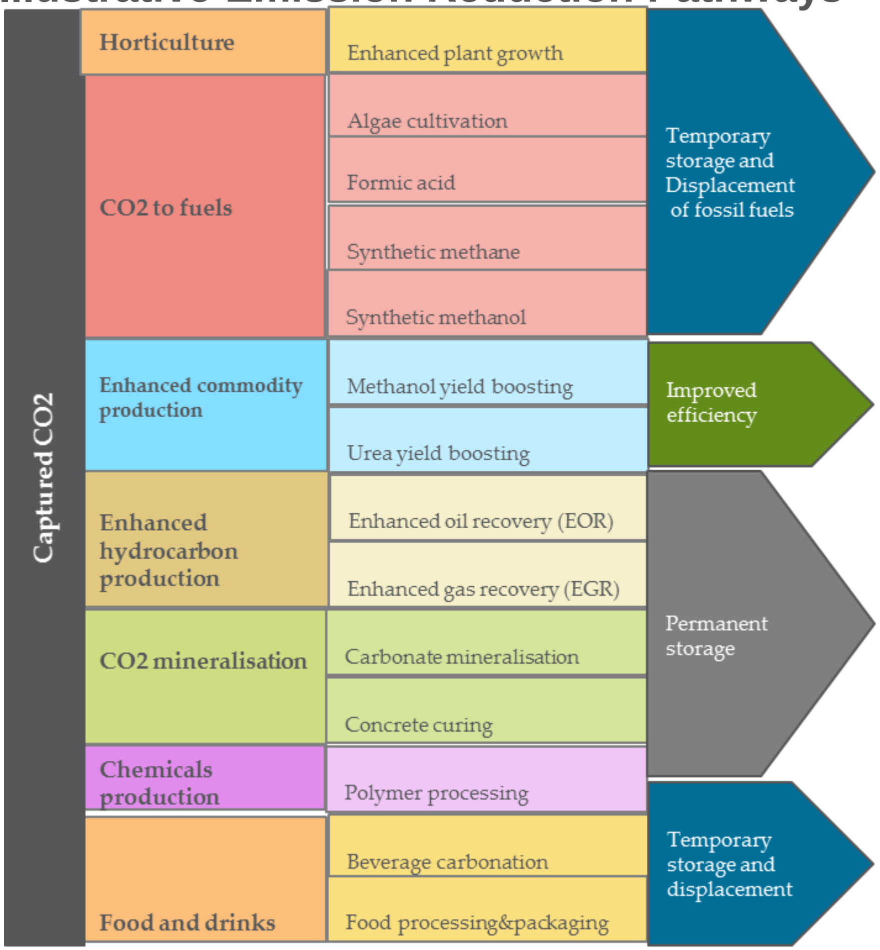
SOCIETAL ASSESSMENT
Q: WHAT BENEFITS CAN CCU APPLICATIONS BRING IN TERMS OF CO_2 EMISSION REDUCTIONS?

CCU applications bring different types of CO_2 abatement effects as is shown in the figure on the right.

- **Displacement of fuels and improved efficiency are the most effective abatement measures** as they prevent CO_2 emissions to take place.
- However **long term CCU potential these measures will be negatively impacted by any CO_2 emissions along the CCU supply chain**: also emissions that result from e.g. burning CCU fuels and excess CO_2 in greenhouses need to reduce to meet emission targets.
- **Measures resulting in permanent CO_2 storage are considered to be as effective as CCS measures**. While currently not part of the EU ETS system a recent court ruling could speed-up adoption in ETS schemes[1]
- To quantify the carbon abatement effects and understand climate benefits of these technologies **a complete analysis of their life cycle emissions is required**. The climate benefits of CCU products depend not only on CO_2 used in products but also on CO_2 emissions required in making the product as well as the emissions resulting from their end of life treatment. This necessitates the development of a standardized LCA methodology for validating the emission reduction potential of CCU technologies.

Illustrative Emission Reduction Pathways[2]



1: Luther lawfirm, Recognition of climate protection measures: Succes at ECJ for the Lime Industry with Luther, 2017

2: For a discussion on short versus long term abatement potential and the role of biogenic CO2, see Appendix C

SOCIETAL ASSESSMENT
Q: WHAT ARE OTHER POTENTIAL SOCIETAL AND ECONOMIC BENEFITS OF A CO_2 SMART GRID?

The CO_2 SG will require innovation, investments and result in increased employment and economic activity.

The scope of the CO2 SG would be unique in the world and offer marketing and export opportunities

Development of CO_2 smart grid will help prepare the market for CCS roll-out and increase R&D activities[1]

- CO_2 transport and injection capacity is expected to become larger than the total transport and extraction capacity for oil and gas production.
- This will require skilled labour and facilities (ships, drilling rigs, platforms etc.)
- CCU (e.g. in combination with CCS demonstration) can already prepare the market by offering a learning environment for companies and students to prepare them for large scale roll-out
- CCU development stimulates innovation and investments in capture technologies that are also required for CCS

Public acceptance of CCU can facilitate broader acceptance for large scale CCS activities

- In the next years we expect the debate on CCS to re-awaken, which will offer the ideal opportunity to engage with the public regarding CCU opportunities[2]

CCU in horticulture is a potentially high impact export opportunity

- There is a growing attention for sustainable, high yield agricultural production and the benefits of greenhouses
- Dutch horticulture expertise is internationally valued
- Greenhouse concepts such as the closed greenhouse, vertical farming and *Kas als energiebron* require extensive knowledge on energy use, nutrients, monitoring and optimization of CO_2 use
- CO_2 SG could add valuable knowledge on required infrastructures and effective synergies with heat grids and geothermal energy

Development of the CO_2 SG will require public investments; a societal cost-benefit analysis is required to indicate cost-effectiveness

- Multiple measures exist that reduce CO_2 emissions
- CCS is claimed to be cost effective, but only for large volumes and large scale off-shore application[3]
- Cost-effectiveness of CCU has not been assessed and will differ on case by case

1: Ecofys, Barriers to implementation of CCS, 2014
2: CO2chem: Roadmap of the future CO2chem and CCU, 2012
3: PBL& ECN, Nationale kosten energietransitie 2030, 2017

BUSINESS ASSESSMENT
Q: WHAT IS THE POTENTIAL FOR ACTORS TO USE THE CO2 SMART GRID TO FACILITATE BUSINESS DEVELOPMENT?

