


Carbon Capture: From dream to realization

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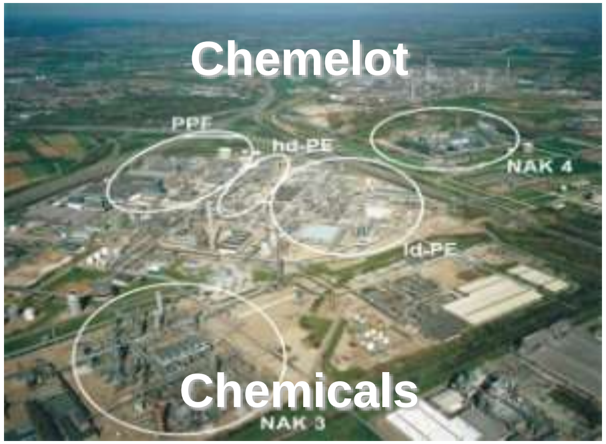
The Netherlands

The Netherlands



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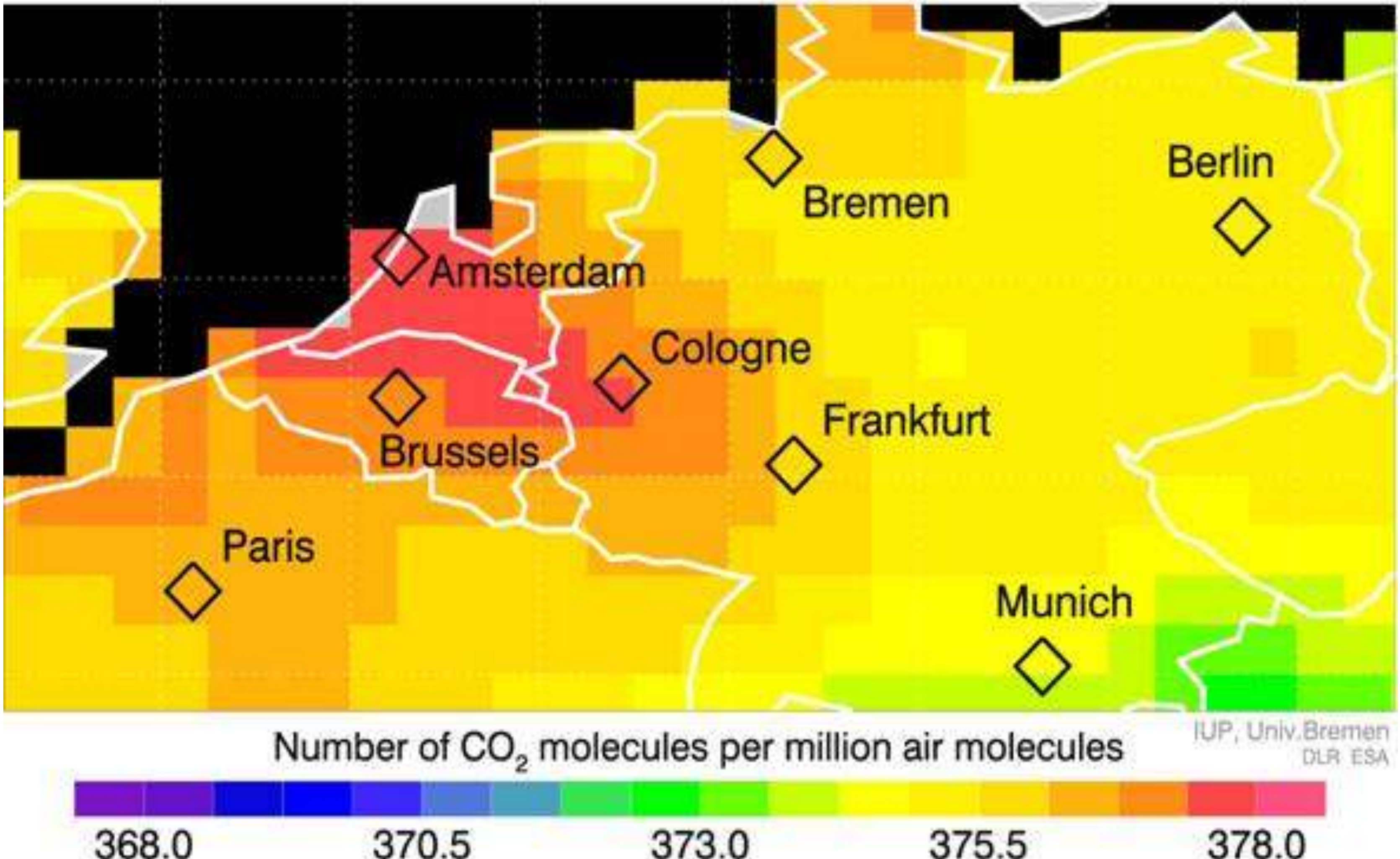
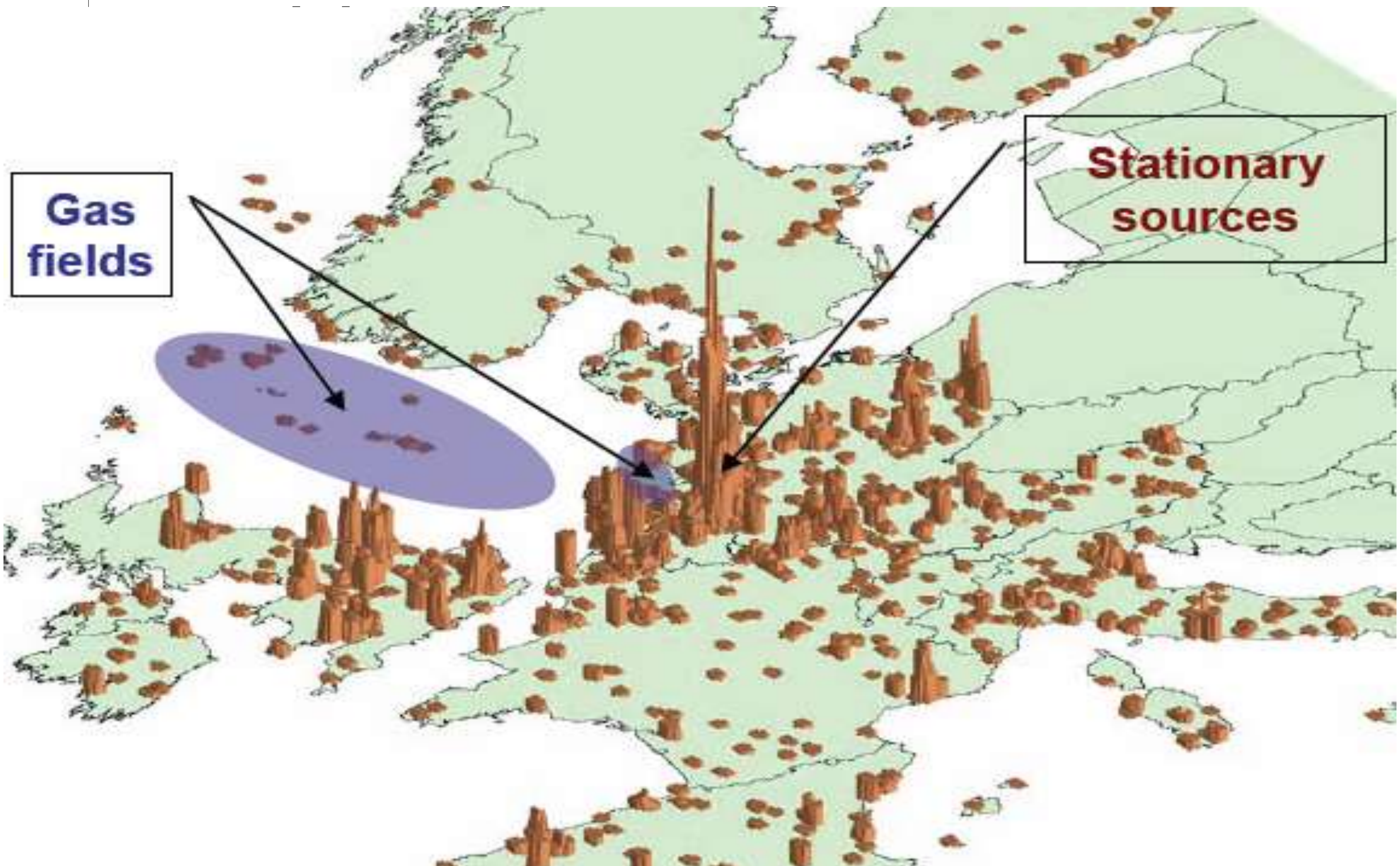
Carbon Dioxide SCIAMACHY/ENVISAT 2003-2005




