DTU

DTU technology demonstration

CO_2 capture, CO_2 conversion, gas cleaning

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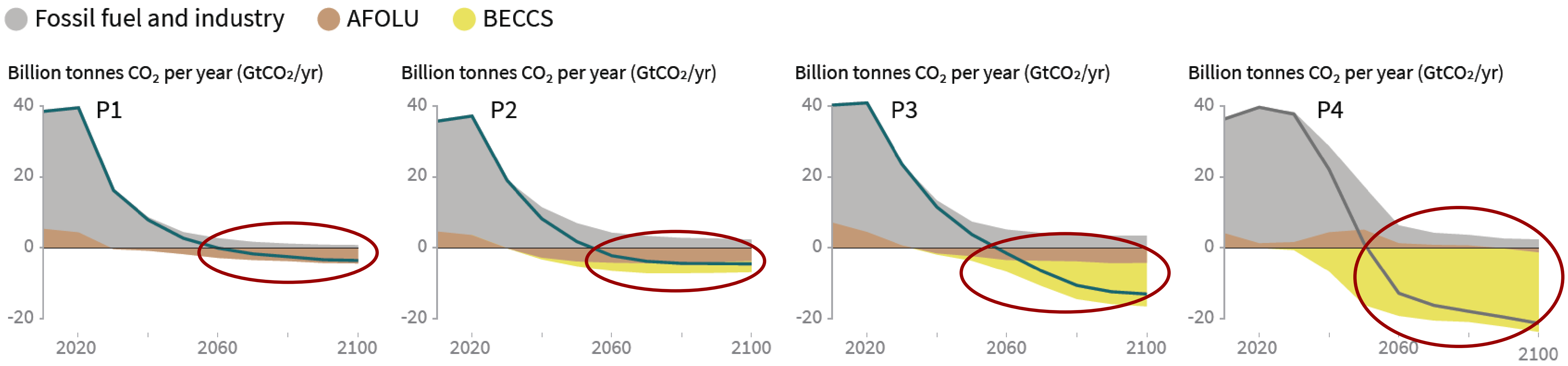
Supported by many innovative colleagues

CERE
Center for Energy Resources Engineering

DTU Chemical Engineering
Department of Chemical and Biochemical Engineering

Future: Negative CO_2 emissions



P1: A scenario in which social, business, and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A down-sized energy system enables rapid decarbonisation of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

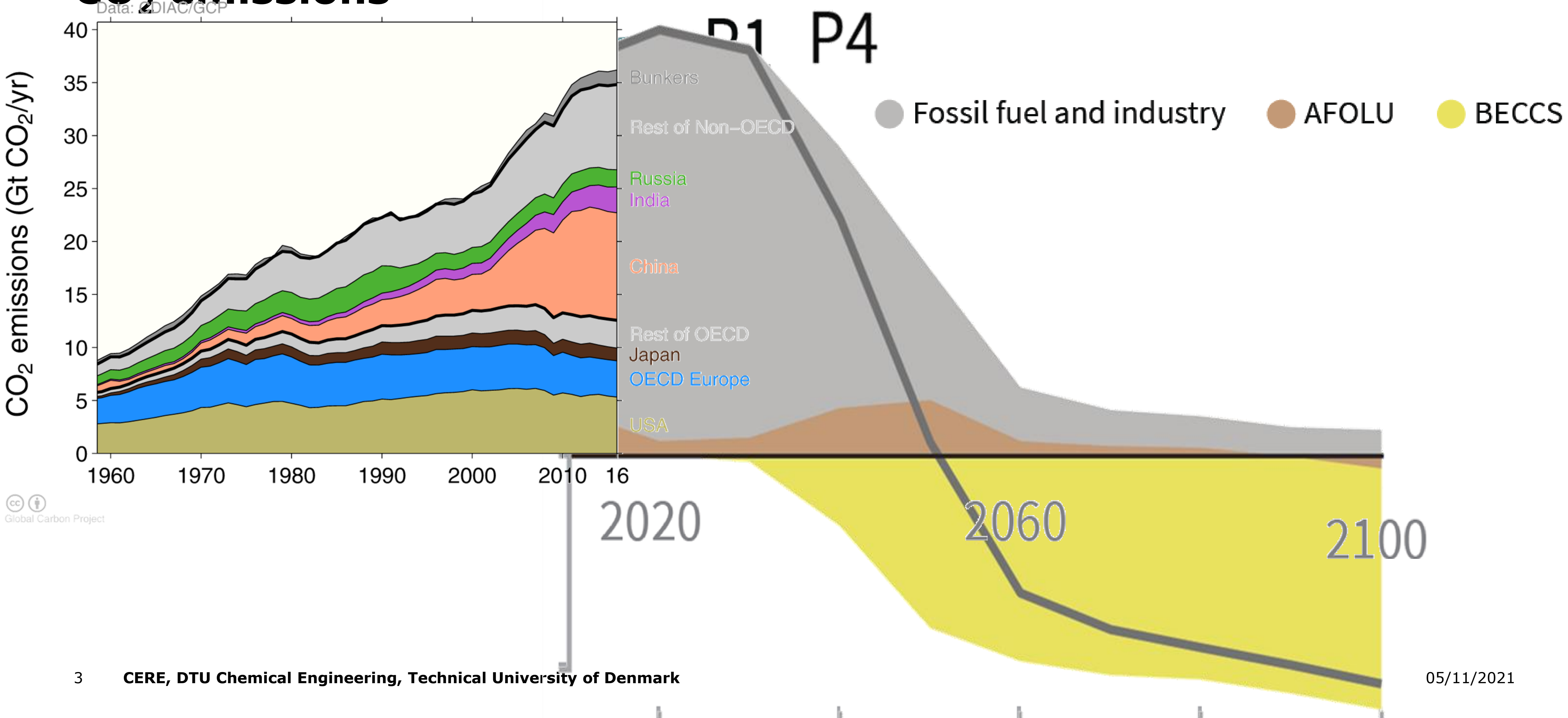
P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

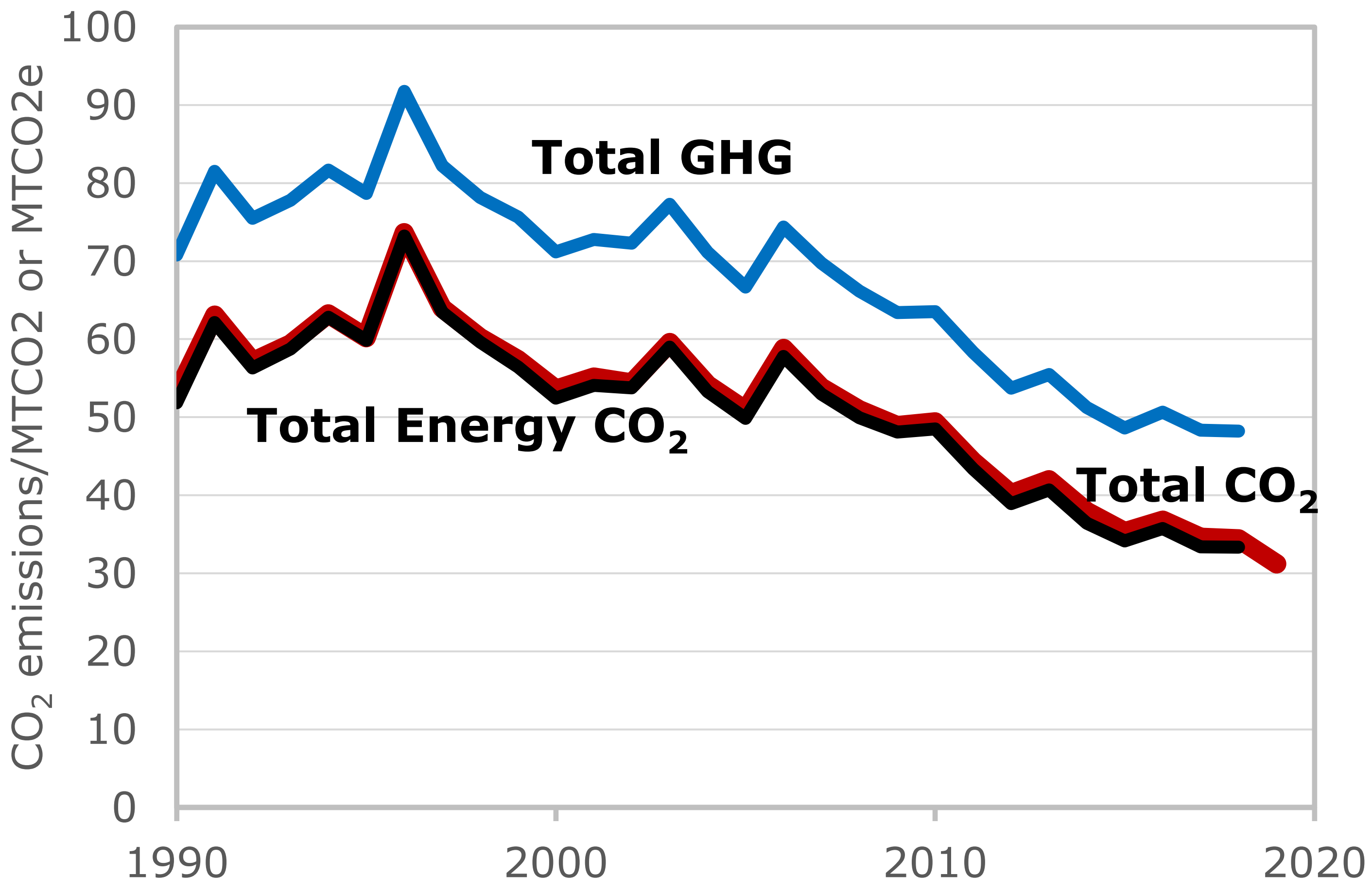
P4: A resource and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Source: IPPC, https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf, side 19

CO_2 emissions



GHG vs. CO_2 (DK)

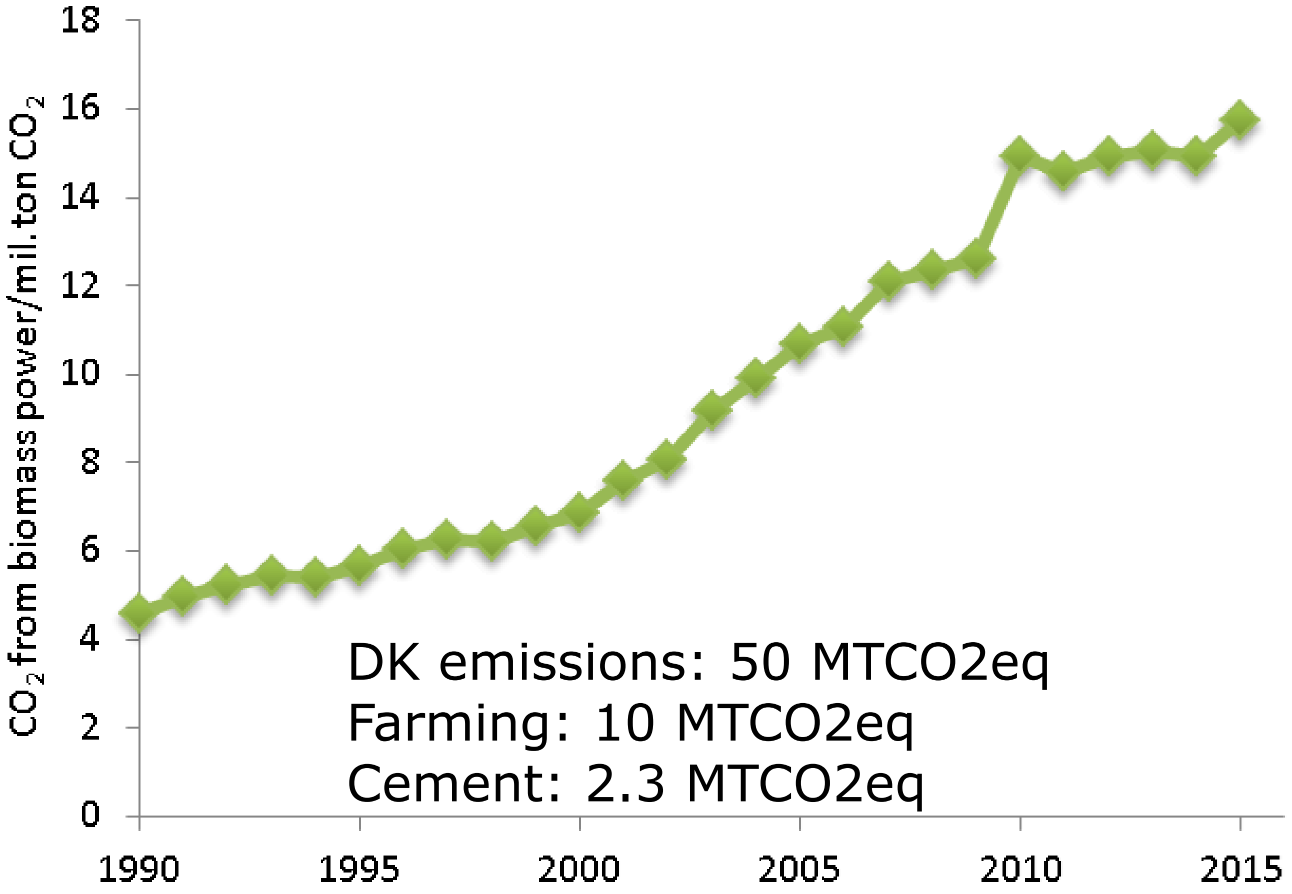


- MTCO2e: million ton CO2 equivalent
- MTCO2: million ton CO2
- Equivalent accounts for all greenhouse gasses (GHG)
  - N_2O x 300 impact
  - CH_4 x 25 impact
  - Fluorides x 20000 impact
- CO_2 accounts for 75% in DK, 81% in USA
- Non-CO_2 emission mainly from agriculture