There is **business development potential for users of CO_2, suppliers of CO_2 and regional stakeholders**. Because of the unique positioning and scoping of this initiative in the international context, opportunities arise **to develop R&D which attract international companies and start-ups and stimulates CCUS innovation and export potential**

- Users of CO_2 are supported if they have a reliable, pure and cheap source of CO_2. With CCU value is added to CO_2 waste streams, than is not the case with venting or CCS.

- Current emitters of CO_2 may also benefit from a connection to the grid. Depending on actual cost sharing agreements, they could offset part of the costs of emitting CO_2 under EU ETS – which is likely to increase over the next 10 years. Additionally, they are provided an opportunity to decouple production growth from CO_2 emissions which aids their long term resilience in a low-carbon society. Especially for sectors which are fundamentally hard to decarbonize other than through end-of-pipe solutions (e.g.: process emissions from certain chemical reactions), the availability of CO_2 infrastructure could become mission critical.

- The CO_2 smart grid provides opportunities for property and area development. As more in general is the case for industrial clusters / seaports, by offering utilities and guaranteed energy/material streams, it could add value to land. A known case of this model is Peel Energy investing in carbon infrastructure and exploring CCS opportunities as subsidiary of Peel Land and Property Group in the UK. Ports such as in Rotterdam, Amsterdam and IJmuiden could benefit from CCUS infrastructure to be more attractive to carbon intense industries.

- Also business development opportunities exist for local or national governments. By supplying critical infrastructure that will enable the transition to low-carbon operations for large-scale industry, investments are made for a longer term resilient industry; safeguarding e.g. environment, investments, employment

- The unique positioning of NH/ZH with large industrial clusters, a high level of off-shore activity and high-tech horticulture within a few hundreds of kilometers makes the area specifically interesting for establishing CCUS infrastructure. In this unique area, the CO_2 SG initiative is also globally unique, offering opportunities to develop into a center for CCUS R&D and new business development.

SOCIETAL ASSESSMENT
Q: WHICH ARE THE MOST RELEVANT STAKEHOLDERS, WHY ARE THEY RELEVANT AND WHEN TO INVOLVE THEM?

Stakeholder	Why is CCUS relevant to this stakeholder?	Involve when
CO_2 emitters	• Consider CCU as a way to improve value from waste • Reduce CO_2 emissions based on financial incentives and/or higher company values • Consider ways to reduce future CO_2 pricing risk to business	1,2,3,4,5,6
Gas network operators	• CO_2 is a new core business opportunity • Diversify portfolio in view of decreasing fossil fuel transport outlook	1,2,3,4,5,6
Gas and oil exploration and production companies	• Opportunities in offshore infrastructure development and CCS • Supply the qualified workforce for CCS implementation • Locate relevant storage locations	1,2,3,4,5,6
CO_2 users	• Cost reductions through supply chain development related to CO_2 sourcing • Reduce fossil fuel demand and reduce total carbon footprint • CO_2 can have qualitative benefits to the products	1,2,3,4,5,6
Government	• Consider CCUS as a potential CO2 abatement measure • Develop a CCUS vision and roadmap and stimulate R&D and demonstration projects • Remove risks and potential legal and regulatory barriers • Potentially set CO_2 targets and CO_2 abatement incentives	1,2,3
General public	• CCU as a way to improve public support for CCS	2
Knowledge institutes	• R&D support and disseminate lessons learned • Innovation of new CCU and capture applications	1,2,3
Regional (port) authorities	• CO2 grid as a way to facilitate area development, combined with other commodity grids, or to improve supply chain efficiencies • Facilitate licenses and permits for CO_2 infrastructure	1,2,3,4,5,6

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POLICY ASSESSMENT
Q: WHICH LAWS AND REGULATIONS MAY PRESENT LEGAL BARRIERS TO A SMART CO_2 GRID?

CO_2 transport and storage are regulated on both the European and national level:

- The European CCS Directive has been issued to implement a set of requirements for CCS, which have been implemented in European national laws by 2011. This directive provided a high level baseline of minimum requirements, while giving the freedom to individual countries to develop their own legislation.
- In The Netherlands, all CCS related legislation is covered by the Mijnbouwwet, particularly focusing on CO_2 transport and storage:
  - CO_2 transport: CO_2 network operators are obligated to transport CO_2 from any supplier under reasonable, transparent and non-discriminatory conditions. Operators can refuse transport on grounds of limited capacity, connectivity, or incompatible technical specifications;
  - CO_2 storage: The law allows for the identification and evaluation of CO_2 storage locations when permitted, as well as the liability of stored CO_2.

No specific legislation is in place for CO_2 capture processes or the reuse of CO_2, although a recent court ruling may open up opportunities to include CCU with long term storage into ETS, such as carbonate mineralization.[1] Under certain circumstances CO_2 can be transferred from one ETS actor to an other, potentially improving CCU financials.[2]

Some legal barriers or uncertainties exist that inhibit the deployment of CCUS in The Netherlands:

- CO_2 injection operators are responsible for the injected CO_2 for a period of at least 20 years. Liability in case of damage resulting from storage of CO_2, for example where CO_2 leaks out of the complex are yet to be included in the Dutch Civil Code;
- International agreements will need to be made to transport CO_2 beyond country borders;
- Purity of the CO_2 has not been regulated, although storage (and transport) operators are expected to adopt very high purity norms for safety reasons. Requirements on acceptable impurity levels also depends on technical details of the specific storage site

An overview of existing laws and regulations on CCUS in EU and the Netherlands is provided in Appendix D.