Gas
fields
Stationary
sources

energy valley

Regional Implementation

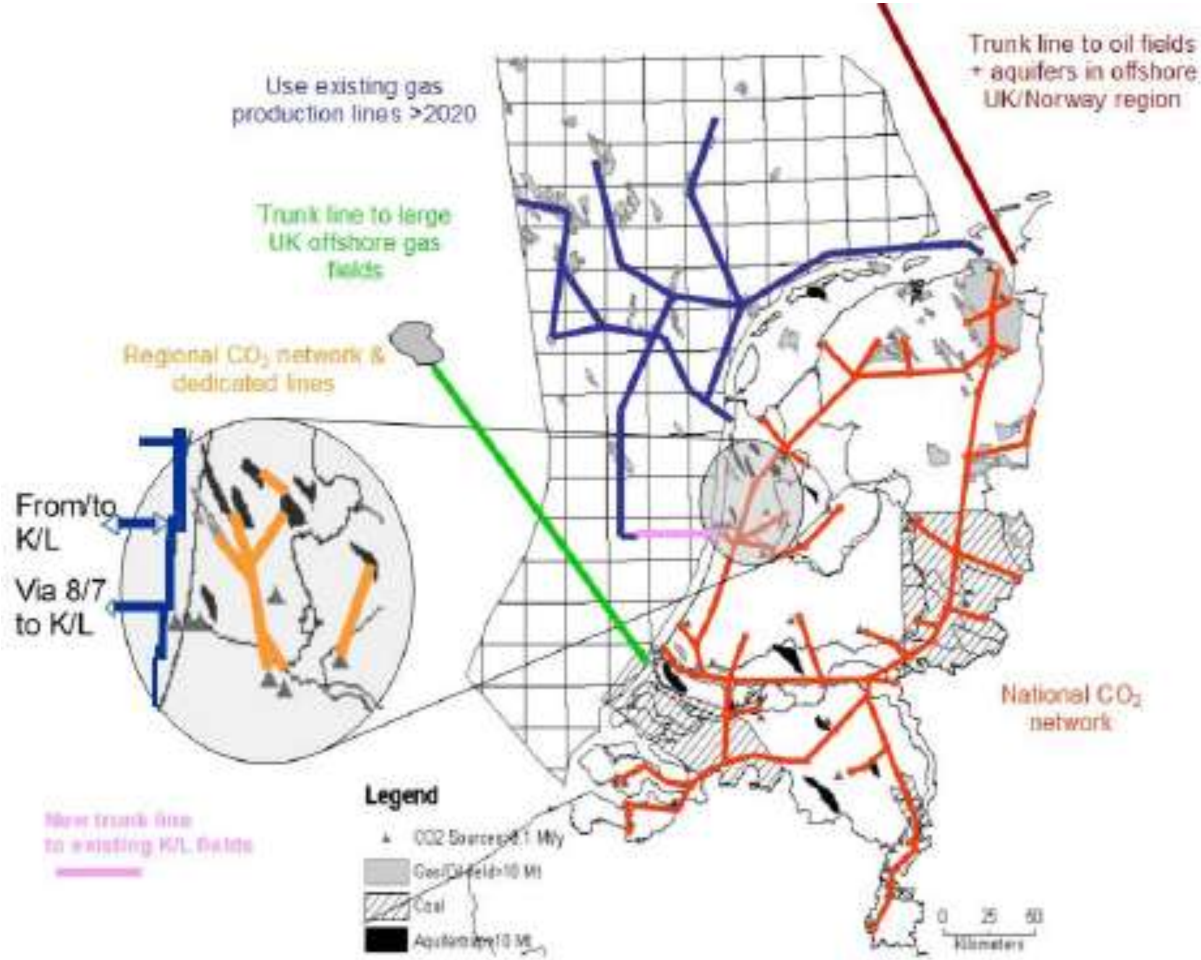
ROTTERDAM.CLIMATE.INITIATIVE

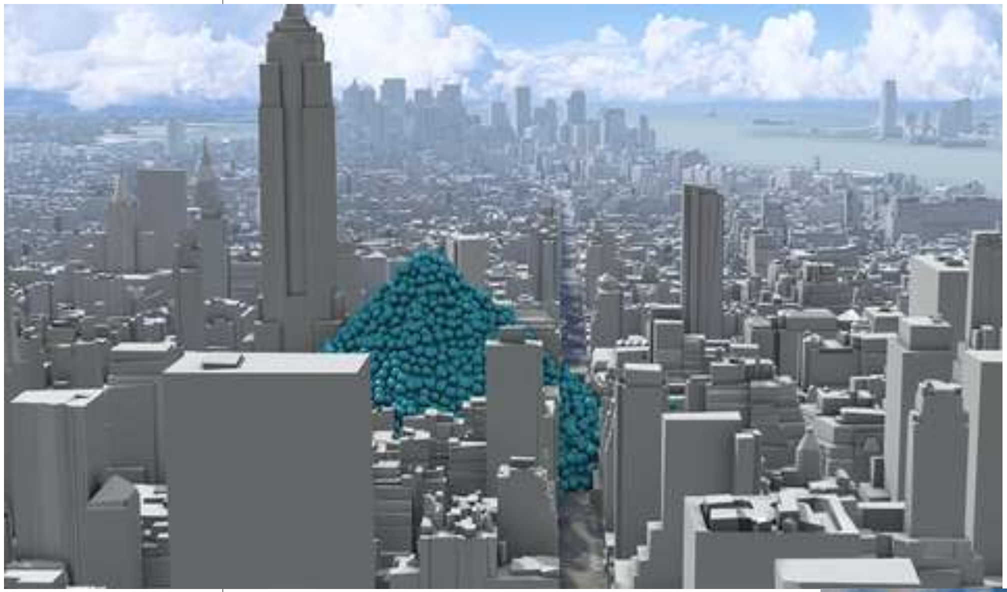
Regional Implementation

cato2

National R&D Support

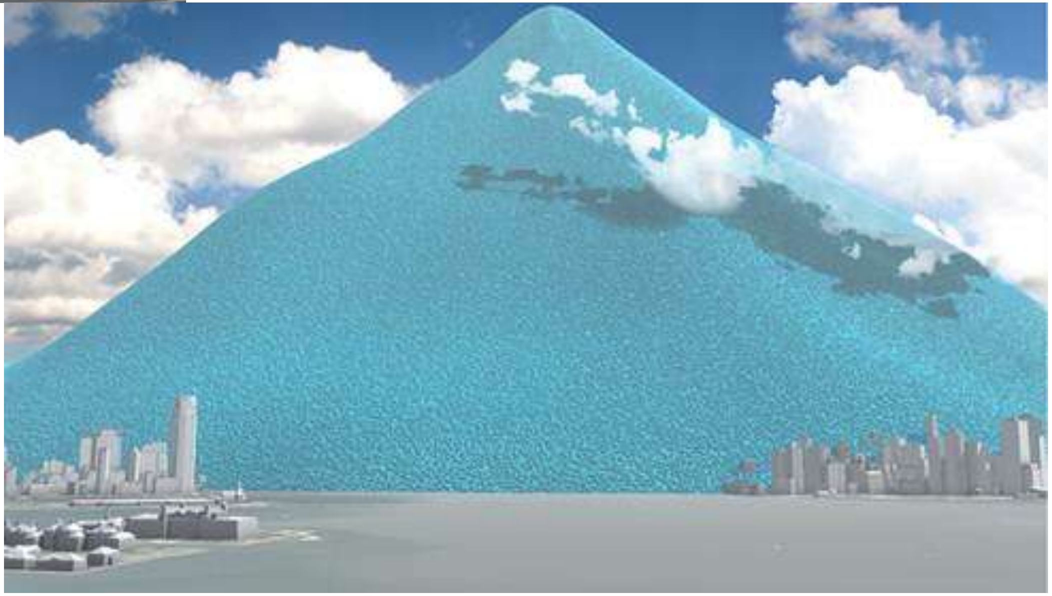
D


Use existing gas
production lines >2020
Trunk line to oil fields
+ aquifers in offshore
UK/Norway region
Trunk line to large
UK offshore gas
fields
From/to
K/L
Via 8/7