Negative emissions is not obtained by CO_2 conversion or using CCS on fossil fuel

Negative emissions are only obtained by storing green CO_2

- CO_2 removal from biomass power
- CO_2 removal from Biogas
- CO_2 removal from green waste combustion
- Direct Air Capture (DAC)

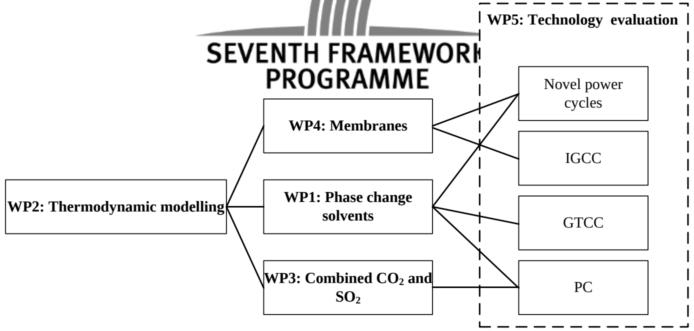


Relevant industries

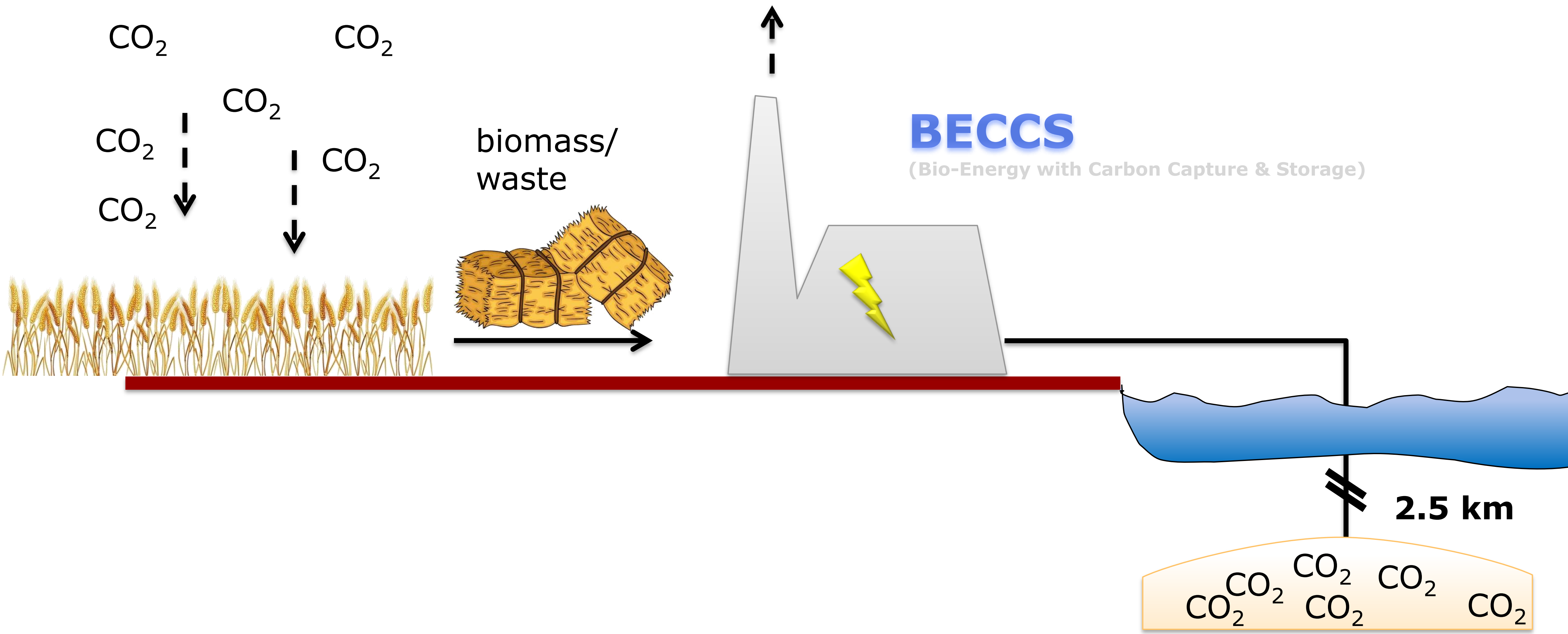
- Biogas upgrading
- Power industry (biomass combustion)
- Cement production
- Steel industry
- Silicium production
- Paper industry
- Direct Air Capture (DAC)
- Refining
- Fermentation
- Ethanol production
- Ammonia Production
- Aluminium production
- Natural gas cleaning
- Hydrogen production
- Large navy industry
- Combined SO_2 and CO_2 removal
- Acid gas treatment

DTU CERE CO_2 projects & activities

- CASTOR (EU, -2006)
- Modelling CO2 capture (STVF, 2006-09)
  - Rate based modelling
- iCap (EU, 2010-14)
  - Demixing solvents
- Ionic liquids for CO_2 capture (STVF, 2009-11)
- CESAR/CLEO (EU, 2009-11)
  - Combined thermodynamic and rate-models
- Chilled am. and amino acids for CO2 capture (2008-11)
- CO_2 capture simulation (Ind., 2012)
- OCTAVIUS (EU, 2012-16)
  - Benchmarking, CAPE-OPEN
- CO_2 capture & hydrates (FTP, 2013-2017)
- INTERACT (EU,2011-18)
  - Lab scale & pilot trials using enzymes
- **BioCO2 (EUDP, 2017-2022)**
- 3D (EU, 2019-2023)
  - Steel capture, compression, liquefaction
- TCM large scale pilot (2018)
- BioReFuel (EUDP, 2020-2023)
- **SRI DOE (2018-2021)**
- **ARC (EUDP, 2020-2024)**
- **ConsenCUS (EU, 2021-2025)**
- EERA (2014-)
  - Preparation of consortia idea creation for new EU calls

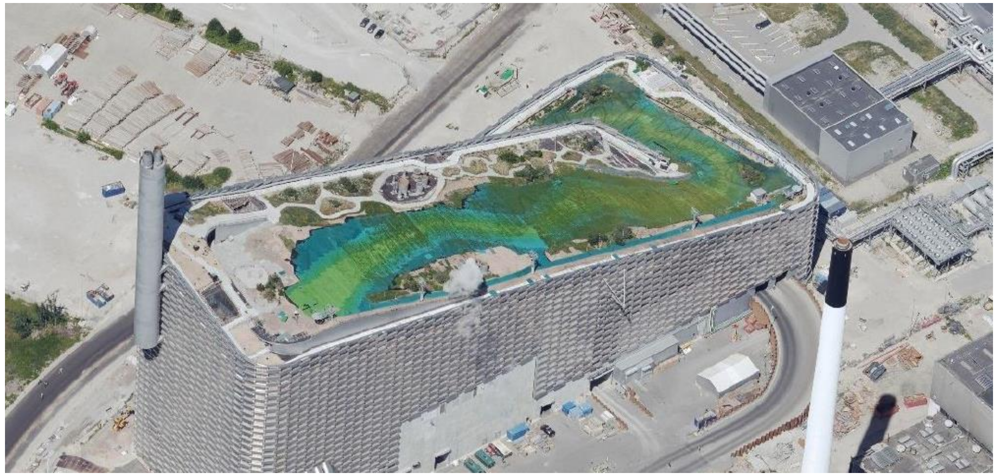


CO_2 capture and storage – Negative emission



Typical sizes

- Power plants (biomass, waste) (400 MW)
  - 220 ton/h
  - 2 mil. ton/year
  - 12% CO_2
  - 1 ton fuel -> 1 ton CO_2, approx
- Biogas plant (5000 Nm3/h)
  - 3.9 ton/h
  - 40% CO_2
- Cement production (AP)
  - 270 ton/h
  - 2.3 mil ton/year
  - 18-20% CO_2
- Direct Air capture (Orca – Iceland)
  - 0.5 ton/h
  - 4000 ton/year
  - 0.04% CO_2



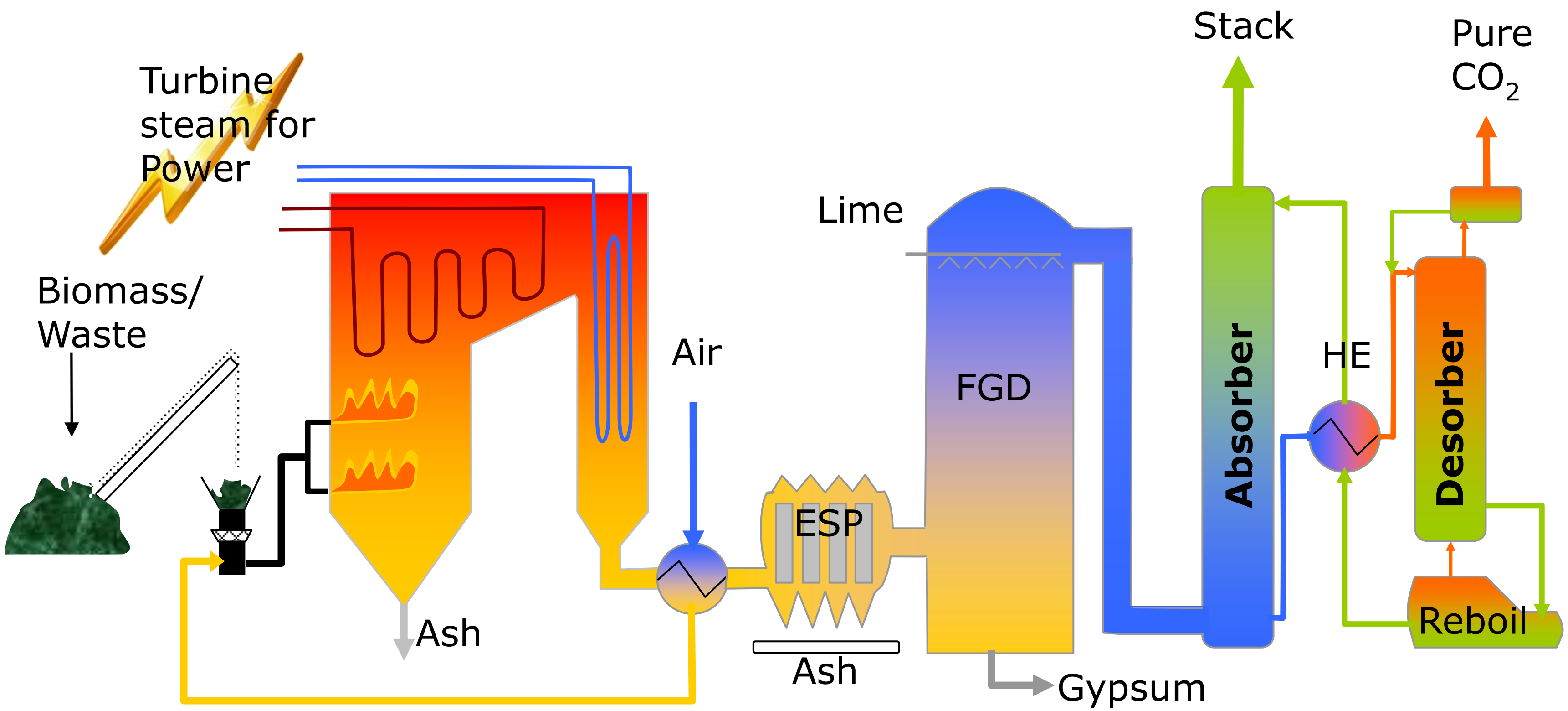
ARC (60ton/h)
Gas combustion (3.5%)
Air (0.04%)
Steel (1400 ton/h)

