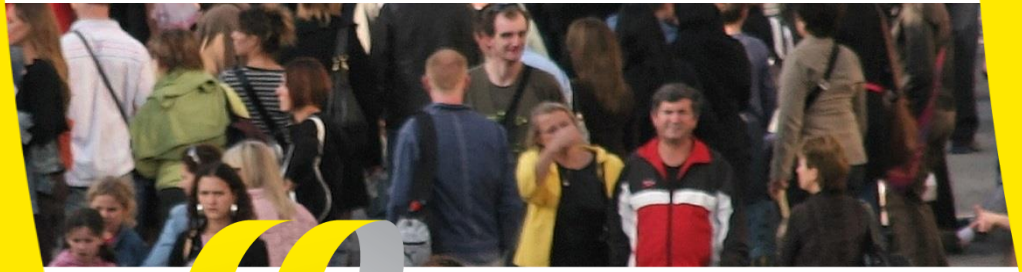
CCU development opportunities in Rijnmond

Start meeting January 25th 2017



CE Delft

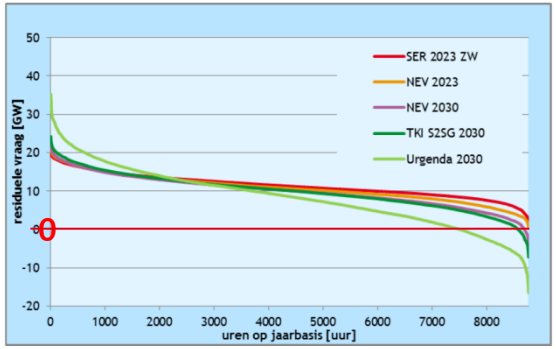
CE Delft

- Independent research and consultancy since 1978
- Transport, energy and resources
- Know-how on economics, technology and policy issues
- 50 Employees, based in Delft, the Netherlands
- Not-for-profit

Clients: industries, mainly Rijnmond, European Commission and Parliament, national and regional governments, Dutch provinces, PBL and NGO's

All our publications www.cedelft.eu or @CEDelft

1. Introduction



Recent developments are very much in favour of CCU, Carbon Capture and Utilisation:

1. Carbon emission reduction, Paris Agreement at **90⁺ % emission reduction**
   Requires disruptive technologies, so less 'Lock-in effects'

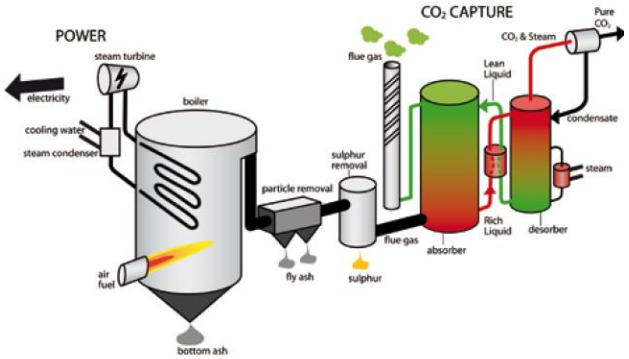
2. Rapid **price decrease** of current renewable energy (wind and solar)
   Grid parity is near, periods of zero price, more inexpensive RE to come..!?

3. RE will deliver **inexpensive renewable building blocks** (H_2 and e),
   solves dependability on fossil fuels and **enables Deep Decarbonisation**

4. Future grid unbalance **requires storage** options
   → carbon recycling with CCU in Power-to-Products (P2P) seems very attractive

1. Introduction

CCU is a 3-step process:



1. CO_2 capture from flue gas
   - concentrations ranging from high (petrochemical industry, ethanol), to intermediate (steel, CFPP), to low (GFPP) to air