1: Luther lawfirm, Recognition of climate protection measures: Success at ECJ for the Lime Industry with Luther, 2017

2: NEA, LEIDRAAD MONITORING EU-ETS 2013-2020 & NEA, Aandachtspunten monitoringsplan EU-ETS 2013-2020

Current legislation does not inhibit deployment of CCU. For storage ownership and leakage liability uncertainties exit, which will inhibit CCS deployment.

POLICY ASSESSMENT
Q: HOW DO CURRENT POLICIES SUPPORT A CO_2 SMART GRID DEVELOPMENT AND OPERATION?

In considering relevant policies for the CO_2 smart grid, we make a distinction between policies that stimulate R&D and demonstration, and policies that support CCU and CCS implementation and operation.

Policies stimulating CCUS R&D to demonstration
There are different policies implemented and instruments available to stimulate the of **CCUS in different development stages** (from early R&D to demonstration). CO_2 smart grid can benefit from this, by using subsidies to build and demonstrate a CO_2 smart grid, e.g. subsidieregeling Carbon Capture, Utilisation and Storage, or connect to already existing subsidized projects. An overview of existing policies to stimulate CCUS in EU and the Netherlands in provided is Appendix D.

Policies stimulating CCUS implementation and operation
On different governmental levels policies are being developed that aim to achieve CO_2 target reduction to comply to European and international agreements. Policies directed at specific CCU markets, such as promoting district heating for horticulture can also facilitate CCU adoption.

However, there is hardly any policy that specifically stimulates the **implementation and deployment** of CCUS as part of CO_2 abatement measures. CCUS is not part of popular SDE+ or EIA schemes, except for costs related to the transport pipeline (EIA 221005).

- Policies lack stimulation of CO_2 capture storage and/or utilisation and clarity on transfer of responsibilities of CO_2 during transportation and storage.
- In the Netherlands new coal-fired power plants build after 2010 should be “capture ready”; CCUS implementation would benefit if this policy could be extended to other large volume CO_2 emitters
- EU-ETS could potentially stimulate the development of a CO_2 smart grid, but its price is still too low to trigger any investments. The ETS price can be supported by additional National policies, e.g. by a CO_2 tax,
- Under EU-ETS, CCU is currently not considered to be counting to emission reduction, although a recent court ruling will open up possibilities to include CCU with permanent storage potential

Current policies focus on CCUS R&D and demonstration mostly. Policies supporting CCUS implementation and operation are required to realize a substantial growth of CCS and CCU in the Netherlands.

POLICY ASSESSMENT
Q: WHAT ARE OPPORTUNITIES TO SUPPORT THE CO_2 SMART GRID INITIATIVE IN EXISTING OR NEW POLICIES?

In order to stimulate the development of a CO_2 smart grid, additional policies are needed. Most policies require smart design and/or **EU-wide/global synchronisation to prevent *carbon leakage*.**

Policies to reinforce CCUS business cases:

- Create specific national policy incentives to stimulate a higher CO_2 price level (e.g. improvement of the EU-ETS price, introduction of a CO_2-tax, etc.); Incentives should focus on CO_2 reuse as an abatement measure (requires lifecycle assessments for different CCU technology to determine CO_2 abatement)
- Create specific financial instruments to stimulate the implementation of CCUS technologies (e.g. a low-carbon version of the SDE+ scheme);
- Reinforce the existing support measure WJZ/17056189 to also include the projects that go beyond research and experimental development, such as in CO2 SG
- Include CCU and CO_2-transport as specific categories under NER400/Innovation Fund;

Policies that enable better alignment of companies' planning and strategy:

- Formulate explicit targets for CCUS and CO_2 targets under national regulations as part of a new Klimaatakkoord, Regeerakkoord or Klimaatagenda
- Develop a national CCUS vision and roadmap that allows industries to align their strategy to
- Stimulate development of multi-commodity grids, e.g. district heating in combination with CO_2 capture/storage for horticulture areas

Policies that remove current CCUS barriers

- Make capture readiness obligatory for industry and other CO_2-emitters;
- Develop criteria for transfer of responsibility of CO_2 storage sites and regulations on cross-border transportation of CO_2

APPENDICES

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ECOFYS
A Navigant Company

APPENDIX A
MAIN CCU TECHNOLOGIES ANALYSED FOR THIS STUDY

CCU technology	TRL	Technology description
Horticulture	9	Growth rates of several plant species increase with elevated CO_2 levels as long as all other nutrients, water and sunlight are available in abundance. Greenhouses currently employ gas engines or buy technical CO_2. In case of a gas engine, a CO_2 vaporiser collects CO_2 from the flue gases and distributes it inside the greenhouse via diffusers. External CO_2 supply reduces energy costs for greenhouse famers.
Carbonate mineralisation	4-8	Carbon mineralisation is the conversion of CO_2 to solid inorganic carbonates using chemical reactions. Mineral carbonation occurs naturally and is a very slow process. In order for carbonate mineralisation to be a viable method to capture and reuse CO_2 from anthropogenic sources such as coal-fired power plants, this process must be accelerated considerably. The carbonates that are produced are stable over long time scales and therefore can be used for construction, mine reclamation or disposed of without the need for monitoring or the concern of potential CO_2 leaks that could pose safety or environmental risks.
Polymer processing	8	Polymers are large molecules composed of repeating structural units. Although polymers are often referred to as plastics, they actually consist of both natural and synthetic materials with a wide variety of properties. A new approach to polymer processing is to use CO_2 in combination with traditional feedstocks to synthesise polymers. This technology allows the use of waste CO_2 and transforms it into polycarbonates. The major polymers that can be created with this technology are polypropylene carbonate (PPC) and polyethylene carbonate (PEC).
Concrete curing	7-8	Concrete curing is an important application, to achieve best strength and hardness. This happens after the concrete has been placed. Cement requires a moist, controlled environment to gain strength and harden fully. The cement paste hardens over time, initially setting and becoming rigid though very weak and gaining in strength in the weeks following. Instead of using traditional energy intensive steam curing methods an alternative method reusing CO_2 can be used. This method, developed by Carbon Sense Solutions, makes use of flue gases from the cement production to cure precast concrete products, while remaining the same quality conditions.
Synthetic methanol	8	The electrolysis of water produces H_2 which is combined with CO_2, compressed and reacted over a metal/metal oxide catalyst to produce methanol and water. The separated methanol can be blended with different grades of gasoline for use as a transport fuel. To be considered low carbon fuel production, the process energy would need to be renewable.
Synthetic methane	7-8	In an exothermal reaction between hydrogen and carbon dioxide, methane and water are produced. The reaction is usually carried out in the presence of a catalyst. To be considered low carbon fuel production, the process energy would need to be renewable.
Methanol yield boosting	9	The yield of methanol from conventional methanol synthesis can be increased by the injection of additional CO_2 upstream of the methanol reformer.