DAC systems

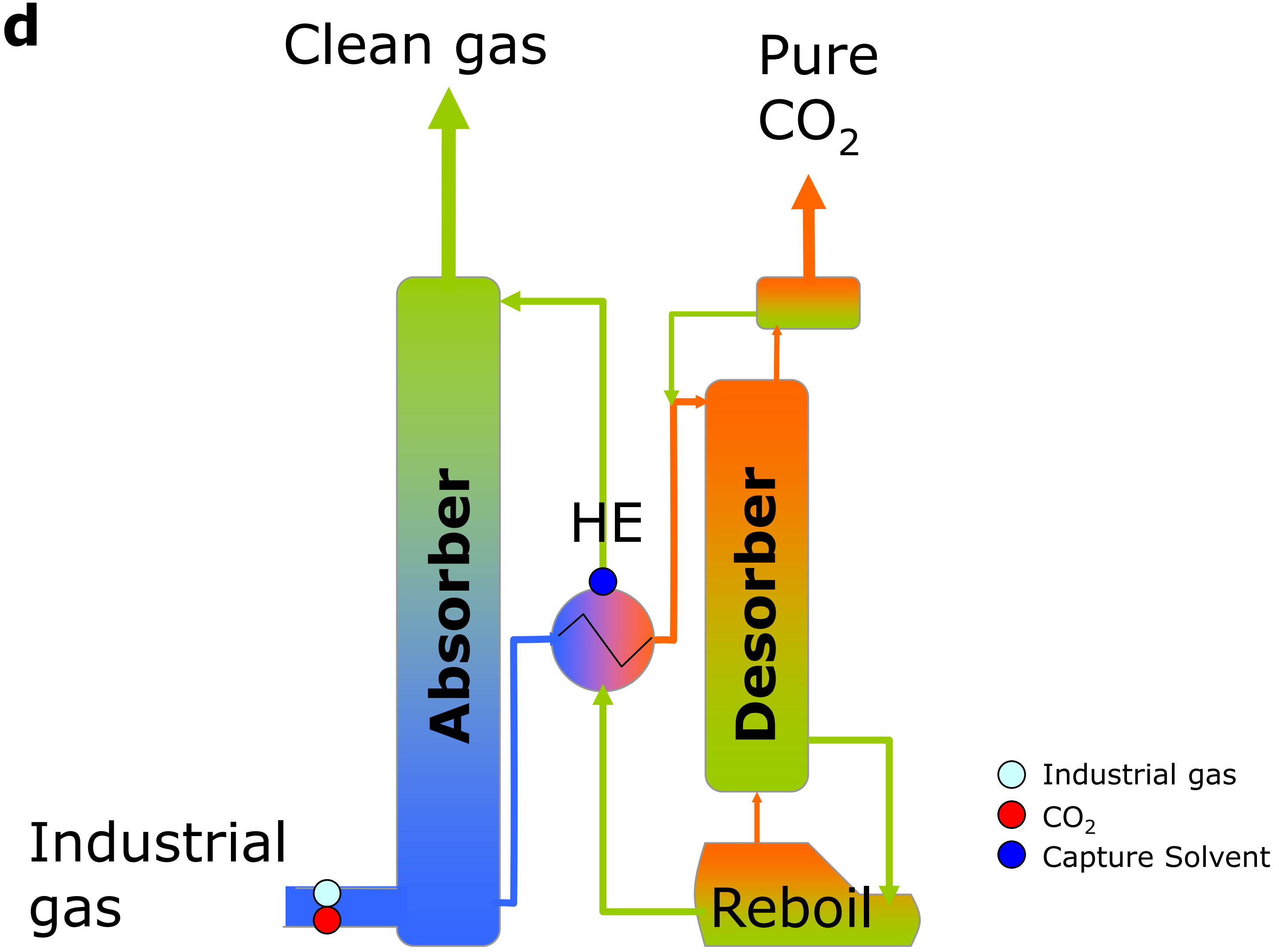
- Climeworks (600 €/ton), 6-10 GJ/ton
- Carbon Engineering (100-150€/ton)
- GlobalThermostat (120€/ton)
- MIT … (1 GJ/ton)

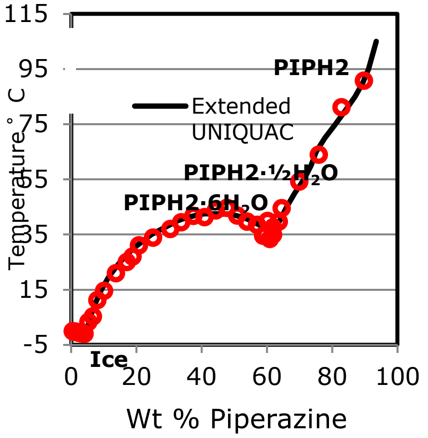
Post-combustion capture & industrial CO_2 removal

- ARC CO_2
  - 66% Biogen
  - 33% Fossil



Solvent based CO_2 capture



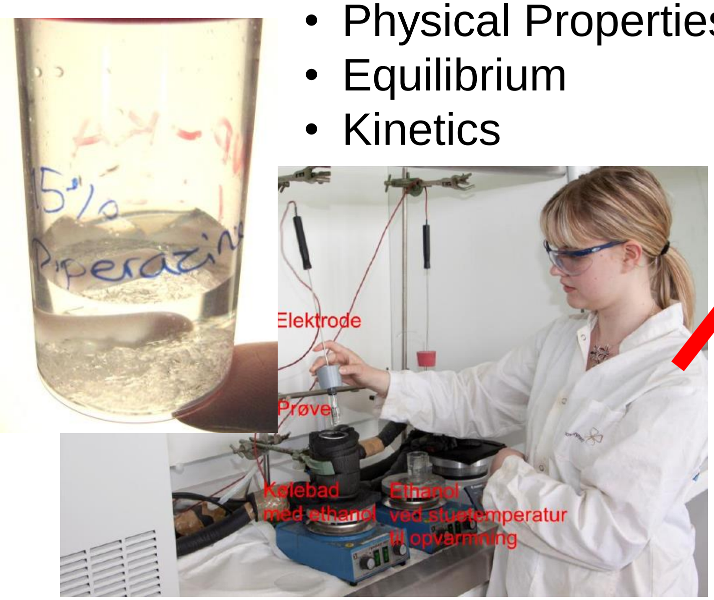


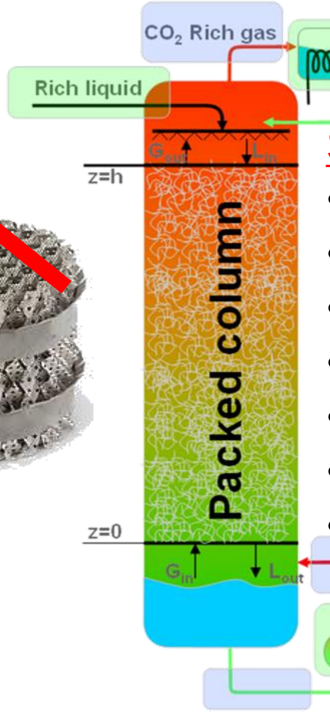
Modelling
- Energy consumption
- Heat of reaction
- Thermodynamics
- Kinetics

Pilot tests
- Real life tests
- Solvent study
- Packing testing
- Energy requirements
- Mass transfer

DTU CO_2 Research

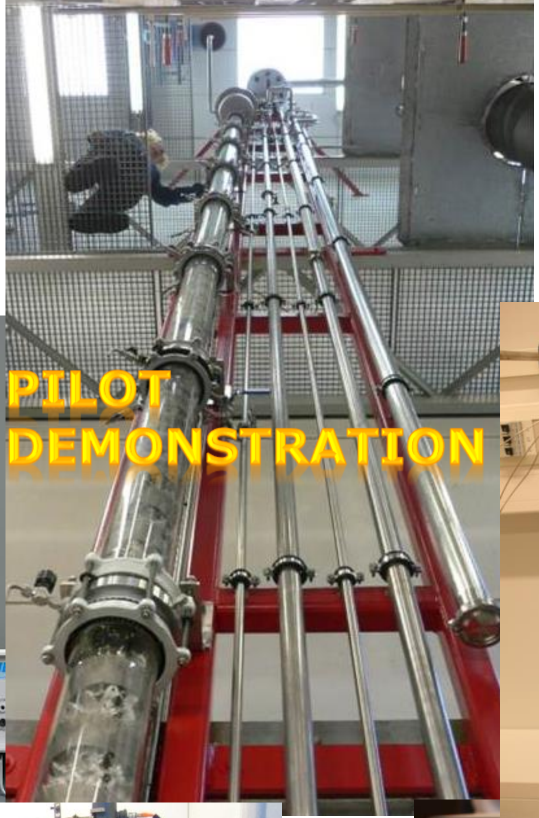
Experimental
- Physical Properties
- Equilibrium
- Kinetics





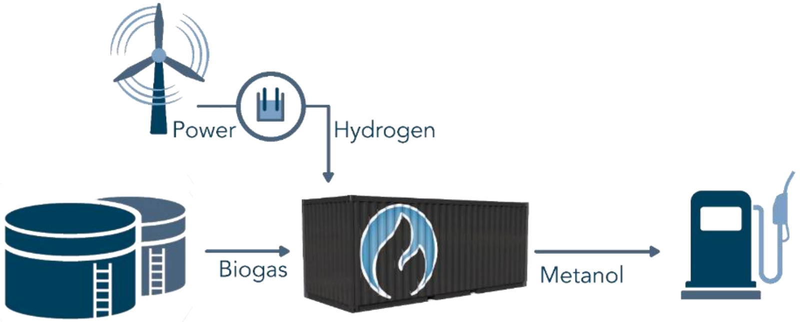
Simulation
- Variance analysis
- Optimization of energy use
- Optimization of packing
- Rate based approach
- Equilibrium approach
- Aspen Plus
- Cape-Open

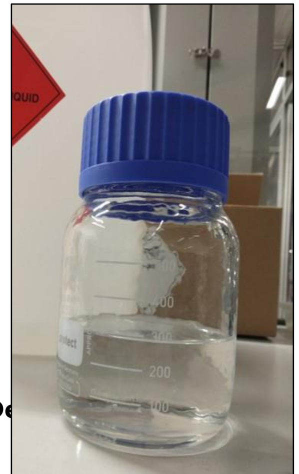
DTU CERE Labs

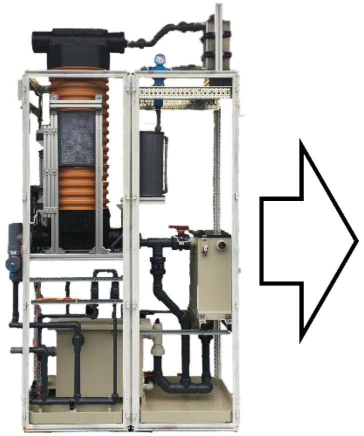


Ongoing EUDP projects

- BioCO2 (CCS) (14 mill DKK)
  - New principles for low energy biogas upgrading
  - Energy reduction
  - Transportable unit (container)
- BioReFuel (CCU) (16 mil DKK)
  - Biogas to MeOH
  - 400L MeOH per day
  - ISO-container
- Be-Clean (P2X) (22 mil DKK)
  - Low cost H_2S removal
  - Electroscrubbing
  - Full scale
  - 1/10 footprint







On-site capture testing, 1 ton/day

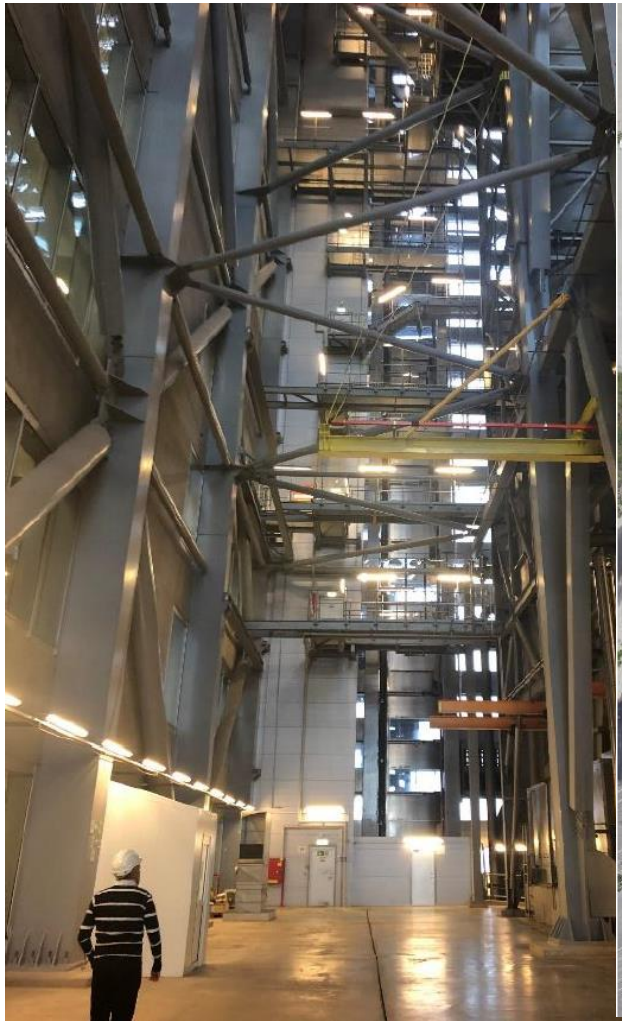
ARC: 62 mil DKK Net Zero Carbon Capture Eneergy consumption