to K/L
National CO_2
network
New trunk line
to existing K/L fields
Legend
Coal



single hour's emissions from New York City: 6,204 one-metric-ton spheres (one sphere is 33 feet across).

a year's carbon dioxide emissions from New York City: 54,349,650 one-metric-ton spheres



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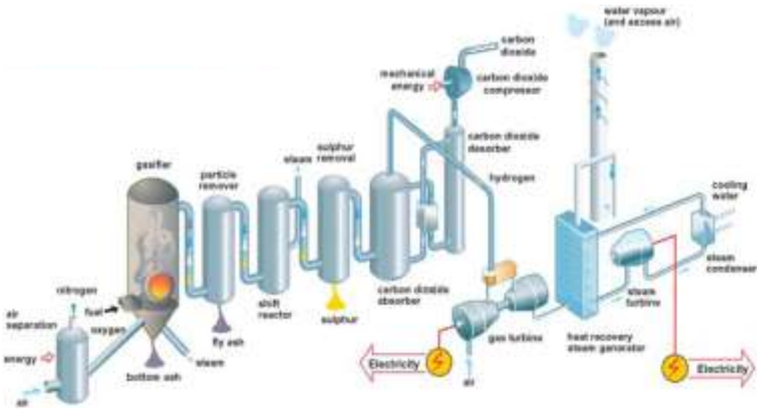
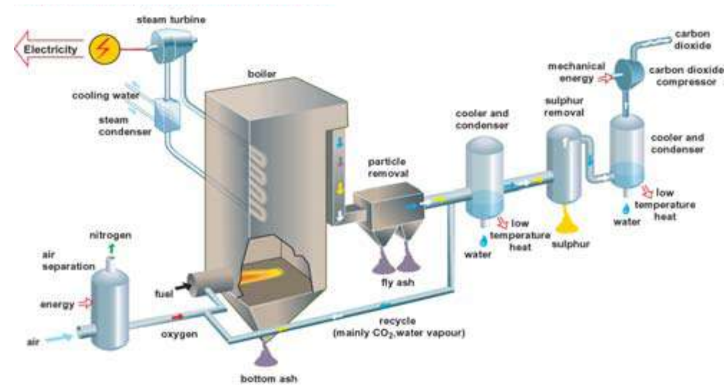
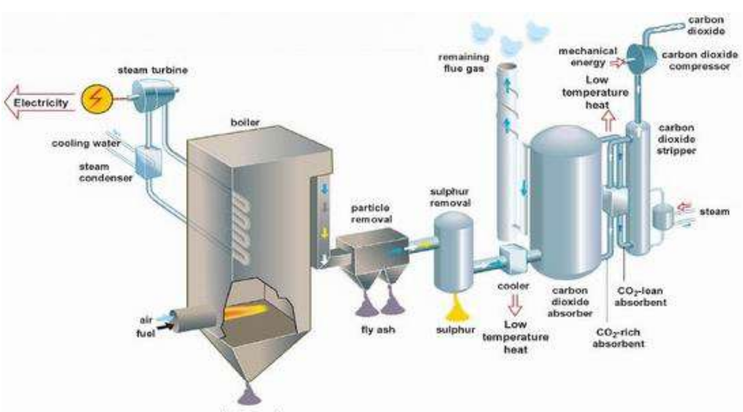