APPENDIX A
ADDITIONAL POTENTIAL CCU APPLICATIONS AND ESTIMATED POTENTIAL

CCU technology	TRL	Development status
Algae	5	Pilot testing is performed in the Netherlands but the technology is not cost-effective at the moment. Some researchers claim that it might become economically feasible by 2025. With the current development status it is not possible to estimate the future potential in terms of CO_2 use. The technology can make a better business case in regions with high sunlight. Abengoa, Independence Bio Products and A2BE Carbon Capture have exited the algae production in recent years due to bankruptcies.
Formic acid	6-7	Research in the reduction of CO_2 to formic acid is still at early stages. Moreover, global formic acid production is between 500-700 ktons. The CO_2 based formic acid wouldn’t promise significant CO_2 use potential unless certain applications are further developed, e.g. the use of formic acid as hydrogen carrier in fuels cells and as chemical intermediate in making adhesives and preservatives, etc. Under Shared Innovation Program in the Netherlands, “VoltaChem” is exploring the production of formic acid from CO_2 for use as a transport fuel. The technology is not commercial yet, and with the current state of development it is not possible to estimate the CO_2 use potential for the Dutch market.
Urea yield boosting	9	The technology is fully commercial and is focused on enhancing the efficiency of the process, reducing energy consumption and mitigating CO_2 emissions. Most of the CO_2 emissions for yield boosting are typically captured from on-site reformer flue gases. At the moment, there is no urea production in the North and South Holland. Urea plants are normally located in the proximity of ammonia plants (examples are ammonia plant in Sluiskil, Zeeland and at Chemelot site in Geleen). The technology can offer significant CO_2 use potential if ammonia production facility is deployed in North and South Holland in the future. Most of this potential would come from on-site captive CO_2. The percentage of non-captive CO_2 or external CO_2 import would be very small.
Beverage carbonation	9	The technology is fully developed and requires high quality CO_2 (<99.9%) as CO_2 is used as food ingredient. The estimated potential for the overall Dutch market is less than 15 ktons and is likely to stay below these volumes in the coming 10 years. The CO_2 use potential in the North and South Holland would be even smaller.
Food preservation and packaging	9	CO_2 is used as a cooling agent for food freezing such as grinded powders like spices. In packaging applications, it is also used in modified atmosphere packaging (MAP) for cheese, poultry, red meat, sea food etc. as well as in controlled atmosphere packaging (CAP) for extending shelf life of fresh fruits and vegetables. Our market insights suggest that the current CO_2 use potential for the Dutch market would range between 50-70ktons per year. A large part of this potential would be concentrated in the North and South Holland. With (assumed) 50% share, the potential in the North and South Holland would range from 25-35 ktons. These applications require food grade CO_2 (<99.9%) which is higher than the quality of CO_2 currently supplied by OCAP.
Enhanced Oil Recovery (EOR)	9	EOR is a mature technology and has been commercially deployed mostly in the US and Canada. The technology can increase oil production by 4-18% beyond what is typically achievable using conventional recovery methods. Oil fields can be classified as miscible and Immiscible for CO_2 recovery. For miscible fields CO_2 requirement is around 0.33 tCO_2/ barrel of incremental oil produced whereas for immiscible fields this could increase to 0.88-1.1 tCO_2 per barrel of oil. The CO_2 use from North Sea EOR would be concentrated in UK and Norwegian parts of the North Sea.
Enhanced Gas Recovery (EGR)	5	EGR has received limited attention when compared to EOR due to its low level of maturity. Moreover, the economics of EGR are less strong when compared to EOR due to high initial recovery characteristics of gas reserves. K-12B is the only demonstration site for offshore injection of CO_2 in a gas field in the Netherlands. The field uses CO_2 from the same reservoir for enhancing gas production. In 2016, around 100ktons of CO_2 were injected in the gas field. However, more research is needed to fully understand the merits and demerits of using CO_2 for gas recovery, and to arrive at robust estimates for CO_2 use.

APPENDIX B
SYNTHETIC METHANE AND METHANOL POTENTIAL

- A promising future CCU application is the production of synthetic methane and methanol as a replacement for fossil fuels and as a green chemical feedstock.
- Although we do see a potential future volume, we assess the potential in the Netherlands to be limited in the next 10 years, for five reasons:
  1. Natural gas prices are very low compared to synthetic methane (Germany: 4-5 times higher). Natural gas production in the Netherlands is significant,~80 billion m3/yr. A couple of demonstration plants in 10 years with a capacity of 10-15 Mm3 can offer CO_2 potential of 18-27 ktons. Synthetic methanol prices are a factor of 3-4 higher than conventional production.
  2. Renewable hydrogen, as required for green methanol and methane production is expected to be limited, until large cost reductions are made to electrolysis equipment and (marginal) electricity costs approach zero most of the time.[1]
  3. Alternative energy carriers such as hydrogen, ammonia and batteries exist that compete with methanol or methane. It is yet highly uncertain which application will be relevant in what sector or market.
  4. Methanol production and distribution is a mature global market, where methanol is produced in locations where costs are low. Some countries offer greater potential due to solar or wind conditions for electricity production.
  5. Burning methanol and methane still results in CO_2 emissions. This means that large volumes can only be used in transport if the origin of CO_2 is biogenic, or there are processes in place that capture CO_2 from the air. The latter is a technology that is not expected to be mature before 2040. Competition for biogenic CO_2 will be fierce resulting in high prices

Synthetic Methane and Methanol Potential

CCU technology	Current 2017 kt CO_2	Near term (5 years) kt CO_2	Long term (10 years) kt CO_2
Synthetic methane	-	-	18-27
Synthetic methanol	-	-	200

- At the moment, there is no synthetic methane production plant in the Netherlands.
- In our estimate we take into account that in ten years we can have one commercial synthetic methanol plant operating in NH/ZH.
- The development of a methanol or methane economy is a black swan event that could completely turn the CCU potential upside down. We recommend to regularly monitor this development to be able to spot opportunities.