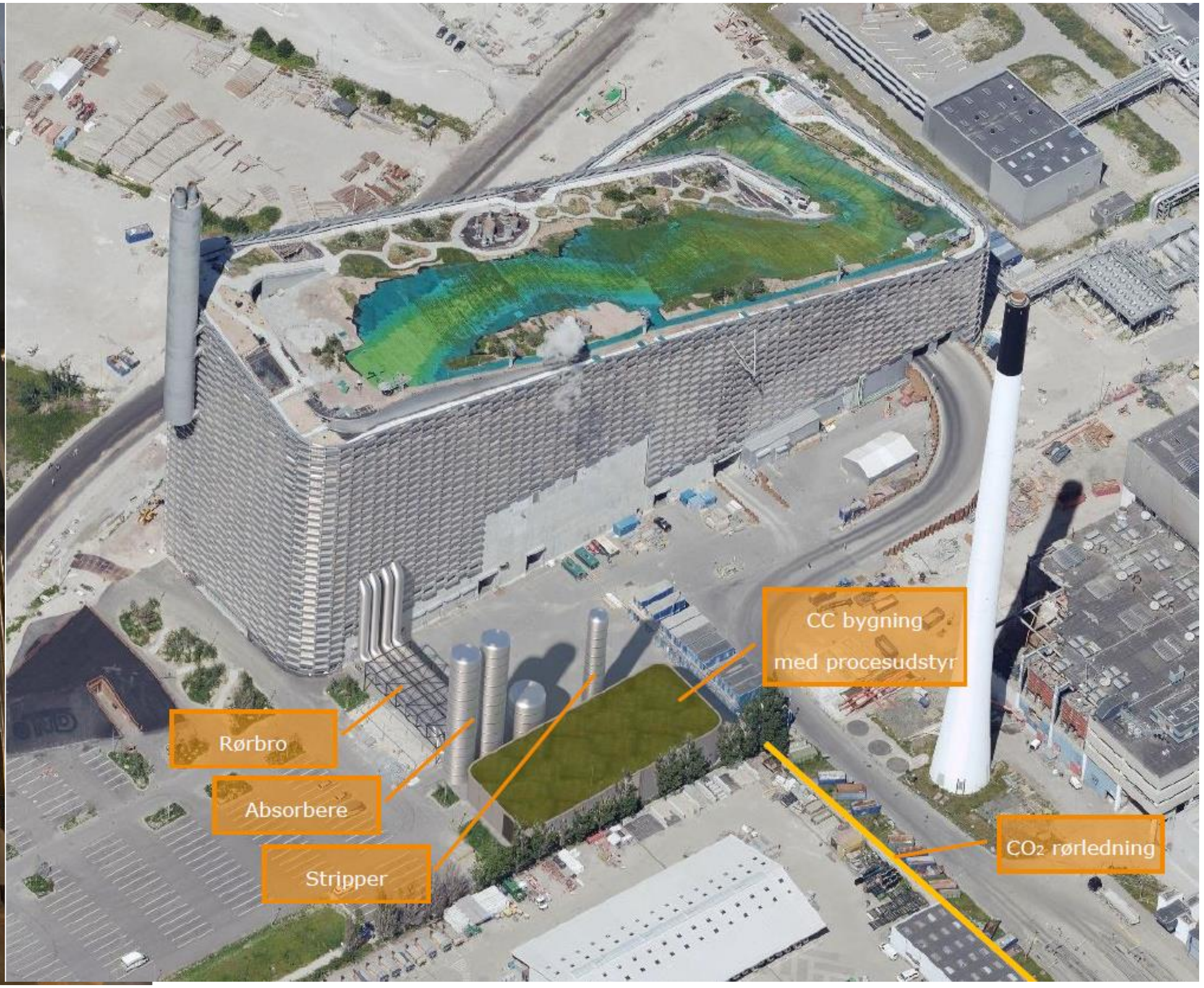
- Objectives
  - Waste heat
  - Heat integration
  - Cost effectiveness

1. Pilot

2. Demonstration

3. Full scale design
   - 0.48 mtpa

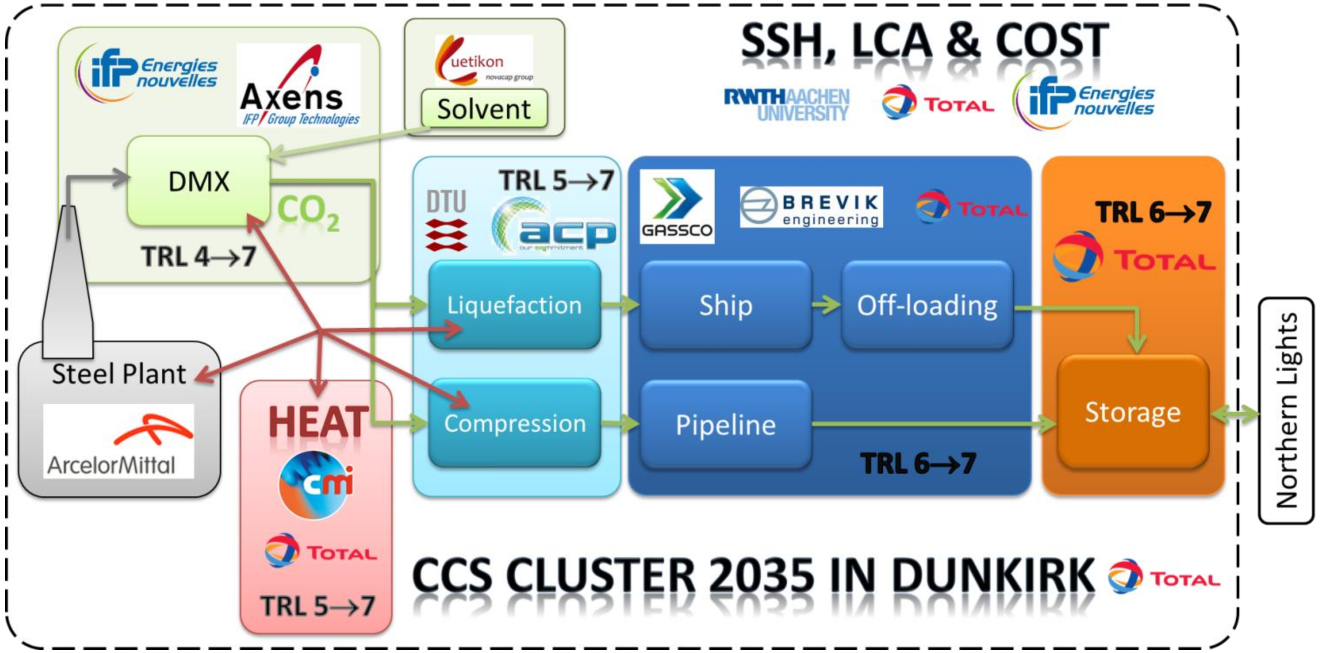


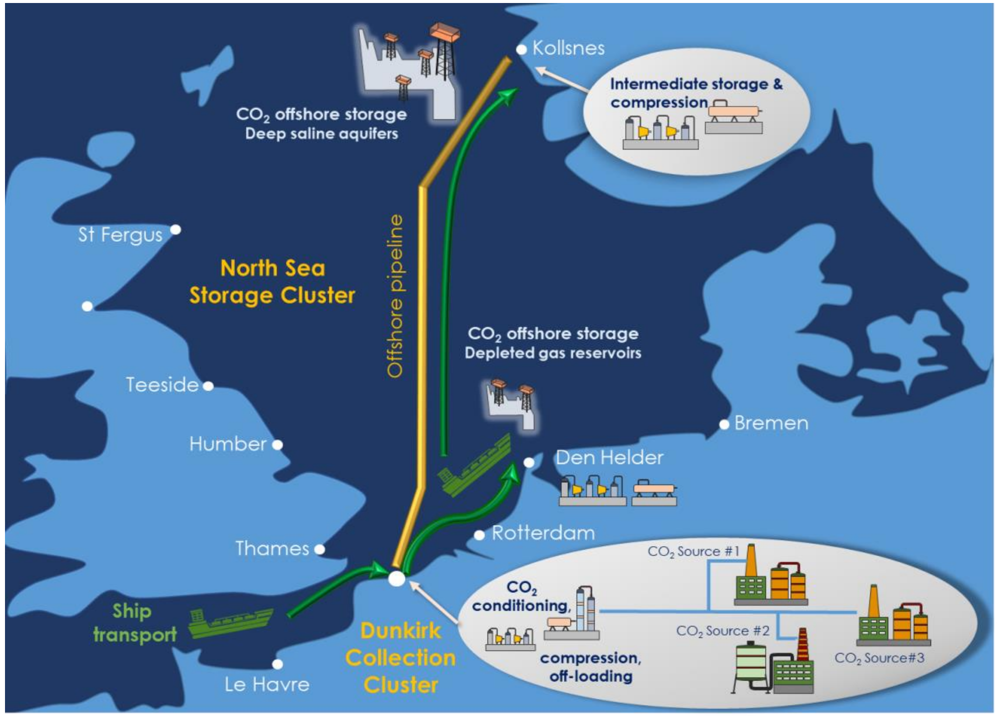


ARC installation

The 3D EU project

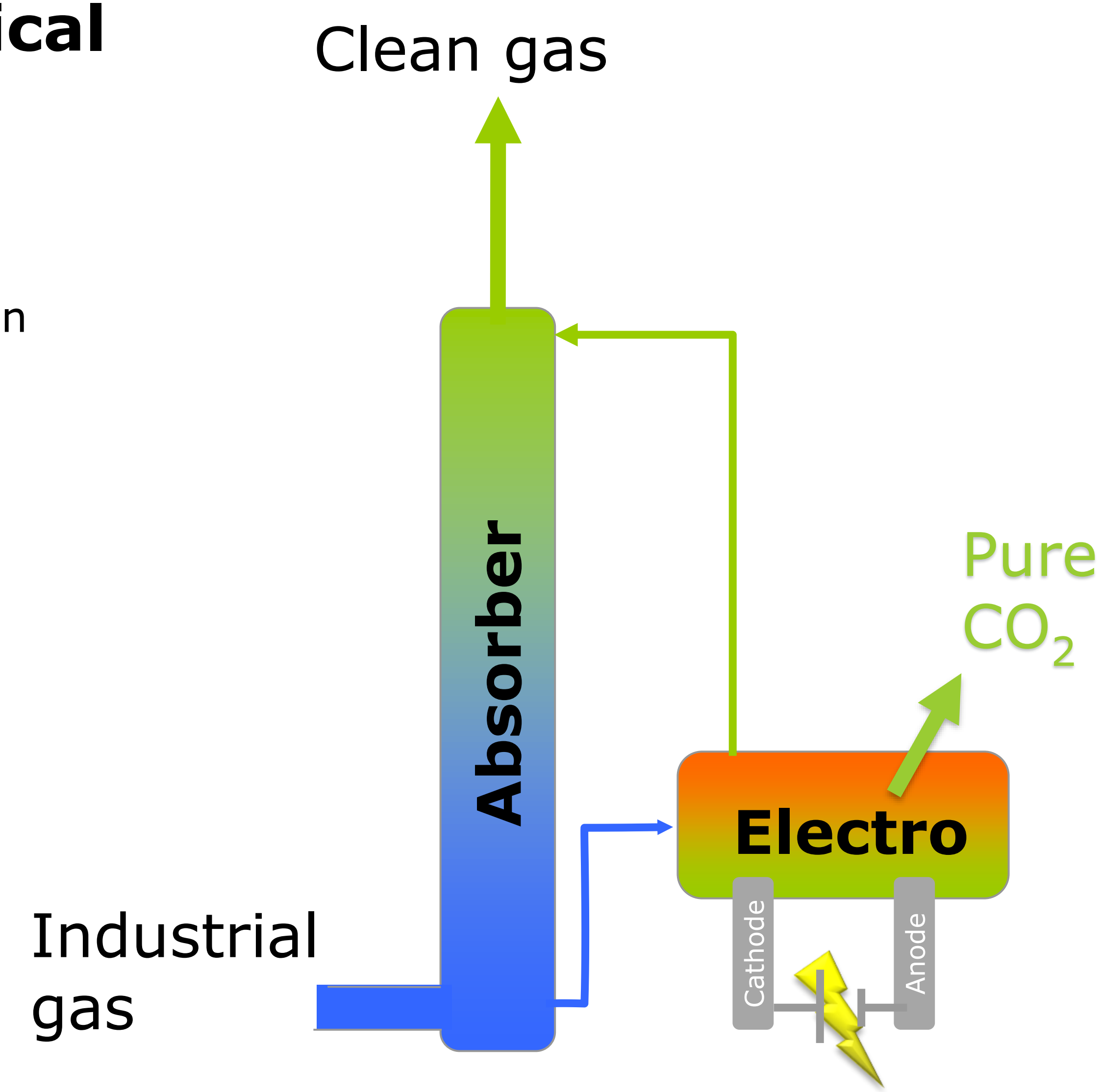
- DTU objective: compression & liquefaction
- 19 mill EURO project