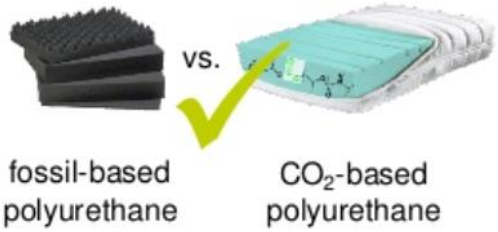
2. Purification and compression
   - intensity depending on process (not always required as in CCS application)

3. CO_2 conversion into material or product i.e.:
   - Mineralisation
   - Methanol, intermediate (MDE, MTO, MTG), or as solvent or fuel
   - Formic acid, as product or energy (H_2) carrier i.e. for FCEV
   - Carboxylate/carbonates
   - Carbamate(esters) for isocyanates and polyol intermediates for 'CO_2 neutral PU'
   - Urea, carbon monoxide, carbon fibres etc. etc.

2. Technology

- **Step 1**, capture process is now well-developed and proven, including for flue gas
- Still being optimised to cut energy consumption with state-of-the-art solvents
- Decreasing required temperatures of the heat input, nearing waste heat levels
- Plant integration is logical for the required heat source
- Positive by-effects of capture using flue gas i.e. PM removal
- Experienced CATO pilot plant will come to Plant One Rotterdam as CO_2 source

2. Technology

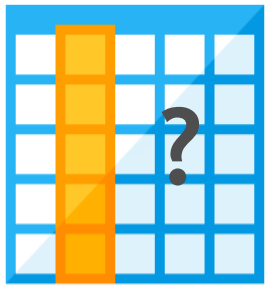


- **Step 2**, purification and compression is well developed i.e. for OCAP
- **Step 3**, the utilisation processes are quite diverse
- Synthesis of chemicals, materials and fuels
- Three product classes are identified in EC-SETIS communication[1] :

1- Renewable feedstock for chemicals, polymers and inorganic materials
2- Energy storage and fuels
3- Direct photo-conversion of CO_2 (i.e. algae, greenhouse)

[1] https://setis.ec.europa.eu/setis-reports/setis-magazine/carbon-capture-utilisation-and-storage/commission-activities-enable-co2

2. CCU Technology options - where to start?



Two criteria for selection of CCU process routes:

Name	Type	Energy	Potential[1] In EU, 2030 In kT/yr	Business case
Methanol	Organic	Hydrogen (electrolysis)	40,000	Profitable at low e-prices / as biofuel
Formic acid	Organic /storage	Hydrogen (electrolysis)	7,000	Profitable at low e-prices
Urea	Inorganic	Hydrogen (electrolysis)	7,000	Not yet profitable
Carbonates	Mineral	-	300	Profitable
Polyols	Organic	-	120	Profitable
Polymers-resins	Organic	Hydrogen (electrolysis)	p.m.	p.m.

[1] https://setis.ec.europa.eu/setis-reports/setis-magazine/carbon-capture-utilisation-and-storage/carbon-capture-and-utilisation-%E2%80%93

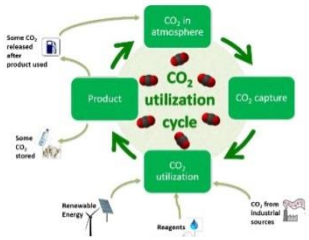
2. Does CCU really impact emission reduction?

‘Kunnen we CO_2 ook recycleren?’ (ethanolproductie uit afgassen van de staalindustrie bij ArcelorMittal)

of

‘Spookrijden op de weg naar nul-emissie van CO_2‘ ?