1: Ecofys: Utilization of renewable energy sources for hydrogen electrolysis and a competitiveness analysis, 2017

APPENDIX C - FOSSIL FUEL REPLACEMENT IS A QUICK WIN. ULTIMATELY IMPROVED CO_2 EFFICIENCY AND BIOGENIC CO_2 USE IS NEEDED FOR SHORT TERM STORAGE APPLICATIONS

- The abatement effect of fossil fuel replacement, such as in horticulture, synthetic fuels or food & beverage is, in the near term, determined by the amount of gas burning that is avoided because of this CO_2 supply.
- This presents a short term quick win CO_2 abatement potential.
- In the long term however, also the CO_2 emissions from reused CO_2 will have to be reduced.
- Over time, we may expect a number of parameters that together establish this abatement potential, to change:
  - The emissions associated with the baseline replacement may change due to deployment of green gas (methane or biogas) and efficiency gains. Especially in greenhouses there is a large potential for CO_2 efficiency improvement (currently 10-20%). Solutions could be greenhouse CO_2 recapture and heat and humidity control to avoid venting.
  - The emissions associated with the processes from industrial emitters may change due to deployment of biomass or other renewable energy or feedstock. The resulting biogenic CO_2 will be a valuable resource to many CCU applications.
- Ultimately, longer term abatement effects in horticulture, chemical manufacturing, synthetic or biofuels and CO_2 for food & beverage are governed by the interplay of these developments.

Why is biogenic CO_2 important in the long term?

- In the short term, avoiding fossil fuels by capturing and using fossil CO_2 is a good thing. In the longer term, even this re-use of fossil CO_2 is to be avoided to stay within our ‘carbon budget’ to meet (inter)national climate goals.
- This is why in the long term, applications that do not permanently store CO_2, like crops, chemicals or fuels (methane, methanol, etc.), should either avoid CO_2 emissions, or use biogenic (so-called ‘short cycle’) CO_2.
- Supply of biogenic CO_2 will be limited; applications with the highest value associated will claim the largest share. For horticulture this could mean biogenic CO_2 could become scarce and expensive.
- Many climate scientists support the role of *negative emissions* to avoid catastrophic climate change, which means large amounts of biogenic CO_2 will need to be sequestered through for instance CCS. This further reduces the available supply for CCU applications.

APPENDIX D
A NUMBER OF KEY SUCCESS FACTORS APPLY; INDICATORS SHOULD BE DEVELOPED TO MONITOR AND STEER?

To be successful in implementing the CO_2 SG, a number of key success factors (KSF) are relevant. See below for a list of KSF based on this pre-feasibility assessment and illustrative indicators

We recommend to use the feasibility study to develop these success factors into indicators and develop an monitoring framework for effective programme steering.

Illustrative

KSF	Indicator
• A CO_2 infrastructure offers clients more benefits than CO_2 distributed by road	• Comparison of pipeline against road distribution on: e.g. cost, security of supply, volumes, adaptability
• CO_2 prices increase, improving the business case for long term storage, but reducing the business case for some CCU applications • CCU applications receive incentives that make CO_2 reuse more attractive	• ETS price and adoption of CCU • National policies affecting CO_2 price or CCU
• CCU is recognized as a cost-effective abatement measure	• Monitor national policy and sector roadmaps to check adoption
• CCU potential in horticulture grows with use of geothermal and district heat. • CCU potential in horticulture may reduce due to CO_2 efficiency improvement	• Monitor developments in horticulture and low-temperature energy generation and distribution
Longer term KSF – monitoring black swan events	
• Capture at large plants is more cost-effective than capture at distributed sources or capture directly from air	• Monitor R&D activities on new capture technologies and costs of container storage and distribution
• Synthetic methanol, methane and other C-based materials will develop into the green energy carrier of the future	• Monitor R&D activities in biofuels and chemical industry • Monitor developments in climate policies and cost-effective abatement trajectories
• Biogenic CO_2 will be a valuable resource in a low-emission economy	• Monitor market developments in use of biogenic CO_2

APPENDIX E - BUSINESS ASSESSMENT HORTICULTURE

- Horticulture is an existing CCU business case that is currently mostly limited by insufficient sources at peak demand in summer.
- In winter time CO_2 demand is low, because of lower plant growth and because CHPs and boilers required for heating also provide CO_2 to the greenhouses
- There is a large additional potential to connect greenhouses to the OCAP pipeline infrastructure and multiple projects to increase this coverage are underway.
- Current OCAP CO_2 prices seem competitive with CO_2 produced from methane, when no additional heat is required.
- CO_2 demand is expected to grow strongly for greenhouses connected to geothermal or district heating, although current CO_2 grid prices could be considered to high to allow both connections.
- The additional potential is estimated from additional greenhouses that are technically feasible to connect over the next 10 years, independent of alternative CO_2 sources.
- This approach is underpinned by the stated ambition by the greenhouse sector to strive towards climate neutrality in 2050.
- Greenhouses release the CO_2 that is not captured by crops (80-90%). In the longer term, dedicated CO_2 capture installations may be added to re-circulate this CO_2. At present, this is not taken into account in these calculations.