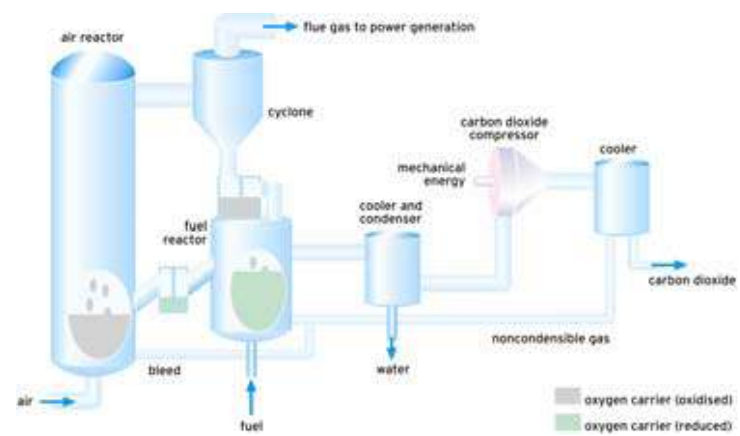
Pre-combustion capture: Capturing CO_2 before combustion



Oxyfuel: Burning with pure oxygen, separation of CO_2 after combustion



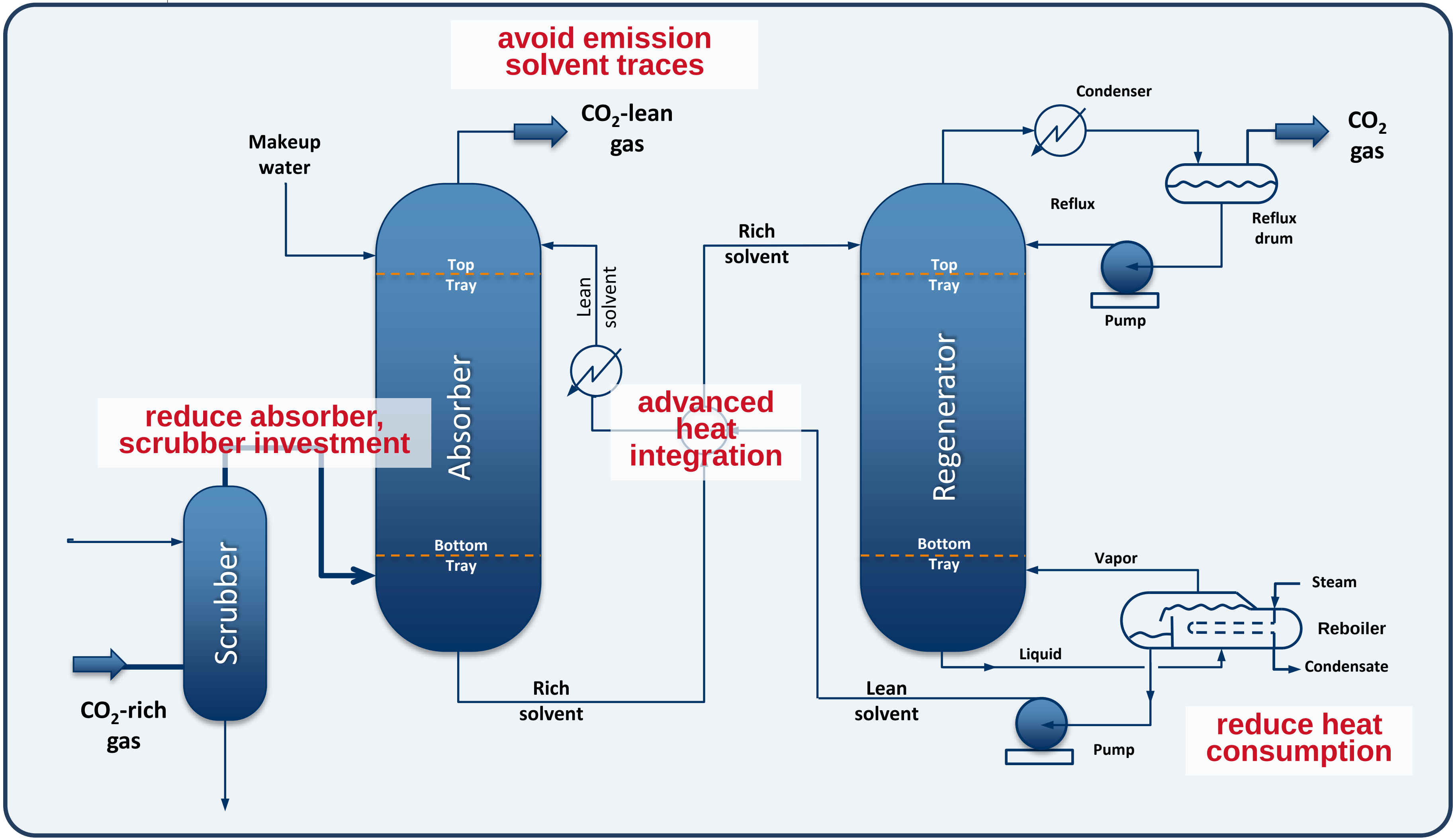
Post-combustion capture: Capturing CO_2 after combustion



Chemical looping: Using oxygen carrier particles for combustion

Courtesy of Vattenfall

Challenges Post-combustion Capture




Content

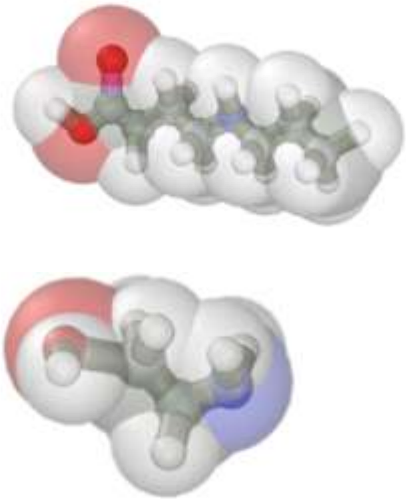
- Reduce OPEX
- Reduce CAPEX
- Reduce emissions