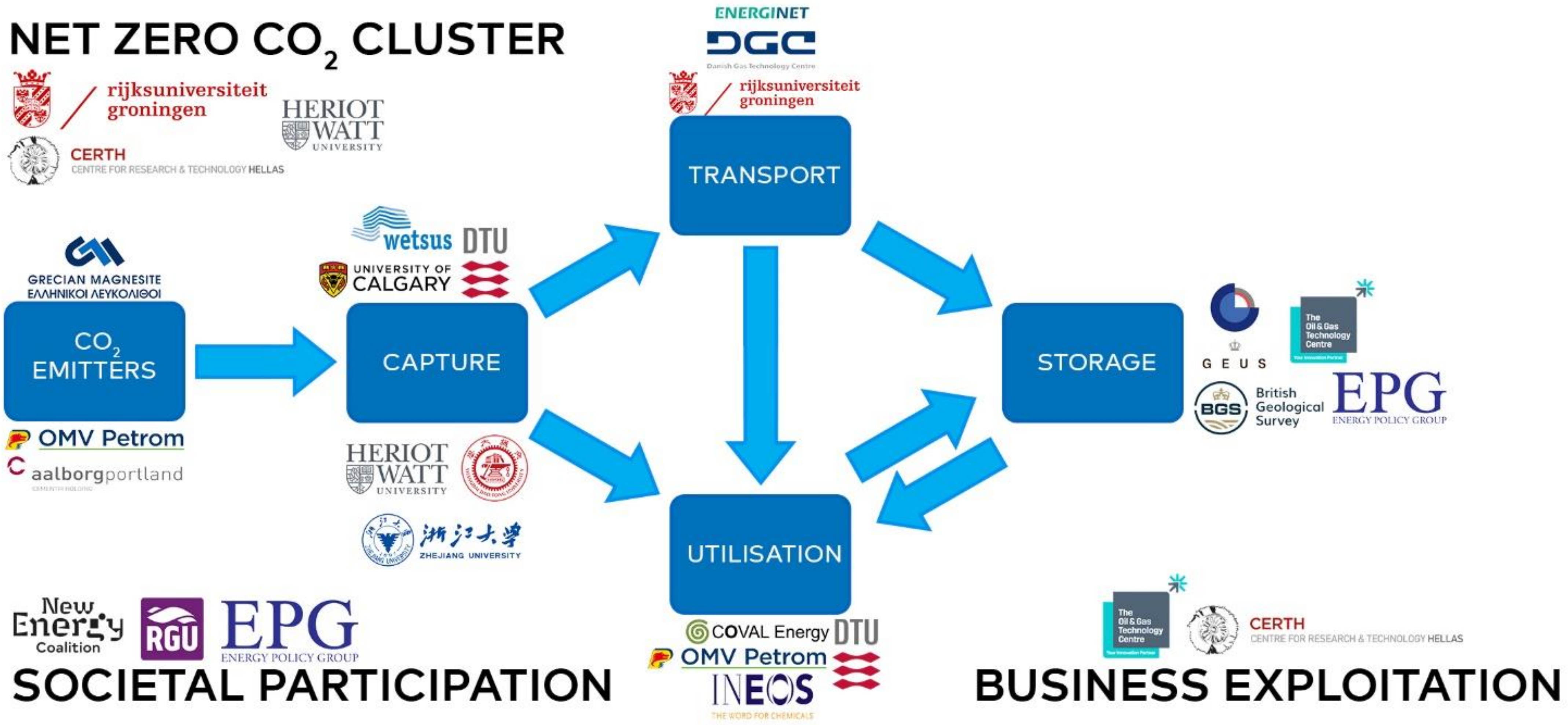


Electrochemical CO_2 capture

- DTU Aim: 1.6 GJ/ton



ConsenCUS 14 mil € (34 mil DKK for DTU), P2X technology



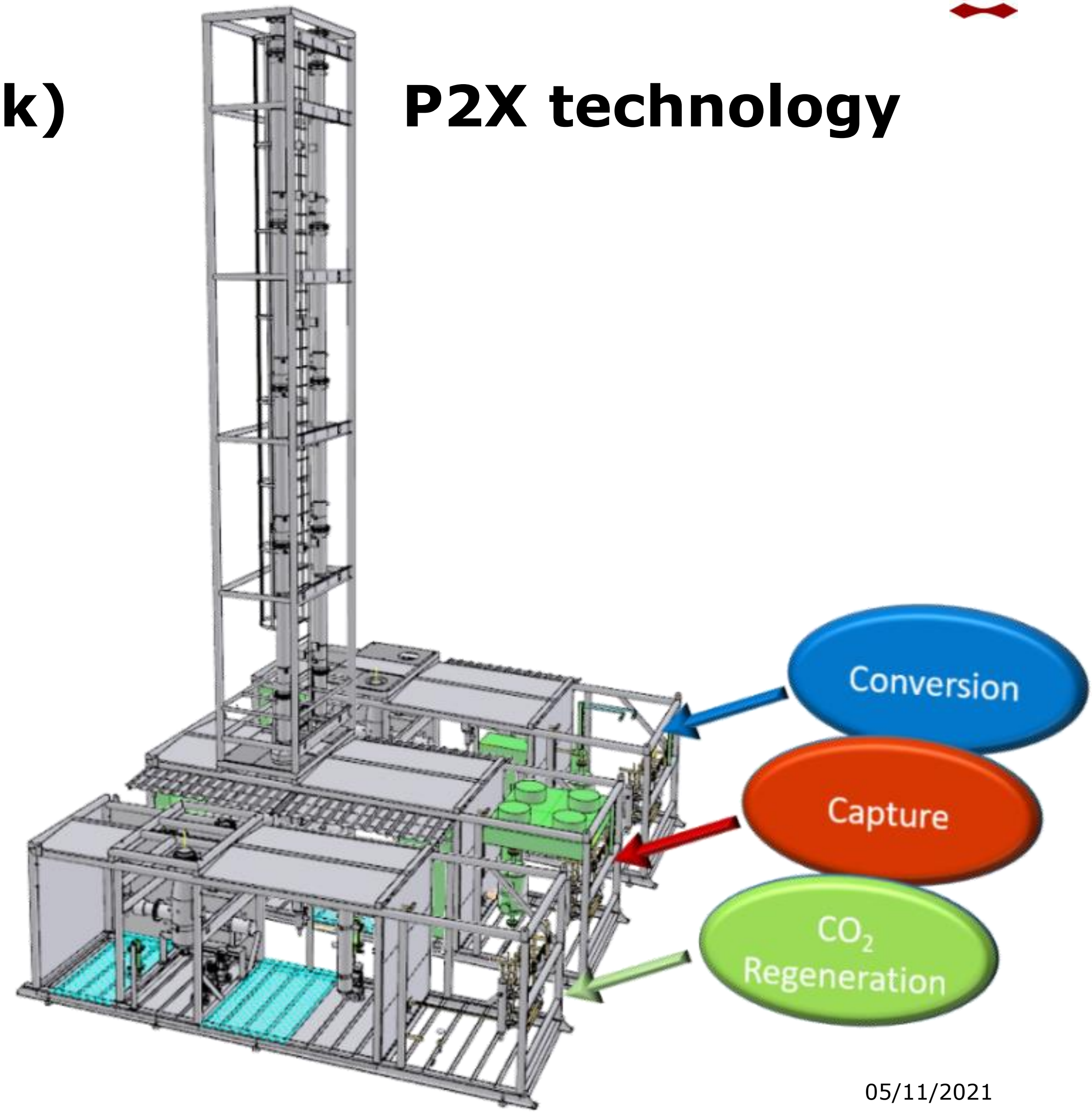
ConsenCUS 14 mil € (dtu: 34 Mdkk)

- 4 year of testing
- 3 test sites
  - Ålborg Portland, cement
  - OMV petrom, refining
  - Grecian Magnesite, magnesium production

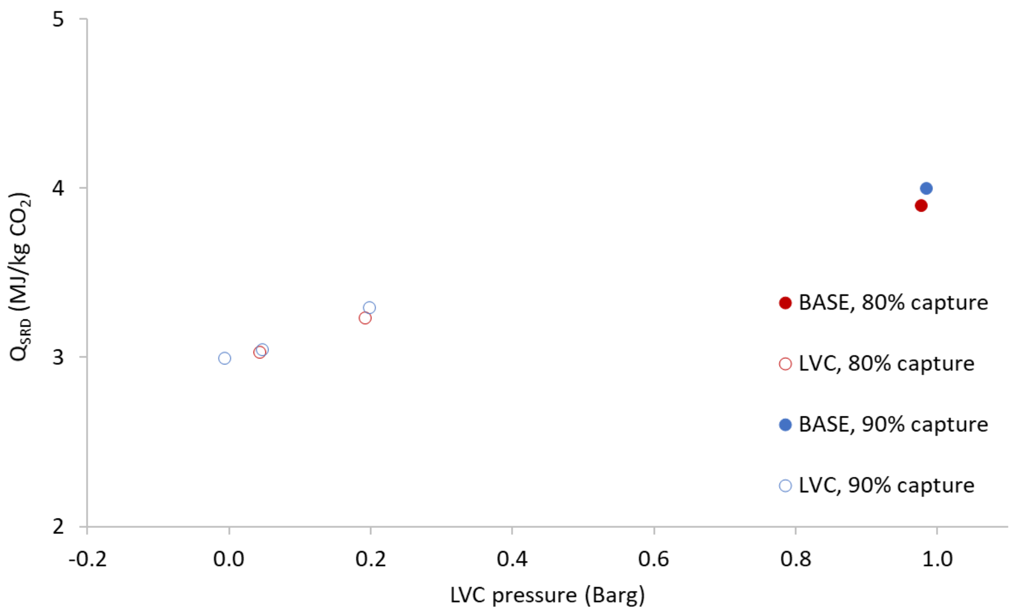
- Technology testing
  - Wetsus electrochemical CO2 solvent regeneration
  - Coval, CO2->formic acid