	Demand	Max. asking price[1]
Current potential	400 kton	€55 /t CO_2
Additional potential	1.2 Mton	€55 /t CO_2

Quality demand

Horticulture application of CO_2 requires good purity CO_2. This does not necessarily mean high volumetric shares of CO_2 but does require absence of impurities in the gas that are potentially harmful to crops. Currently, the gas supplied by OCAP is 99% CO2 as directly supplied by the sources Shell and Alco.

Subsurface 'buffering' of CO_2 in combination with CCS may introduce additional impurities. Additional R&D needs to be done to answer this question.

[1]Current CO_2 prices from OCAP. Alternatives: current CO_2 cannisters are cheaper (€65 / t CO_2) than dedicated gas burning (currently € 89 / t CO_2)

APPENDIX E - BUSINESS ASSESSMENT POLYMER PROCESSING

- CO_2 can be used in the synthesis of useful chemical intermediates and products such as polycarbonates and polyols. Research into other types of polymers is in infancy, and most widely developed route is the co-polymerization of epoxides to make poly-carbonates and polyols. Shell and Huntsman are making polyols and can potentially deploy this technology.
- The production of polyether polyol from Shell, Huntsman and Dupont (facilities in the proximity of CO_2 pipeline) is ~300k tons/yr. This represents **feasible potential of 12-23 ktons/yr of CO_2** (assuming 50% CO_2 use by weight in polycarbonate polyols, 4% CAGR for conventional polyols and 5-10% replacement of conventional polyols) in the near term. The CO_2 demand from polycarbonate applications is expected to be 30% of the polyols demand. In the long term, CO_2 based polyols are expected to replace conventional polyols by 10-15%.
- The raw material replaced by CO_2 is propylene/ethylene oxide which costs in the order of magnitude < 1000 euros/ton. **The value of CO_2 used will therefore be >100 euros/ton**.
- Main challenge to large scale deployment is the **risk averseness of chemical industry to try new products,** because a new technology can potentially change the downstream chemical processes.
- Some technology developers also claim that their technology can be used with little retrofits in the existing system thus avoiding replacement of the old system. This provides an **opportunity for an early and fast deployment of the technology** in the industry.
- Bio-based polymers may compete with CO_2-based polymers for different end-use applications in the long run. Currently bio polymers are being used in the production of polymers like PP, PE, PET, etc. But before 2030, CO_2-based polymers and **bio-based polymers are expected to enter polymer market through different market applications**.

CCU Process and CO_2 Potential

Process/route	Polymer type	Applications
Carbonation of epoxides with catalyst A	Polycarbonates	Ceramic binding, packaging, electrical equipment, etc.
Carbonation of epoxides with catalyst B and a starter (glycerin, ethylene glycol, etc.)	Polycarbonate polyols	Polyurethane synthesis

CCU Process and CO2 Potential

CCU process	Current 2017 kt CO_2	Near term (5 years) kt CO_2	Long term (10 years) kt CO_2
Polyols	-	9-18	22-33
Polycarbonates	-	3-5	7-10
Rounded total	**-**	**12-23**	**30-45**

Note: Di-isocyanates are currently being explored, robust estimates cannot be generated . CE Delft reports CO2 potential of 400 ktons.

Quality demand

The CO_2 used does not necessarily need to be very high quality. For instance, CO_2 from coal fired power plants can be used if first scrubbed and dried properly. Covestro is using CO_2 extracted from the flue gas of a brown coal power station operated by RWE.

APPENDIX E - BUSINESS ASSESSMENT CARBONATE MINERALISATION

- Carbonate mineralization entails the permanent sequestration of carbon by chemically trapping it to other materials. In NH/ZH, the sources of waste materials that are relevant for chemical binding of CO_2 are listed in the table on the right
- This rounded total is meant as a total theoretical maximum, in other words: annual waste streams are assessed on their theoretical capture potential, leading to an estimate of about 300 kton CO_2 / year of abatement potential.
- The business case for these applications is deemed mostly dependent on a policy incentive like a carbon price; the current waste materials are already used in the Dutch economy, for instance bottom ash for construction material. In these applications, we do see potential added value in two ways:
  - Better bottom ash stock management for the production of secondary raw construction material as large weathering areas and extended maturation are avoided by accelerated carbonation
  - The waste products are totally carbonated and stabilized potentially leading to improved performance in their end-use application
- The carbon that is abated is abated permanently as it is chemically bound to the waste product.
- Subsidies or EU ETS induced carbon prices will need to exceed combined capture, transport and storage costs to enable mineralization. Costs are estimated to be 60-100 € /ton stored[3].

Abatement potential (kton CO_2 /year)

Industrial process[1]	Waste Stream	Total potential
Coal (and biomass) combustion	Fly ash	162
Construction and Demolition	Mineral waste	6
Iron and steel production	Steel slag	88
Waste / sludge incineration	MSWI ash	21
Rounded total		**270**