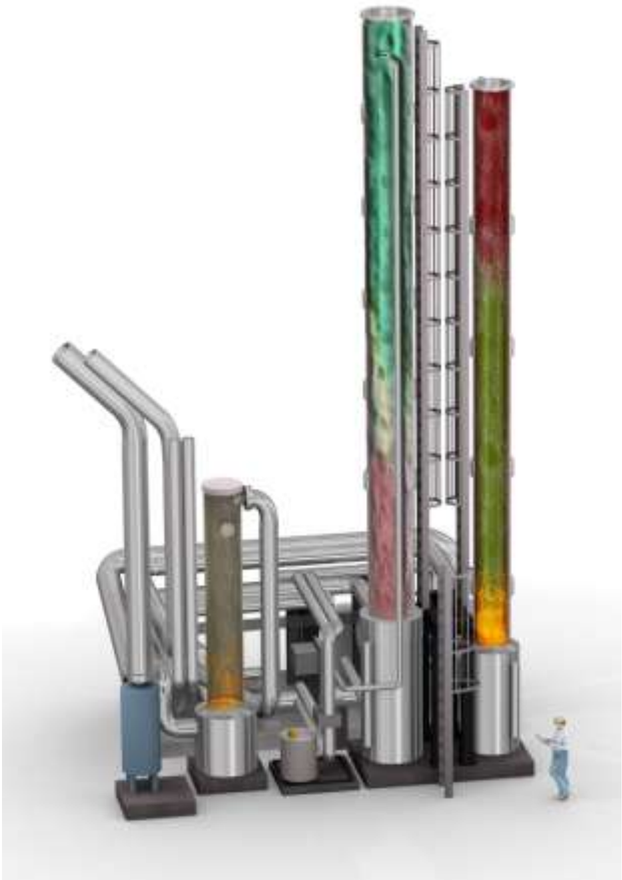
Realization


OPEX reduction

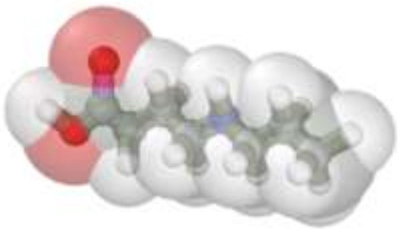
- Lower energy demands solvent regeneration
- Improved flow sheet
- Improved integration

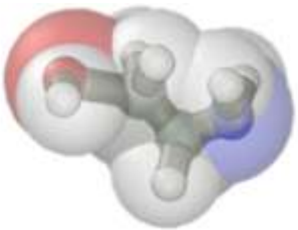
Lower energy demands solvent regeneration

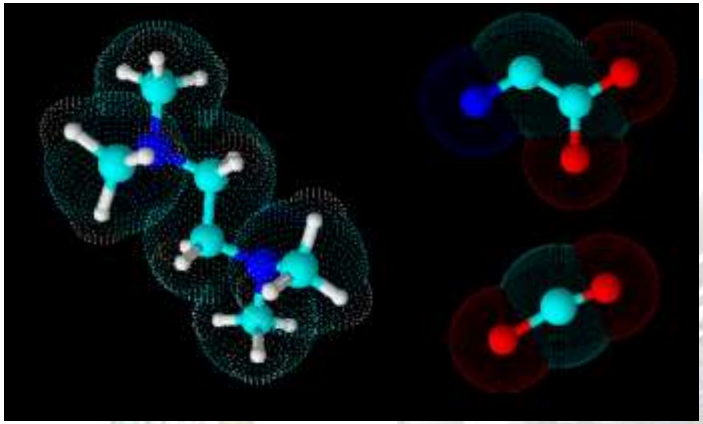




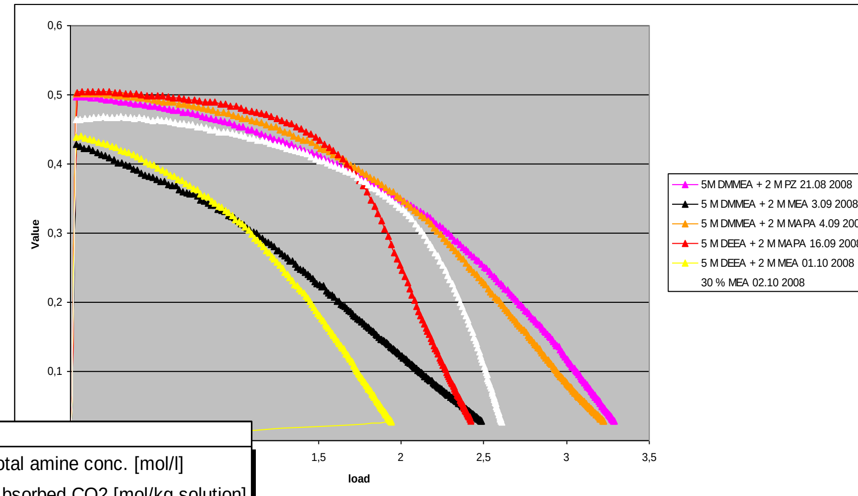
High throughput screening versus computational modelling