- Container size
  - 5 month onsite testing

P2X technology

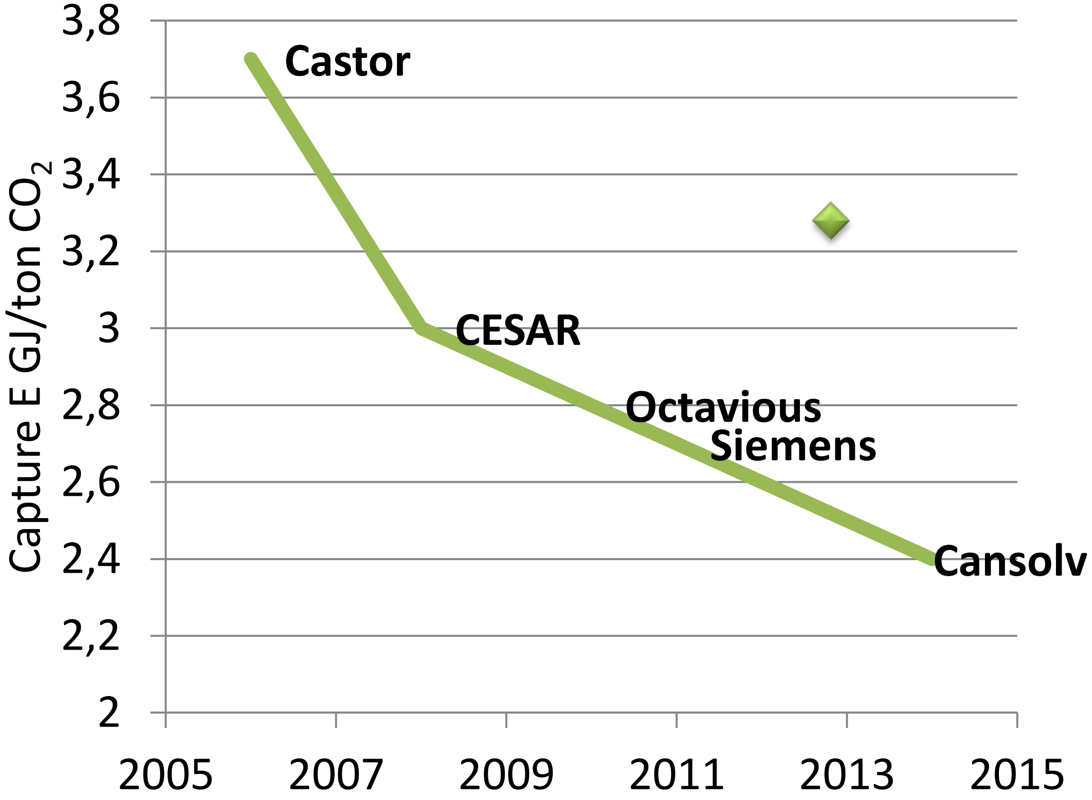


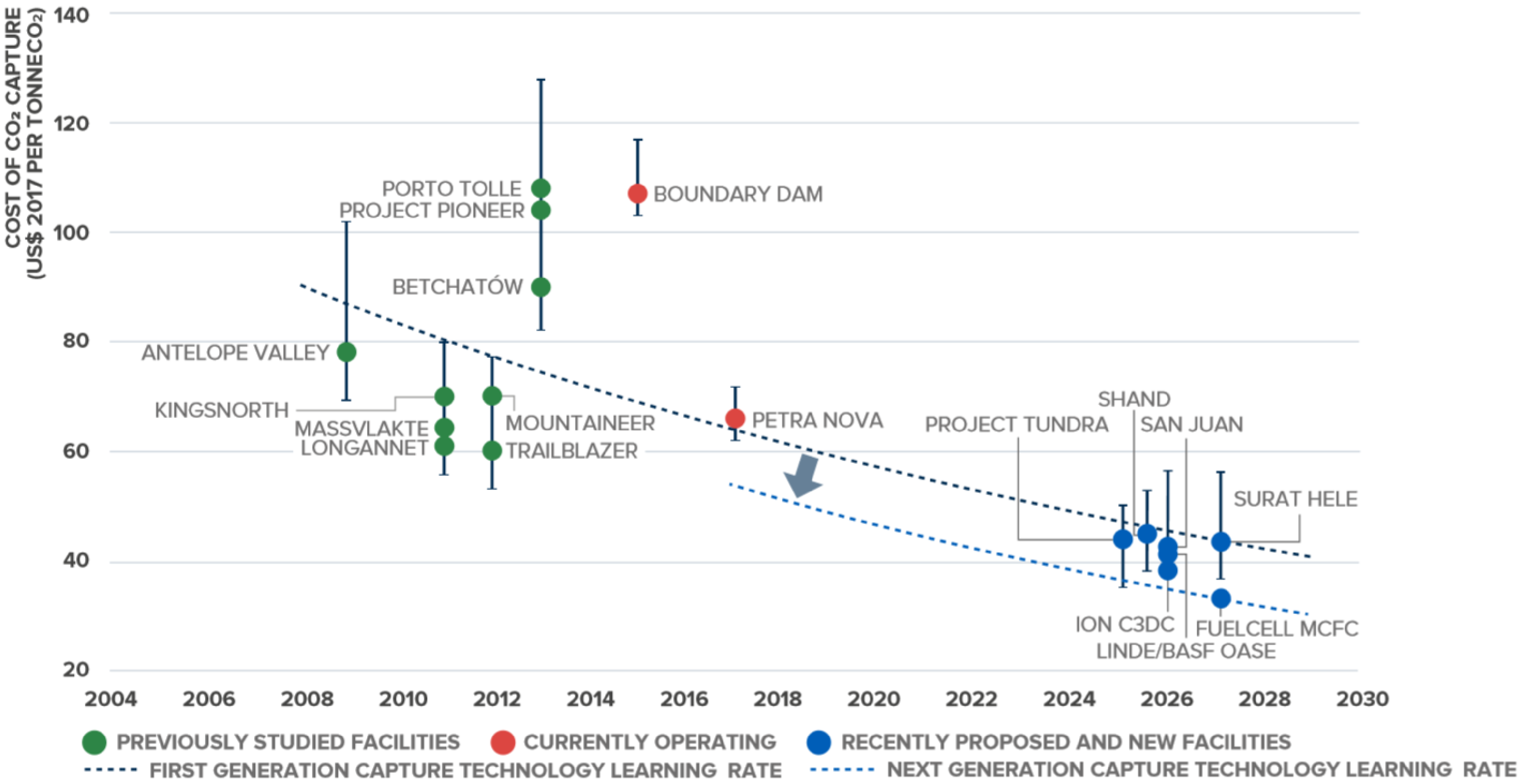
TCM collaboration – LVC campaign 2018



Historical capture energy cost

- Energy consumption (gas containing approx. 10% CO_2)
  - State-of-the-art 3.7 GJ/ton
  - Advanced technology focus: 2.4 GJ/ton
- DTU ambition: lower!
  - 2.2 GJ/ton
  - 1.6 GJ/ton

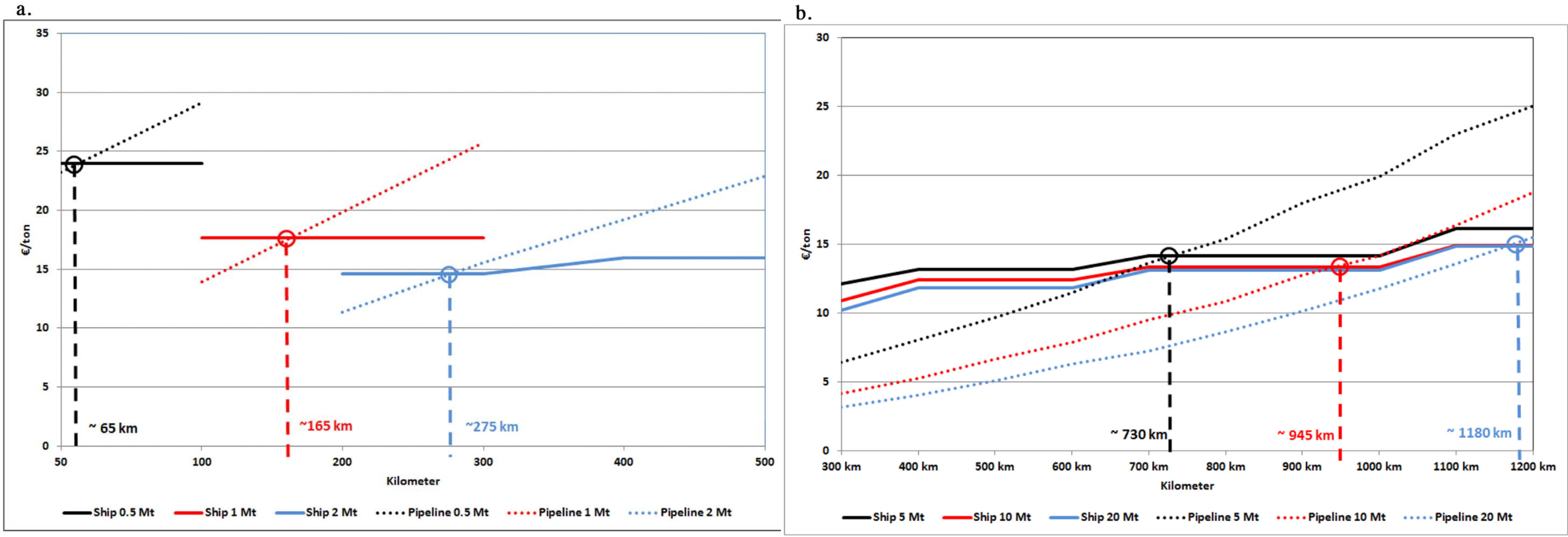




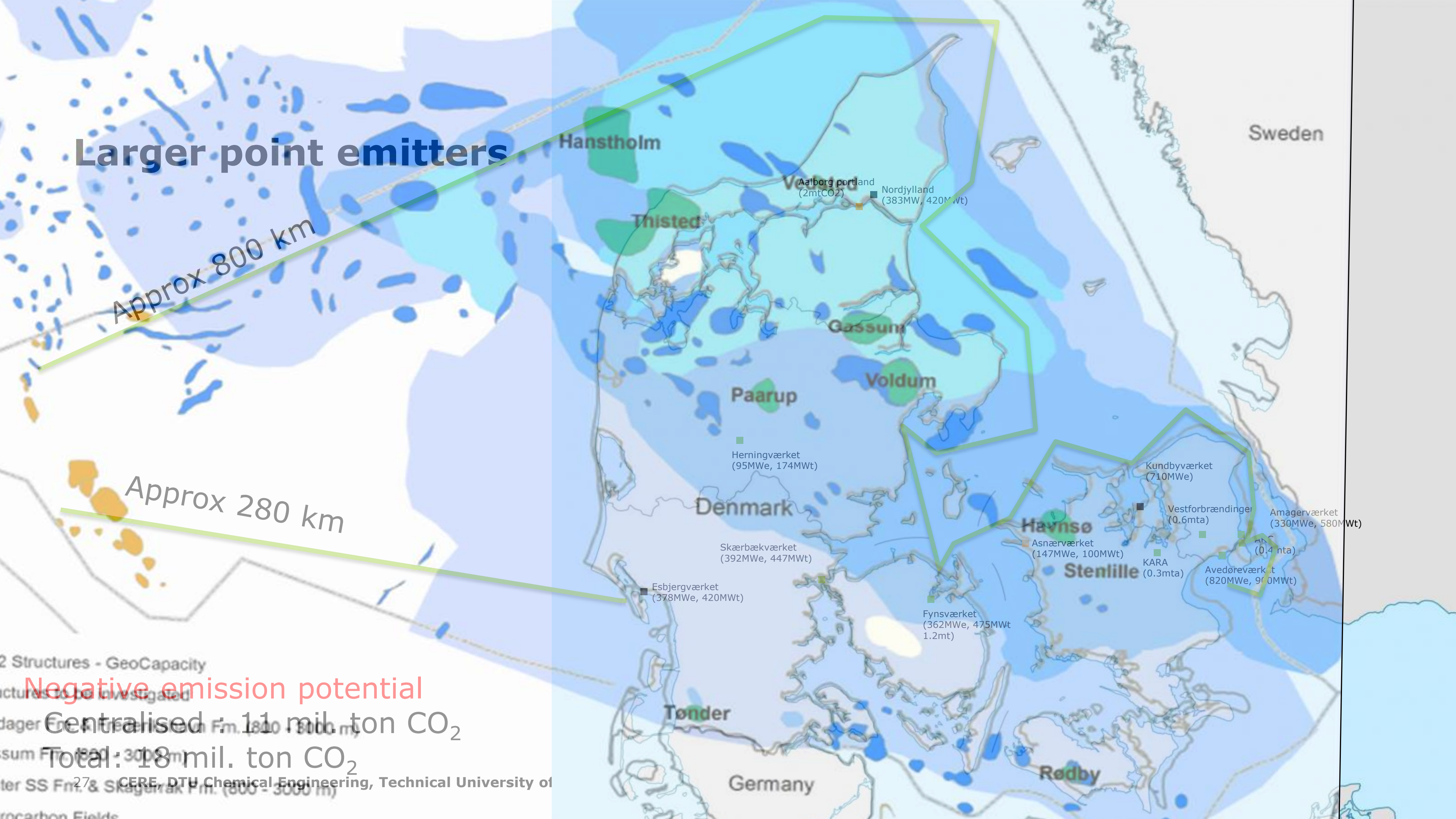
Source: Global CCS institute 2019, https://www.globalccsinstitute.com/wp-content/uploads/2019/12/GCC_GLOBAL_STATUS_REPORT_2019.pdf