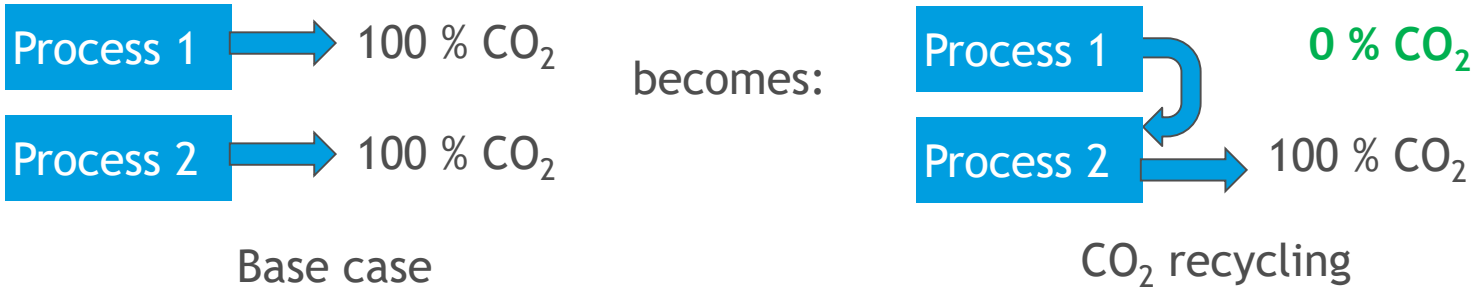
2. Real impact of CCU technology options



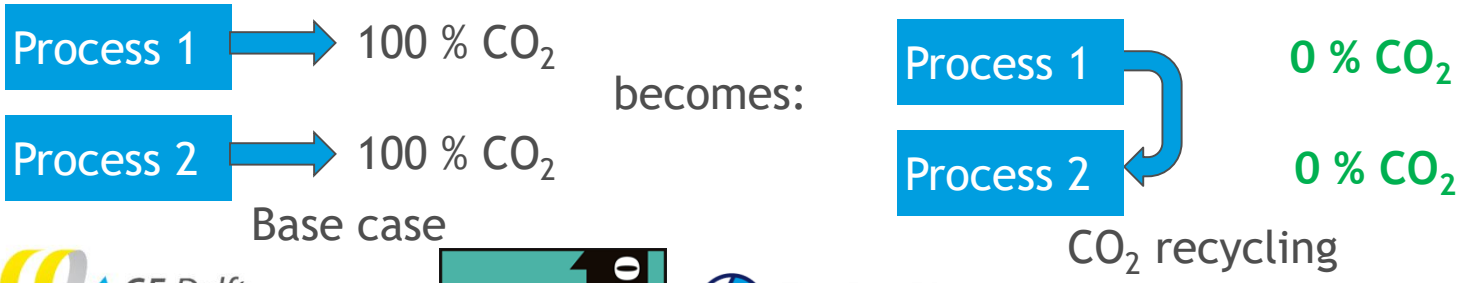
Source: How Can CCU Provide a Net Benefit? - presentation by Peter Styring at the UKCCSRC Cardiff Biannual Meeting, 10-11 September 2014

LCA as objective criterion for selection of different CCU process routes:

1- Short cyclic (CO_2 is reused but finally emitted in a next product or process)
Either fossil or biogenic feeds and CO_2