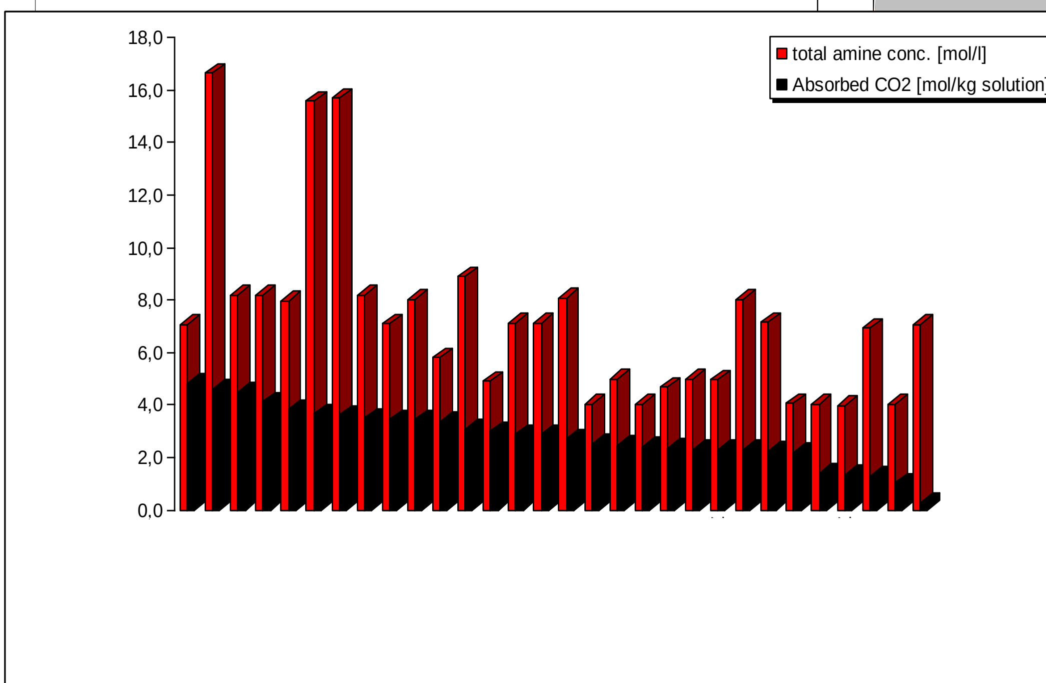




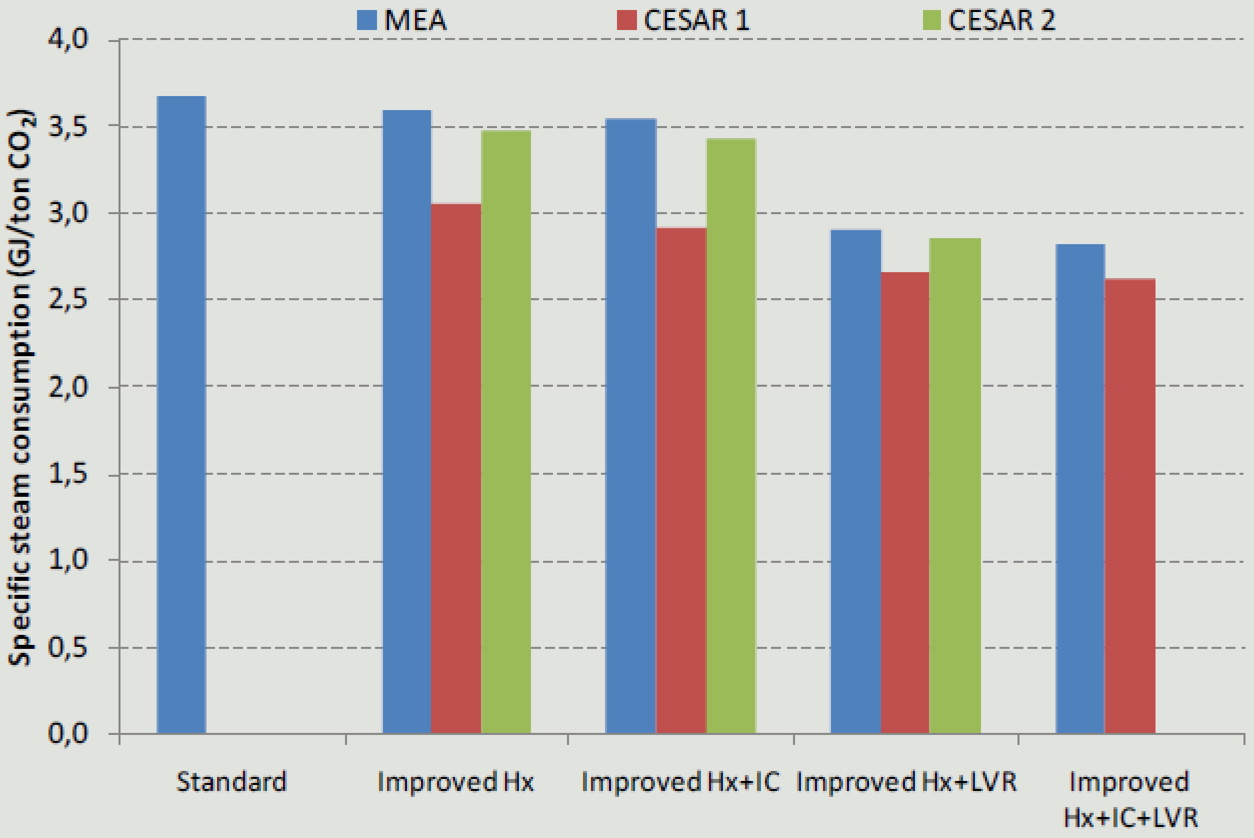


Screening tests based on molecular properties and experience





Conditions: Flue gas flow 5000 Nm³/h, Optimal L/G, CO_2 removal • 90% , Stripper pressure 1.85 bara