CO_2 transport and storage - cost

- Existing cases indicate up to 100 €/ton for FOAK



Larger point emitters

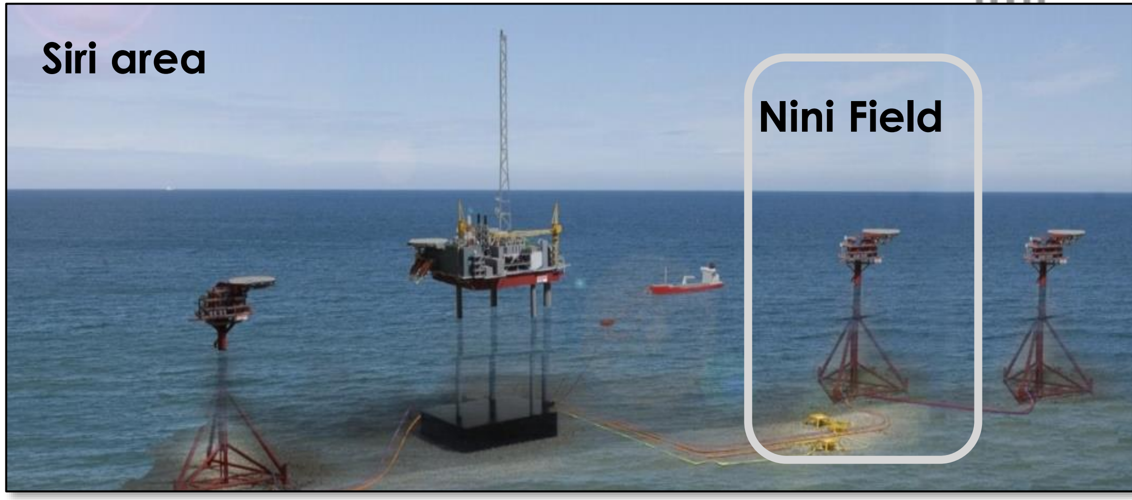


Negative emission potential

Centralised : 11 mil. ton CO_2

Total: 18 mil. ton CO_2

Siri Area storage Potentiale
Ineos prediction - Greensand

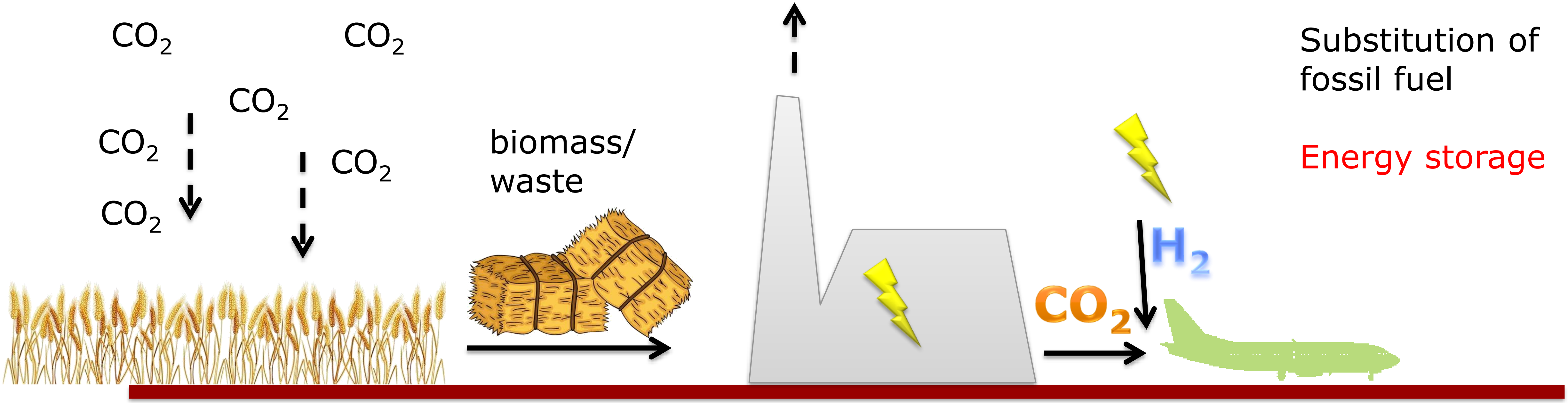


CO_2-store	Statement of Feasibility	Pilot	CO_2 Ready	mta	Data basis
Nini West	2020	2022	2024	0,45	confirmed
Nini Main	2021	Not required	2024	1	Estimate
Nini Ty	2021	2022	2024	0,5	Estimate
Cecilie Ty	2021	2023	2025	0,5	Estimate
Cecilie Aqu	2022	2023	2027	1	Estimate
Nini East	2022	Not required	2027	1	Estimate
Stine Seg 2	2022	2023	2025	2	Estimate
Siri Main	2023	2023	2028	3	Estimate
Total				9,5	
Safety				**4,5**	

CCS, is it possible? Yes, Canada and Norway are doing it

CCS – 1st generation exists

CO_2 utilization

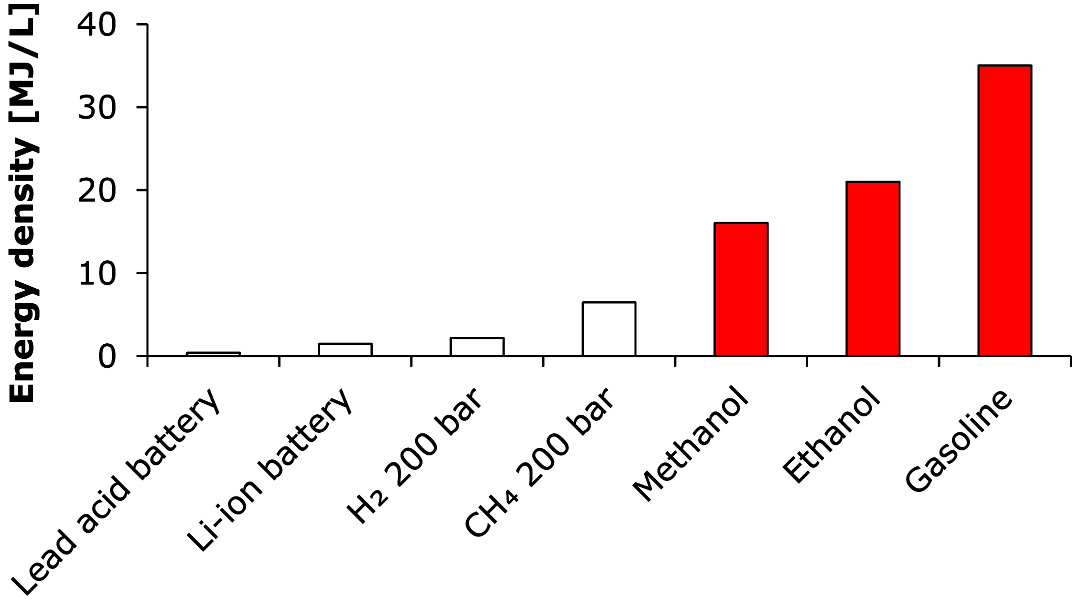


Substitution of fossil fuel

Energy storage

CO_2 utilization for aviation industry

H_2 + CO_2



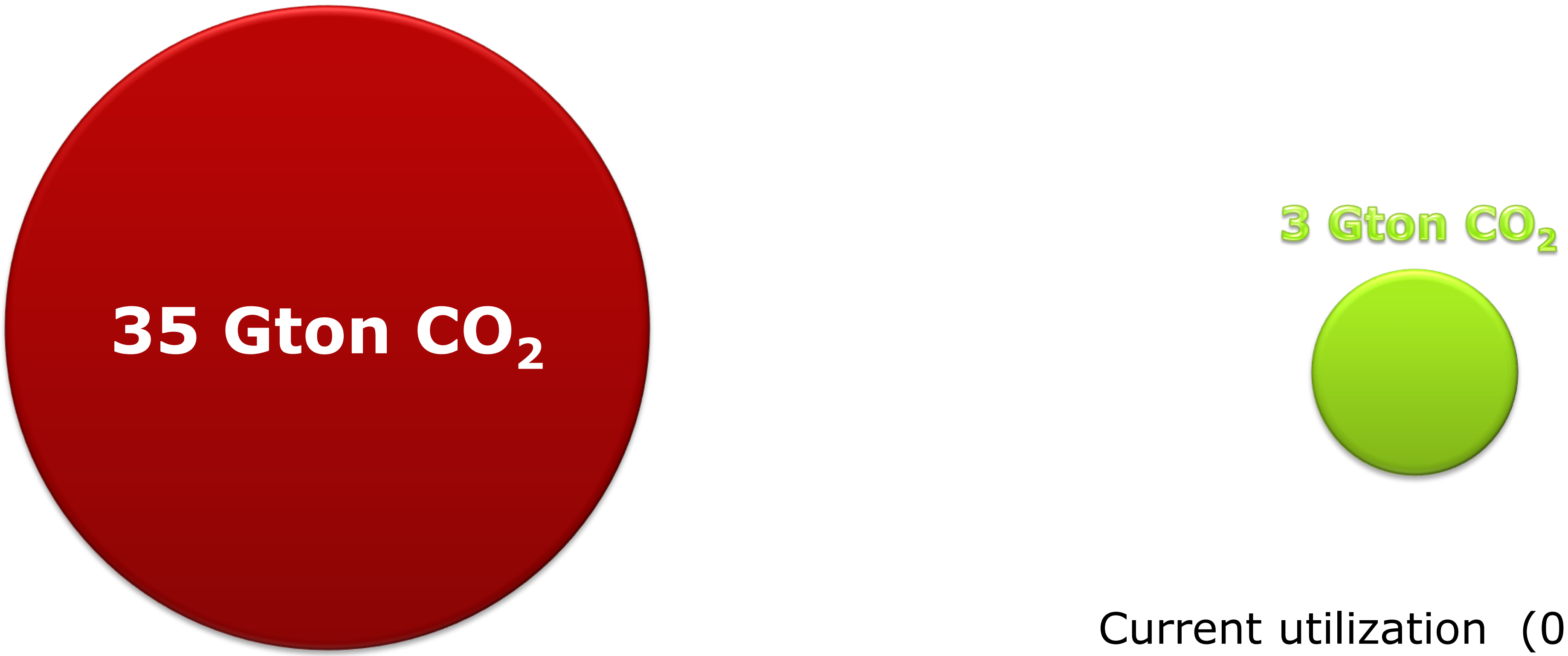
Current CO_2 utilization

Emissions

Utilization (1%)

Source: E. Alper, O. Yuksel Orhan / Petroleum 3 (2017) 109

Challenges in the future



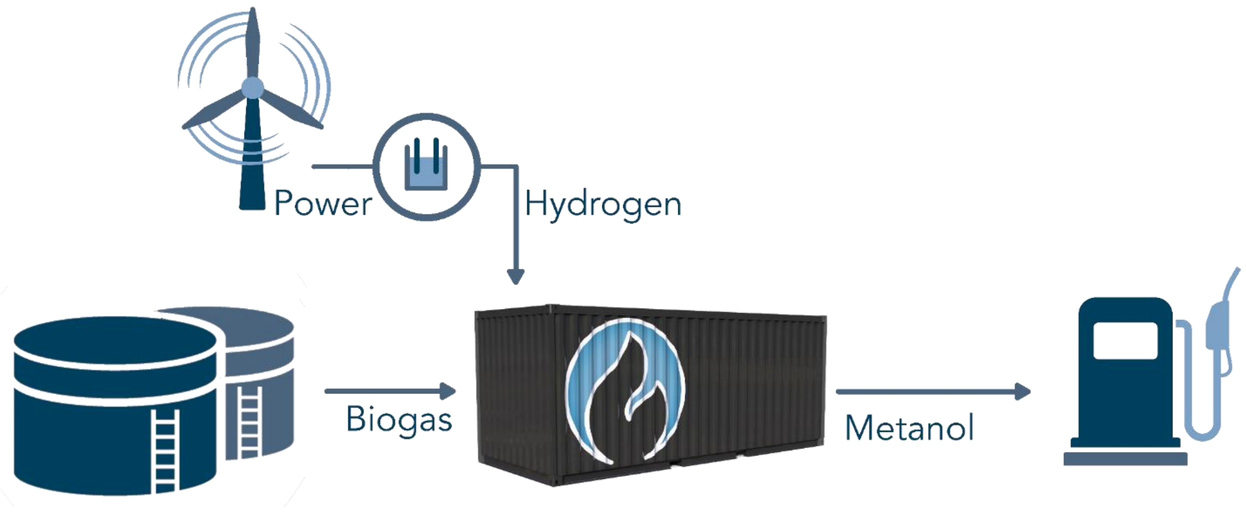
Emissions

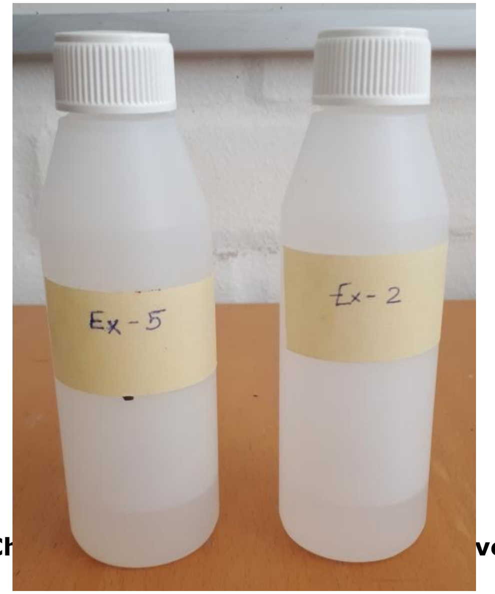
Current utilization (0.3 Gton)+
Synthetic fuel (1 Gton) +
All plastic (1 Gton) +
Other (0.7 Gton)

Source: PlasticEurope, 2015

Project: Bio-ReFuel (methanol from Biogas)

- Next generation biogas upgrading
- Objectives:
  - Convert biogas to methanol
  - Lab & pilot scale
  - Funding: 16.5 mil. DKK
- Supported by: EUDP





Biogas conversion:
$2\ CH_4 + H_2O + CO_2 = 3\ CO + 5\ H_2$

To reach stochiometric balance, additional H_2 is added:
$3\ CO + 6\ H_2 = 3\ CH_3OH$