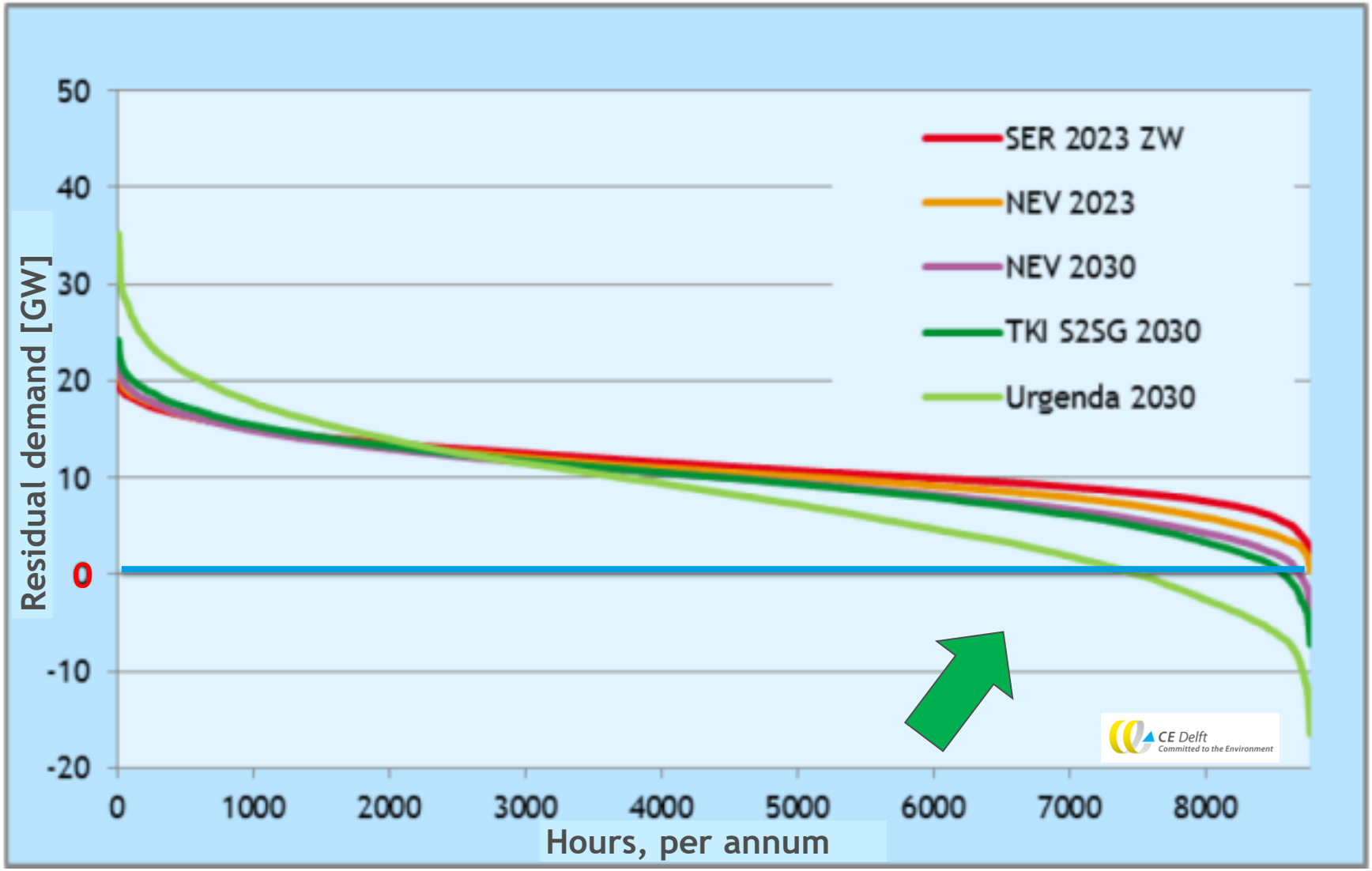
2- Long cyclic (CO_2 is stored in a stable material i.e. in mineral/concrete)