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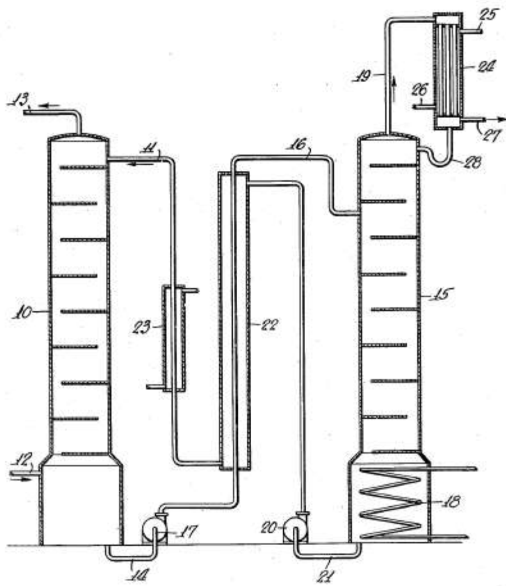
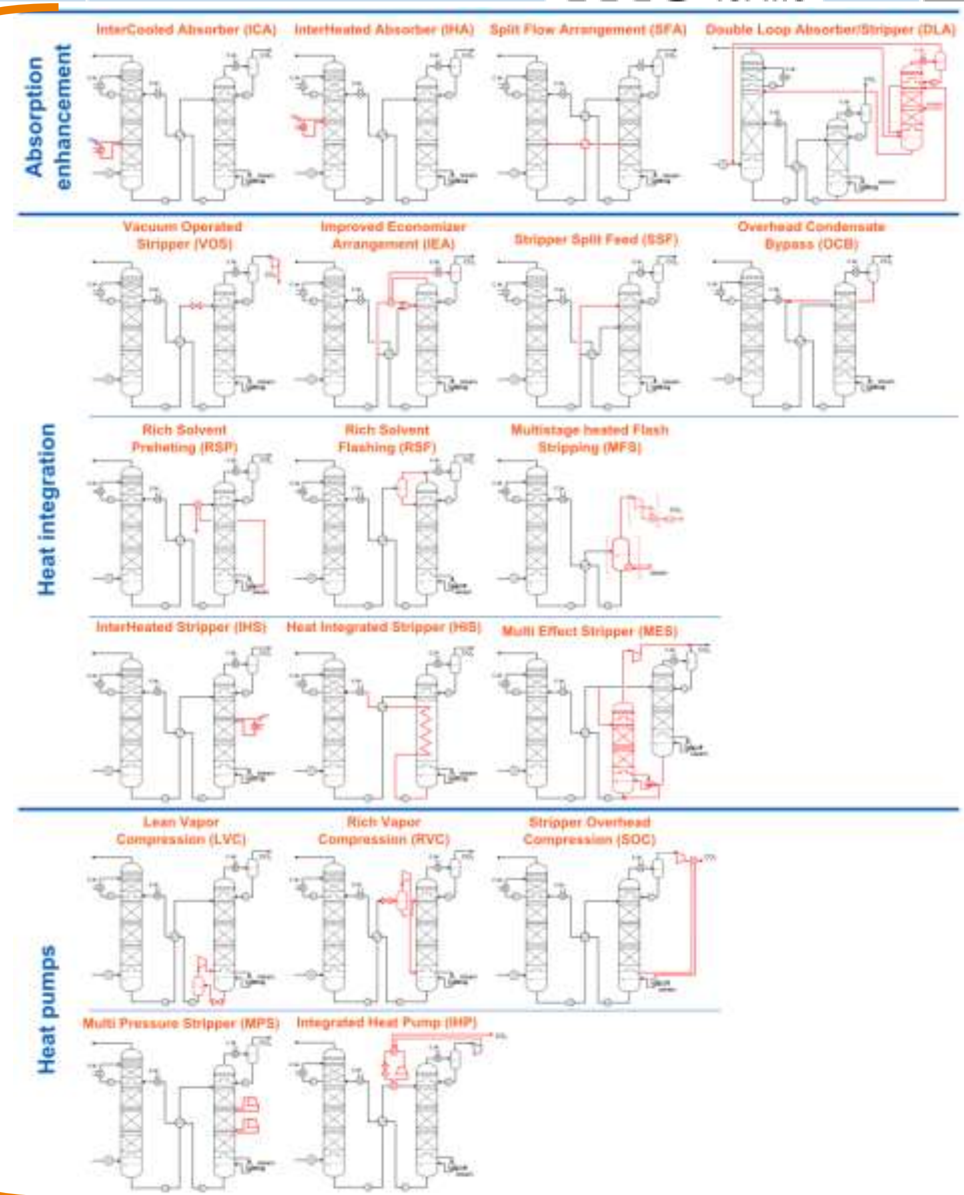
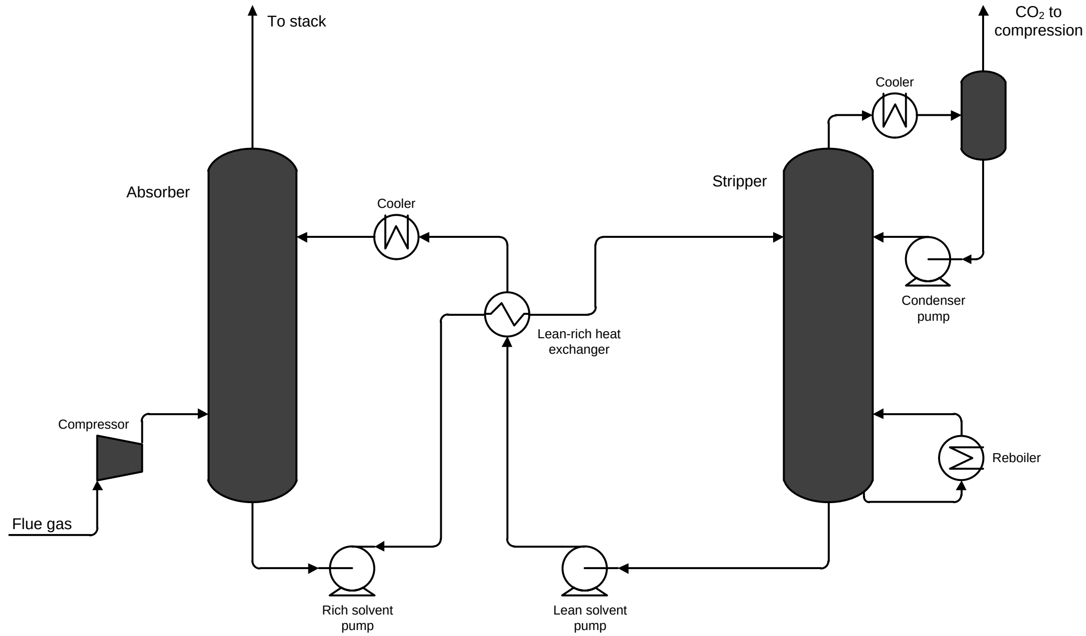
Process





Capture plant: Base Case



Reboiler duty	**Heat Exchangers (HEX)**	**HEX total specific UA** [a]	**Cooling duty**
[GJ_{th}/ton CO_2]	[number]	[(GJ_{th}/K)/ton CO_2]	[GJ_{th}/ton CO_2]
3.54	1	0.62	4.57

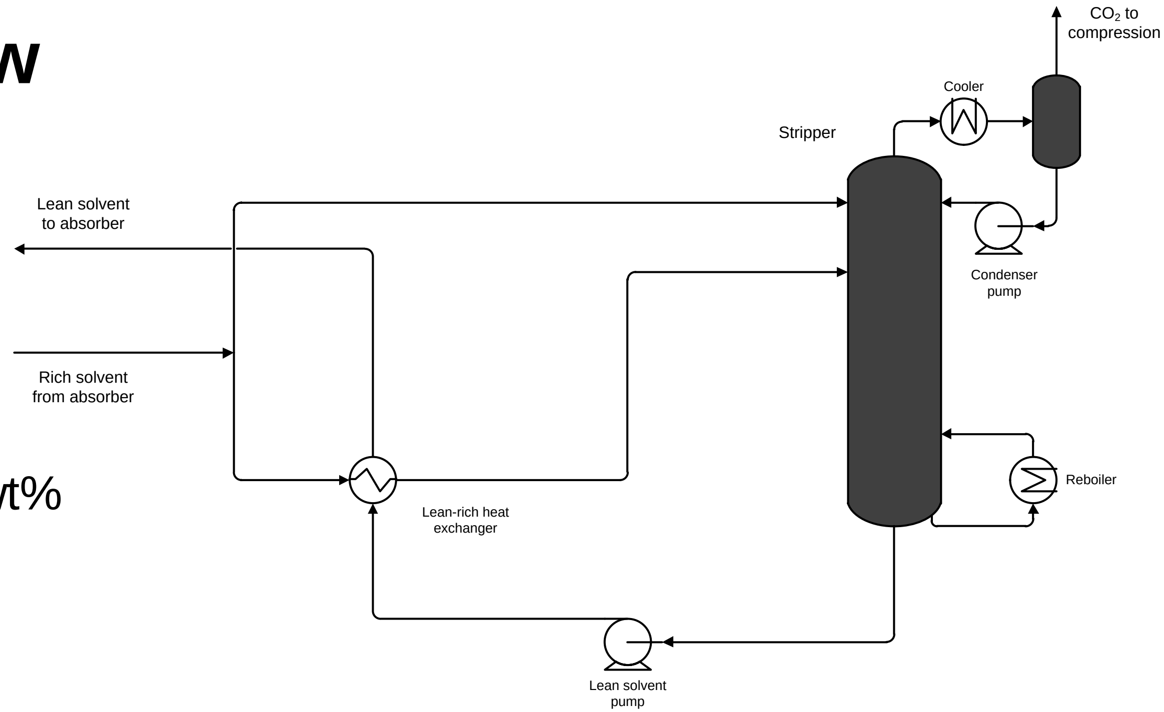
Electricity use

Capture	**Compression**	**Total**	**Total including reboiler** [b]
[GJ_e/ton CO_2]	[GJ_e/ton CO_2]	[GJ_e/ton CO_2]	[GJ_e/ton CO_2]
0.09	0.32	0.41	1.29

[a] U is the overall heat transfer coefficient; A is the contact area in the heat exchanger. If U is considered constant, UA is proportional to the contact area.