Quality demand

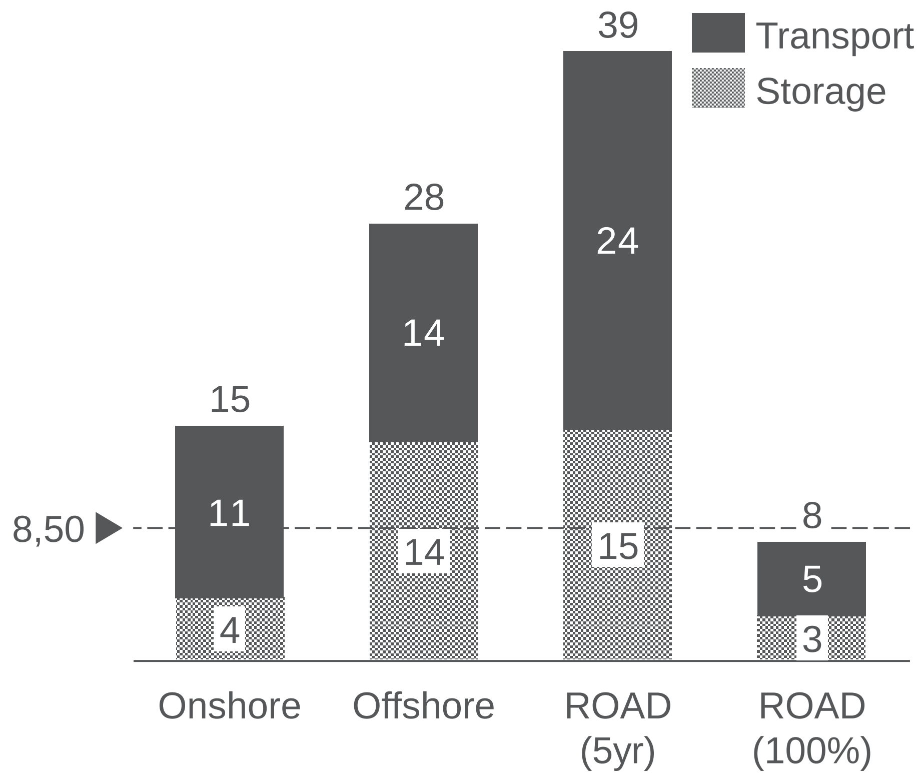
Carbonate mineralization does not impose highly stringent criteria on the quality of applied CO_2 mix. Indeed, already the stack gas of EfW facilities (around 10 vol% CO_2) could theoretically be directly diverted to the waste streams. This also holds true for impurities. The CO_2 smart grid is currently transporting a higher grade of CO_2 gas, which can be seen as value destruction to apply this 'high-grade' CO_2 gas to waste. Separate CO_2 infrastructure can be considered to accommodate low grade CO_2 for concrete curing application.

1: Waste stream estimates and abatement potentials are from literature review and interviews.
2: Personal communication with Pol Knot and Steffen van Rijs
3: Ecofys, Carbon counts, Implications of the reuse of captured CO2, 2013

APPENDIX E – BUSINESS ASSESSMENT OFFSHORE STORAGE

- The business case for CCS is dictated by an externally set carbon price and/or government subsidy.
- A literature review yielded a range of transport and storage costs that will be added on top of capture costs for a viable CCS project.
- The chart on the right depicts these ranges for average onshore costs, offshore costs, the estimated ROAD pilot costs and the costs for this same project setup in the scenario where the offshore gas fields are filled to their maximum capacity (estimated to be in the order of 35-43 Mton)
- The more stringent requirements for CO_2 (supercritical phase and high purity) will affect transport (and compression) costs significantly. Therefore these are here taken as part of the overall offshore storage' business case cost
- The additional price level indicated by the horizontal line indicates estimated UTC for offshore storage in the event a number of (connected) offshore fields (from the K12-L10 cluster) are used for CCS, bringing economy of scale to offshore storage. This is close to the longer duration ROAD project and could be viewed as a long-term UTC level.
- Subsidies or (EU ETS induced) carbon prices will need to meet combined capture, transport and storage costs to enable CCS at this scale.

CCS Transport and storage cost estimates (UTC in € / tonne CO_2)



Sources: Ecofys / Cato2 (2010), TNO (2011), EBN / Gasunie (2010)

APPENDIX F: OVERVIEW OF EXISTING LAWS AND REGULATIONS STIMULATING THE DEVELOPMENT AND DEPLOYMENT OF CCUS IN THE EU AND THE NETHERLANDS

#	Law / Regulation	Coverage	Year	Scope
1	Mijnbouwwet	NL	2002	CO_2 storage - Permits should be obtained for the exploration of suitable storage-complexes (Article 25) and for storage of CO_2 (Article 26); - Scope of the CO_2 exploration permit (Article 9, 11, 13, 18, 21); - Scope of the CO_2 storage permit (Article 31 and 32); - Transfer of liability (Article 31) CO_2 transport - Authorisations for the laying of pipelines (Article 49); - Access to transport network (Article 32);
2	CCS Directive	EU		
3	Capture readiness	NL	2011	The Decree on Emission Requirements for Large Combustion Plants (BEES A), as amended, requires that holders of permits for installations with an output of 300 MW or more granted on or after the 25th of June 2011, must assess: - the availability of suitable CO2 storage-complexes; - the economic and technical feasibility of transport of CO_2; - the economic and technical feasibility to retrofit the installations for CO_2 capture.
4	Wet mileubeheer	NL	2017	No free allocation of greenhouse gas emission allowances takes place for: - CO_2 capture for transportation and geological storage at a CO_2 storage site; - CO_2 transport with the objective to store at a CO_2 storage site; - CO_2 storage a CO_2 storage site;

APPENDIX F: OVERVIEW OF EXISTING LAWS AND REGULATIONS STIMULATING THE DEVELOPMENT AND DEPLOYMENT OF CCUS IN THE EU AND THE NETHERLANDS

#	Law / Regulation	Coverage	Year	Scope
5	Regeling omgevingsrecht	NL	2017	When a CO_2 capture permit is applied for a facility with a nominal capacity of 300 MWe or more evidence should be included for: : a. The availability of CO_2 storage location; b. Technical and economic feasibility of CO_2 transportation to storage location; c. Technical and economic feasibility of CO_2 capture at the facility;
6	Besluit milieueffectrapportage	NL	2017	An environmental action plan is mandatory for: - The construction, modification or extension of CO_2 pipelines with a diameter of >80 cm and a length of >40 km; - The implementation, modification or extension of a CO_2 capture facility with a capacity of 1.5Mton CO_2 or more; - The implementation, modification or extension of a CO_2 capture facility for geological storage (in accordance with Directive 2009/31/EG (PbEG L 140));
7	Mijnbouwbesluit	NL	2015	- Requirements for obtaining CO_2 storage activities permit; - A risk control plan should be in place for the duration of the permit, that includes procedures on correcting irregularities during storage and to act in case of CO_2 leakage; - A CO_2 monitoring plan should be in place, describing activities monitoring the CO_2 injection facility, the storage complex and its direct environment; - A plan on to prevent or limiting damage from soil movement (bodembeweging); - The permit is only applicable to the transportation and storage of CO_2 and substances directly related to the CO_2 capture, transportation, injection and/or monitoring process;
8	NEN 3650 serie: Buisleidingsystemen	NL	2012	Criteria for pipeline systems that transport CO_2
9	Nederlandse norm NEN-EN 936	NL	2006	Includes CO_2 quality criteria for products used for human consumption