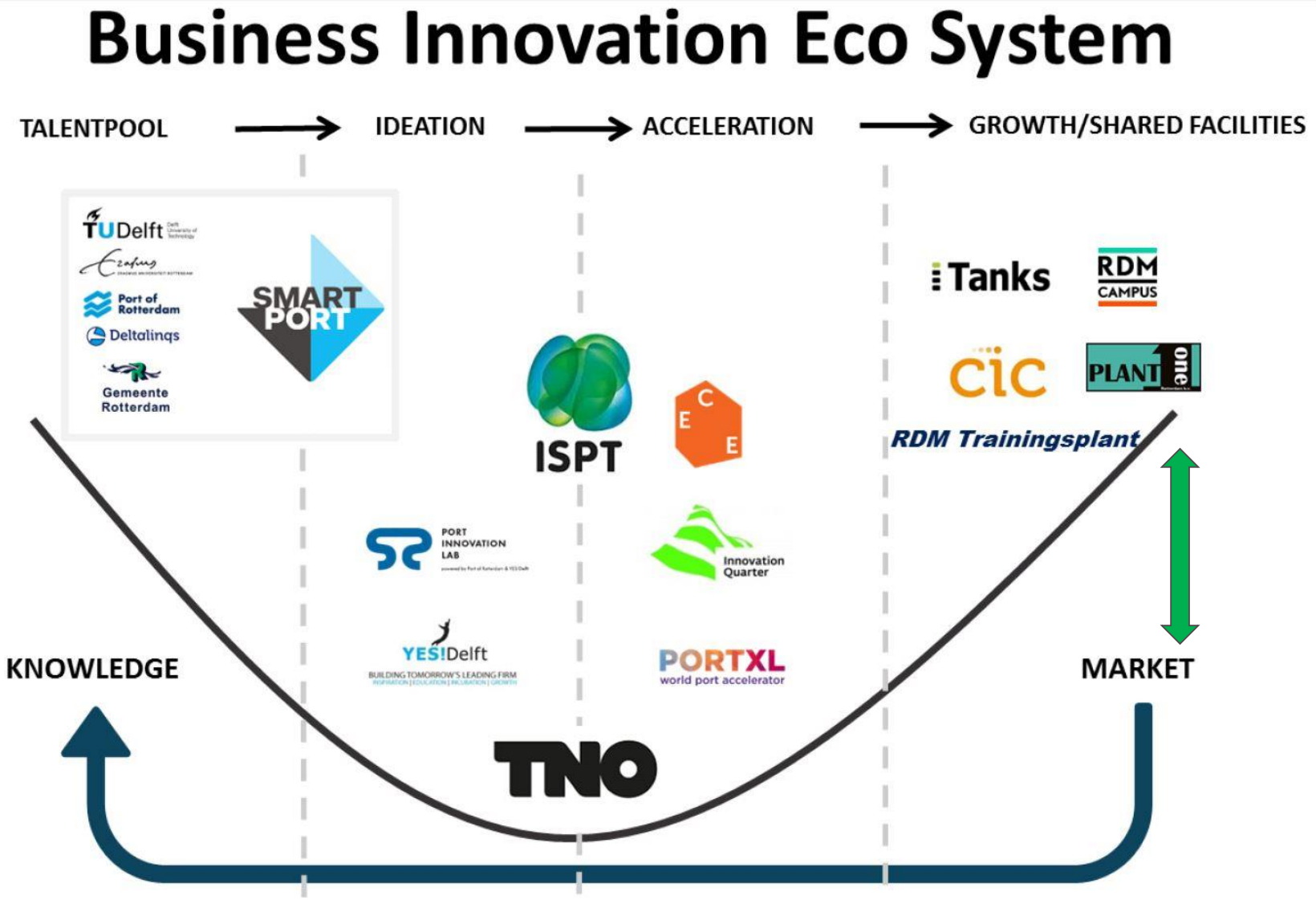
3. Business case outlook

- Boundary condition: use of hydrogen from renewable source (electrolysis)
- **Electricity price is main cost component → but current trend to low prices**
- Catalysts exist, but new catalyst development will lower OPEX and CAPEX cost
- Common reactors, no requirements for high-tech expensive CAPEX developments
- ETS CO_2 price is less strong driver, no need for waiting for policy changes
- Already close or at same order of magnitude
- Element of competition: offering carbon neutral feedstocks will incur a premium driven by the LCA effect in the supply chain required by the clients