Pictures: Sebastian Nis Bay Villadsen

BioReFu


CDDU 982114 2
45G1
MAX.GR
TARE
THIS END
Thomas Berg
Hadsten Tip-Service
R730

Future challenges – negative emissions

35 Gton CO_2

Emissions

IPCC negative

22 Gton

Climate goal

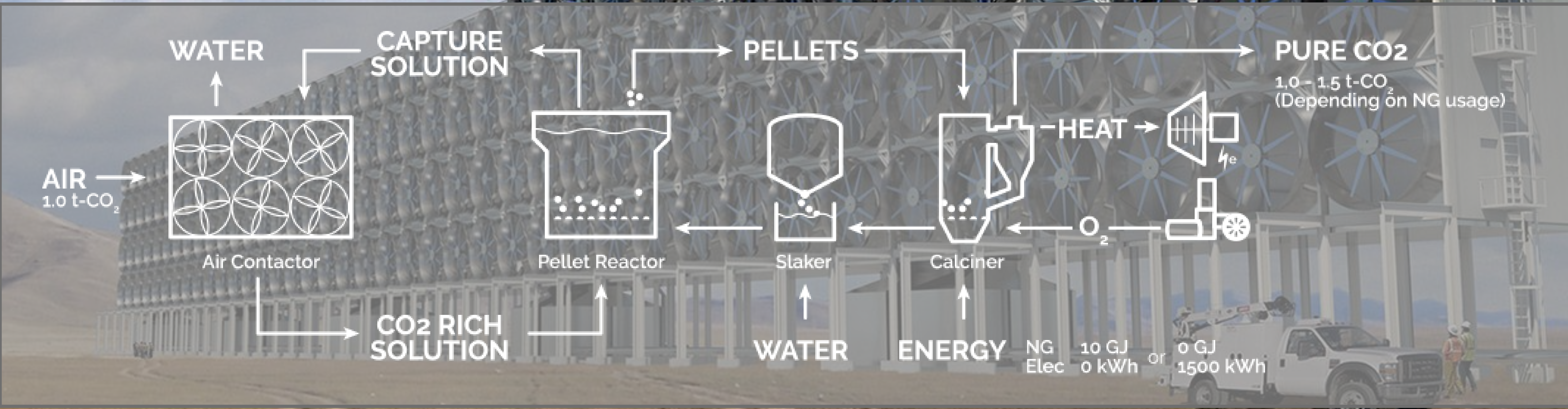
We must remove CO_2 from the atmosphere

Utillization is OK, but we must do it even better

Thank you

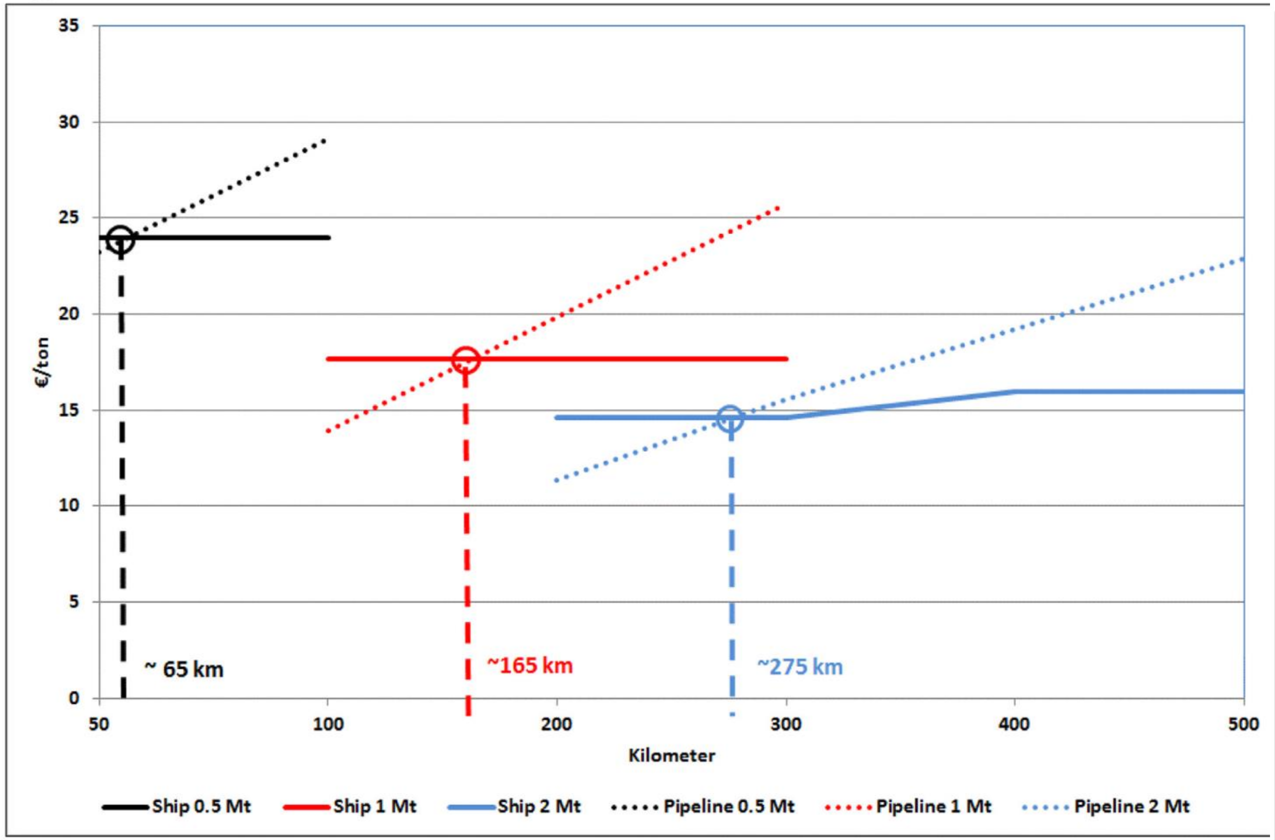
DAC – carbon engineering

- Challenge: Funding, FEED (250 ton/h)



CO_2 transport and storage - cost

a.



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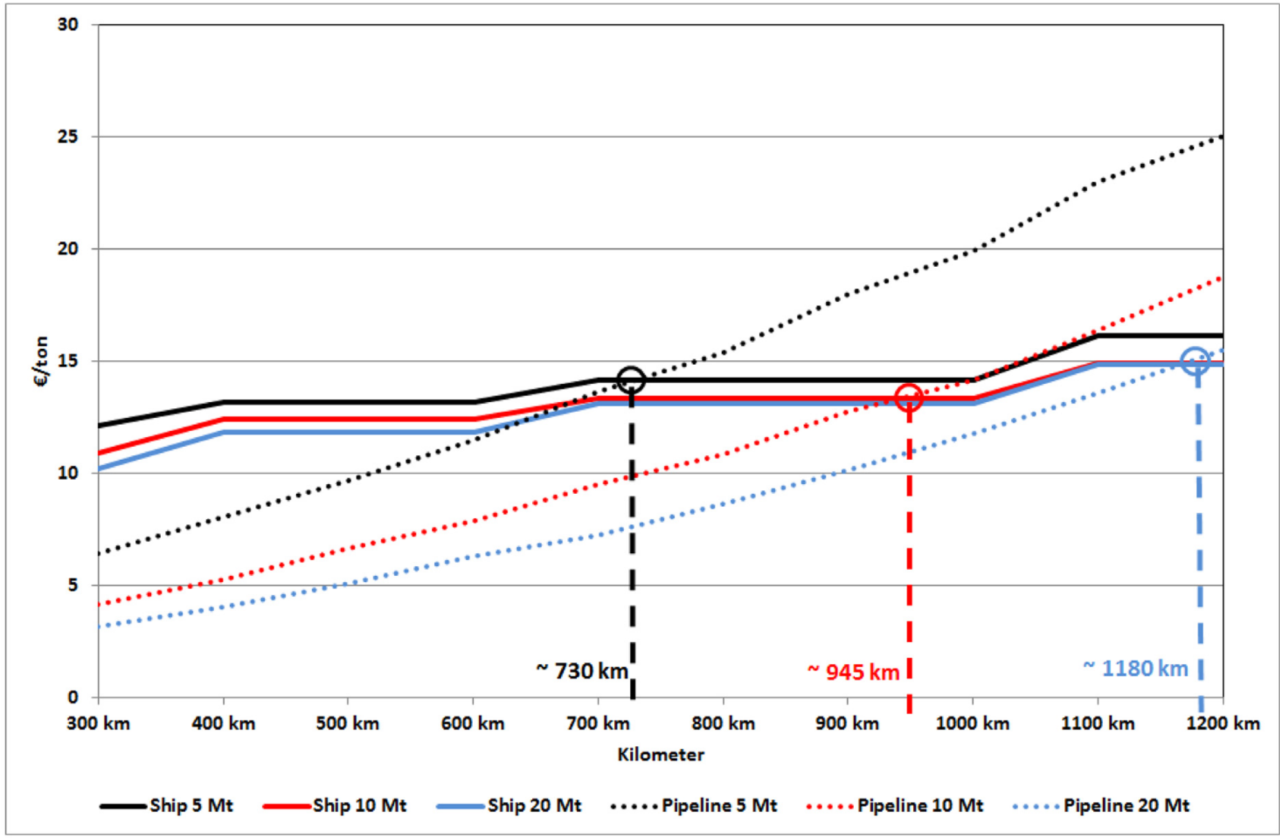
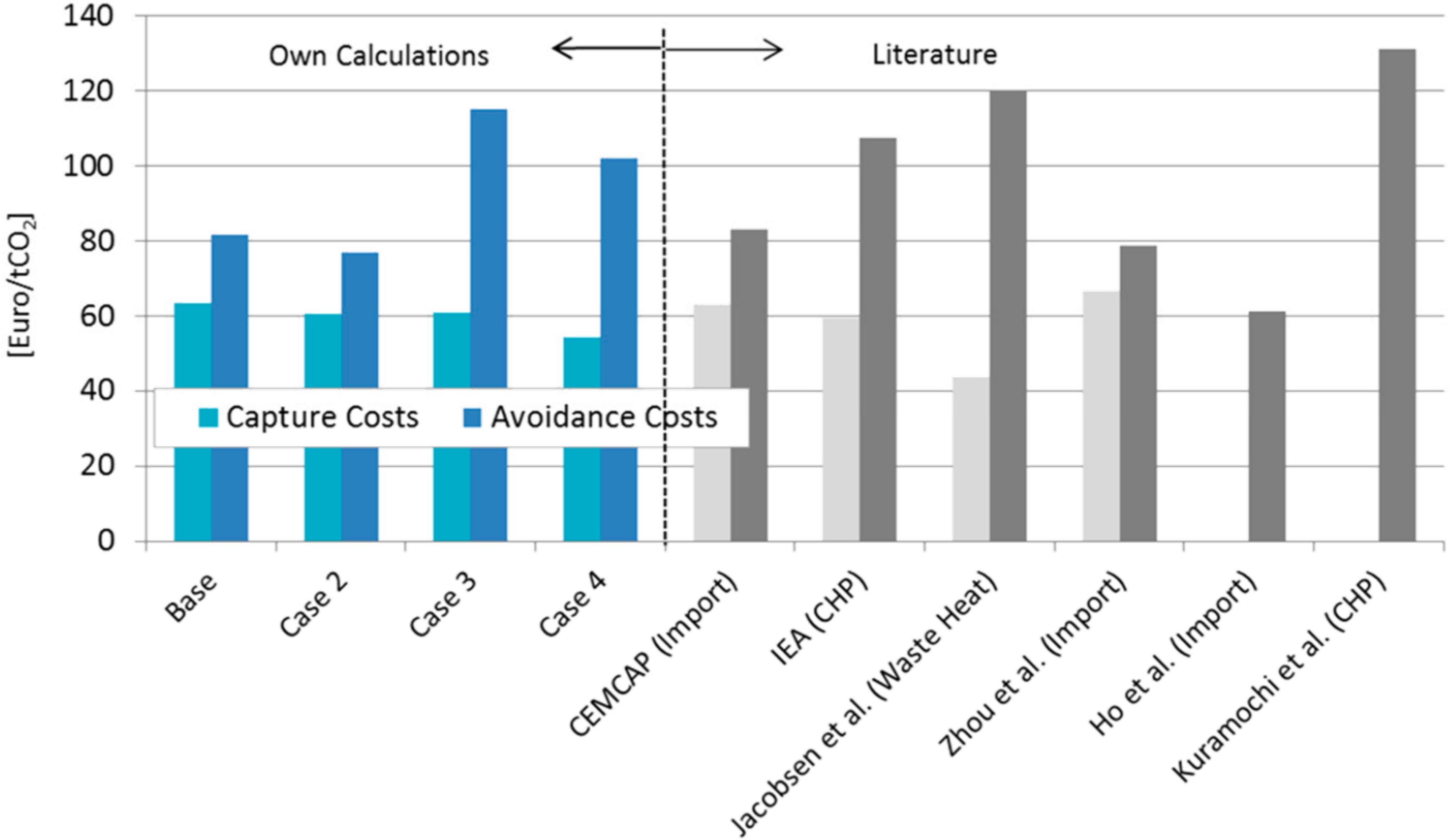


Cost of capture in the cement sector

- Typical emissions:
  - Fuel: 40%
  - Calcination: 60%

- Benchmark: 3.6GJ/ton
- Gas: 18% CO_2
- MEA base case

- Case 2-4 includes various interlinks to nearby boilers



Energies 12, 2432, 2019