APPENDIX F: OVERVIEW OF EXISTING POLICIES STIMULATING THE DEVELOPMENT AND DEPLOYMENT OF CCUS IN THE EU AND THE NETHERLANDS

#	Policy / Instrument	Coverage	Type	Impact	Opportunities for CO_2 smart grid
1	Subsidie regeling Carbon Capture, Utilisation and Storage (CCUS)	NL	Instrument	The instrument focuses on projects that: - Remove technical, economic and societal barriers at CCUS-projects; - Reduce costs, increase energy efficiency and increase safety of CO_2 capture, transport and storage; - Stimulate the utilisation of CO_2; Budget of 1 M€, max. subsidy is 250 k€ per project	Different topics among which CO_2 transport
2	Energie- en Investeringsaftrek (EIA)	NL	Policy	Includes possibility on tax benefits for investments in transport pipelines for delivery of CO_2 to greenhouses, CO_2 processing equipment and CO_2 compression. The subsidy cannot be used for CO_2 distribution in the greenhouse, CO_2 capture, CO_2 storage in the underground and CO_2 compression needed for CO_2 storage	CO_2 transport for greenhouses
3	Aanwijzingsregeling willekeurige afschrijving en investeringsaftrek milieu-investeringen 2009	NL	Policy	Applicable for: - F 1409 Pyrolyse- of kraakinstallatie voor verwerking van afvalstoffen - B 2110 Kas voor milieuvriendelijke productie met Milieukeur - B 2111 Kas voor biologische teelt - F 2112 Groen Label Kas voor biologische teelt of milieuvriendelijke productie met Milieukeur - F 2114 Groen Label Kas met vis-, schaal- of schelpdierenkwekerij - A 2316 Milieuvriendelijke productie van gewassen of producten in een gebouw volgens Milieukeur	

APPENDIX F: OVERVIEW OF EXISTING POLICIES STIMULATING THE DEVELOPMENT AND DEPLOYMENT OF CCUS IN THE EU AND THE NETHERLANDS

#	Policy / Instrument	Coverage	Type	Impact	Opportunities for CO_2 smart grid
4	ACT: Accelerating CCS Technologies	EU	Instrument	Budget of 41 M€, no call open currently	Different topics among which CO_2 transport (up to 10 M€)
5	ECCSEL: Excellent CCS laboratories	EU	Instrument	Initiative to provide access to CCS research projects in Europe	
6	Innovation Fund (NER 400)	EU	Instrument	The Innovation is the successor of the NER300 programme, with a budget of billions € for the period 2021-2030. Currently, the debate on the functioning of the Innovation Fund is ongoing. It is expected that in 2017 the European Parliament and Council of Ministers will likely adopt the primary legislation.	CCUS projects are most likely eligible to apply for subsidy
7	Horizon 2020	EU	Instrument	Largest R&D funding programme in the EU, currently includes one call related to CCUS on *innovative products utilising CO_2 that could significantly reduce the atmospheric emissions of CO_2 when deployed at commercial scale.*	CO_2 transportation will be required for this project
8	European Strategic Energy Technology Plan (SET-Plan)	EU	Instrument	Accelerate the development and deployment of low-carbon technologies by bringing down costs by coordinating national research efforts and helping to finance projects.	Improving CCU technologies, accelerating the implementation
9	Interreg	EU	Instrument	Interreg projects are focused on improving the performance of regional development policies and programmes. Third call ends 30 June 2017, no information about following calls	This could be useful in the development of a policy framework that would stimulate the development of a CO_2 smart grid

APPENDIX F: OVERVIEW OF EXISTING POLICIES STIMULATING THE DEVELOPMENT AND DEPLOYMENT OF CCUS IN THE EU AND THE NETHERLANDS

#	Policy / Instrument	Coverage	Type	Impact	Opportunities for CO_2 smart grid
10	Regeling nationale EZ-subsidies	EU	Instrument	A support for CCUS industrial or experimental research with a maximum of 250k€	Opportunity to include small-scale CCUS R&D projects to the scope of the CO_2 SG

APPENDIX G
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APPENDIX H
GLOSSARY

Abbreviation	Description
B2B	Business-to-Business
CAPEX	Capital Expenses
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture, Storage and Utilization
CHP	Combined Heat and Power
CO_2	Carbon Dioxide, the main greenhouse gas
COP21	Conference of Parties 21 of the United Nations Framework Convention on Climate Change (in Paris)
EU	European Union
IOC	International Oil Company
CO2 SG	CO2 Smart grid
SCBA	Societal cost-benefit analysis
LCA	Life-cycle assessment

Abbreviation	Description
JV	Joint Venture
KPI	Key Performance Indicator
NOC	National Oil Company
O&M	Operating and Maintenance
OPEX	Operating Expenses
PU	PolyUrethane
R&D	Research and Development
RFP	Request for Proposal
SWOT	Strengths, Weaknesses, Opportunities and Threats
VAT	Value Added Tax
VPP	Virtual Power Plant
NH/ZH	The provinces of North-Holland & South-Holland
KSF	Key success factors
EfW	Energy from waste facilities

CONTACTS

ECOFYS, A NAVIGANT COMPANY

JURIAAN VAN TILBURG
Senior Consultant
M: +31 (0)655 482 893
T: +31 (0)30 662-3017
j.vantilburg@ecofys.com
Kanaalweg 15-G, 3526 KL Utrecht, the Netherlands

MARK SCHENKEL
Senior Consultant
M: +31 (0)6 1521 2720
T: +31 (0)30 662-3307
m.schenkel@ecofys.com
Kanaalweg 15-G, 3526 KL Utrecht, the Netherlands

ECOFYS
A Navigant Company