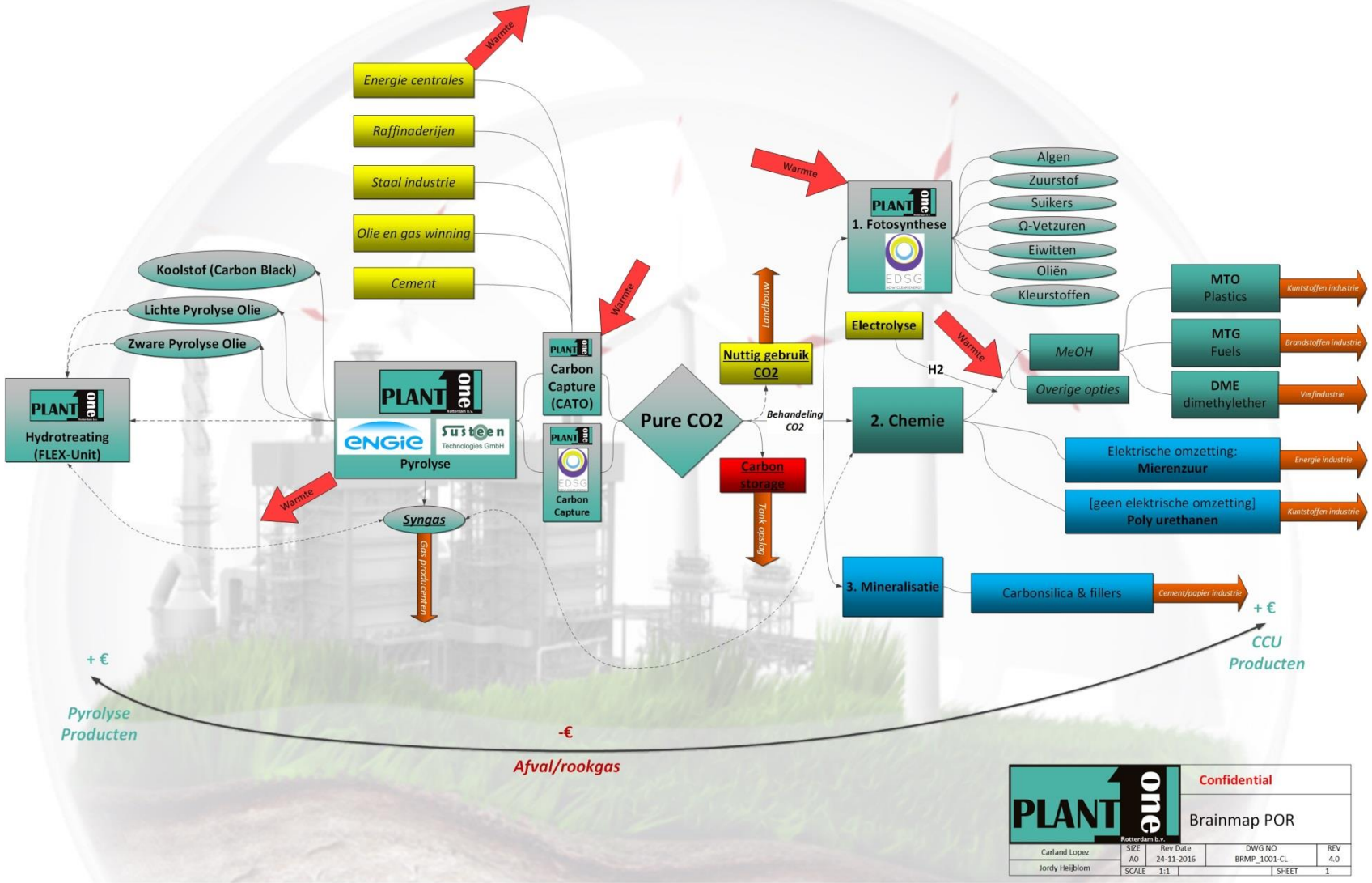
3. CE Delft study – future E-demand in The Netherlands



3. Plant One – study Rein Willems

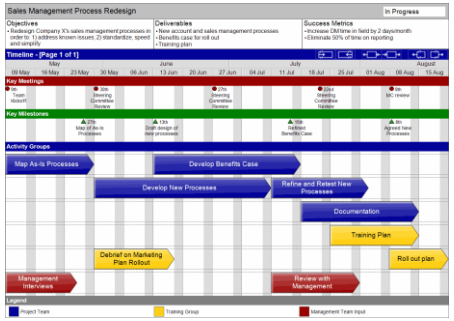


3. Plant One – CCU mini-grid



PLANT one Rotterdam b.v.	Confidential		
	Brainmap POR		
Carland Lopez	SIZE A0	Rev Date 24-11-2016	DWG NO BRMP_1001-CL / REV 4.0
Jordy Heijblom	SCALE 1:1		SHEET 1

4. Project development at Plant One Rotterdam <refer to POR cluster scheme>



1. POR is 'one-stop-shopping' for CCU pilot plants
2. Commission crude CO_2 sources (pyrolysis pilot plants, other..)
3. Commission CATO pilot plant for CO_2 capture
4. CO_2 drying and compression
5. CCU reactor options for various processes, i.e.:
   - Algae
   - Polyuretanes - Carboxylation / carbonation (ROCOP, i.e. Novomer catalysts)
   - Methanol (various catalysts)
   - Formic acid
   - Mineralisation (Solidia/Carbstone)

6. Heat integration between pyrolisis, capture and reaction compartments
7. Use of residual hydrogen from pyrolysis syngas and local source make-up and reuse it in CCU processes

5. Near and future outlook

CHEMISTRY WORLD

Carbon dioxide-to-methanol catalyst ignites 'fuel from air' debate

BY ANDY EXTANCE | 14 JANUARY 2016

Nobel winner's team hopes 'air capture' of greenhouse gas can store renewable energy – but others see problems

- Maximum attention – Key Enabling Technologies (KET) at EU DG RTD
  - Ford announces use of 'carbon emission free' polyurethane
- DREAM CCU program in Germany resulted in fast decision for larger scale carbon neutral polyurethane plant by Covestro (former Bayer)
- Profitability seems close, helped by very low renewable E-price trend
- CCU reactions will benefit of better catalysts, but reactions are known
- Recently discovered: reactive capture from air into methanol at only 150 °C …

6. Goals of CCU development projects at the Plant One Rotterdam CCU facility?

- GOAL 1: develop relevant CCU process to enable near full scale realisation and **offer clients carbon emission free products at lowest cost**

- GOAL 2: **increase competitiveness of Rijnmond area** by attracting CCU operations with key facilities and simultaneously decrease local CO_2 emissions

7. Group sessions today

pixtastock.com - 17577990

- Group selection, i.e.:
  1- Mineralisation
  2- Polyurethane and polymers/resins
  3- Solvents and fuels (MeOH, FA)
  4- Photosynthetic (algae)

- Desk study on detailed CCU options for specific products

- Product requirements / LCA - long vs short cyclic CCU / CO_2 specs

- Pilot project requirements

8. Next steps

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- Separate CCU project definitions
- Desk study on detailed CCU options for specific products
  (Deltalinqs-Uniper study, ready March 2017)
- Product requirements, LCA of process routes- long vs short cyclic CCU, CO_2 specs
- Pilot project requirements / funding
- Route to full scale CCU applications

8. Next steps – full scale outlook

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- Full scale locating options:
  a- All at source
  b- Capture at source, transport via OCAP, CCU at central location
  c- Capture at source, transport via OCAP, CCU at various locations

- Capture preferably at waste heat source

- CCU preferably at (waste) hydrogen and/or wind electrical source and/or waste heat source

- Multiple opportunities for plant integration and industrial symbiosis

- Full scale business models – CCU outsourcing options

- The Rijnmond area has the best starting point to attract commercial CCU activities

8. Next meeting

- Next meeting CCU Platform: March 30th, 14.00 – 16.30
- Location: Plant One Rotterdam
- Agenda: Desk study on detailed CCU options for specific products (Deltalinqs-Uniper study)