[b] Assuming 1 GJ_e = 4 GJ_{th}


Split flow



Split flow: 8wt%

Reboiler duty	Heat Exchangers (HEX)	HEX total specific UA [a]	Cooling duty
[GJ_{th}/ton CO_2]	[number]	[(GJ_{th}/K)/ton CO_2]	[GJ_{th}/ton CO_2]
3.40	1	0.95	4.44

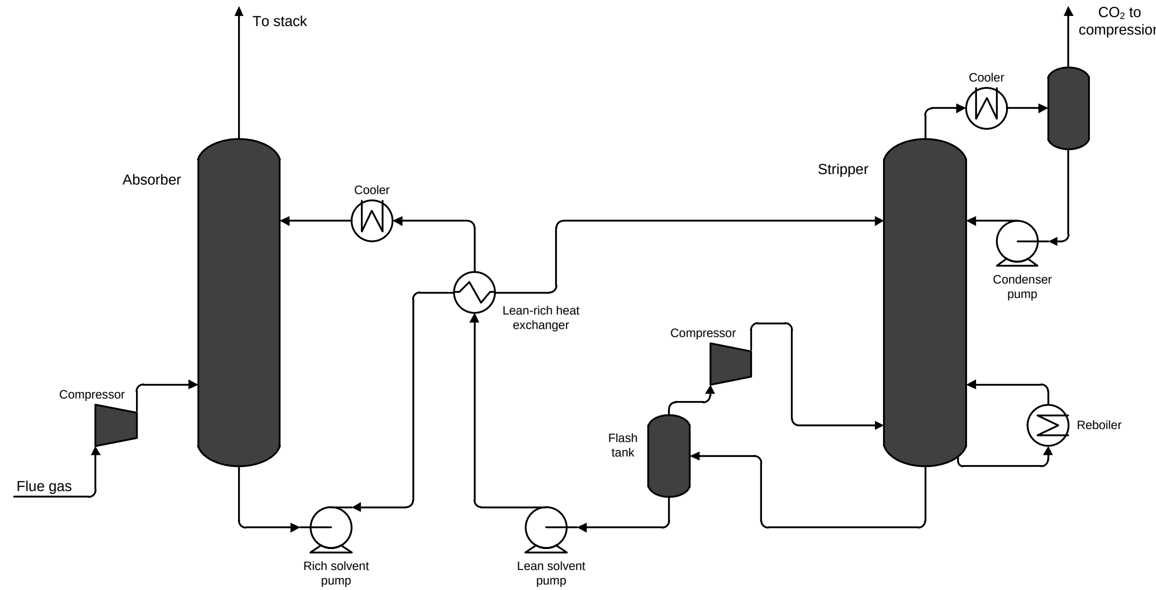
Electricity use

Capture	Compression	Total	Total including reboiler [b]
[GJ_e/ton CO_2]	[GJ_e/ton CO_2]	[GJ_e/ton CO_2]	[GJ_e/ton CO_2]
0.09	0.32	0.41	1.26

[a] U is the overall heat transfer coefficient; A is the contact area in the heat exchanger. If U is considered constant, UA is proportional to the contact area.

[b] Assuming 1 GJ_e = 4 GJ_{th}

Lean vapour compression (LVC)



Reboiler duty	Heat Exchangers (HEX)	HEX total specific UA [a]	Cooling duty
[GJ_{th}/ton CO_2]	[number]	[(GJ_{th}/K)/ton CO_2]	[GJ_{th}/ton CO_2]
3.07	1	0.53	3.96

Electricity use

Capture [b]	Compression	Total	Total including reboiler [c]
[GJ_e/ton CO_2]	[GJ_e/ton CO_2]	[GJ_e/ton CO_2]	[GJ_e/ton CO_2]
0.13	0.32	0.45	1.21

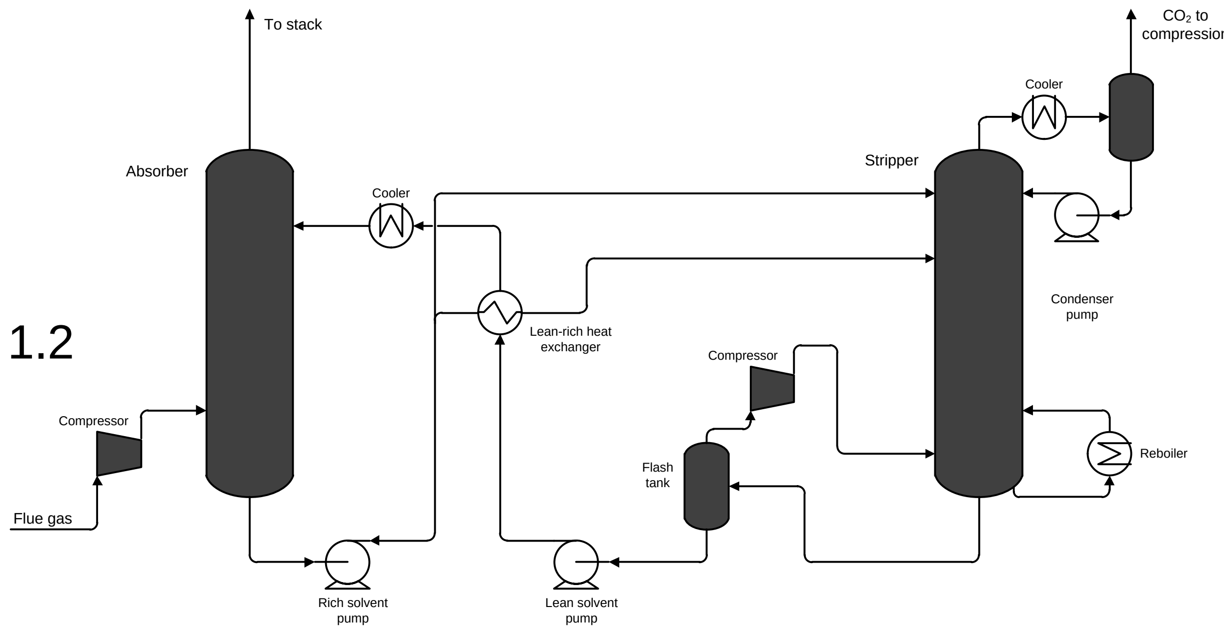
[a] U is the overall heat transfer coefficient; A is the contact area in the heat exchanger. If U is considered constant, UA is proportional to the contact area.

[b] For this case, the electricity use for capture also includes the LVC compressor.

[c] Assuming 1 GJ_e = 4 GJ_{th}

Lean vapour compression and split flow

Split flow: 8wt%
Flash pressure: 1.2



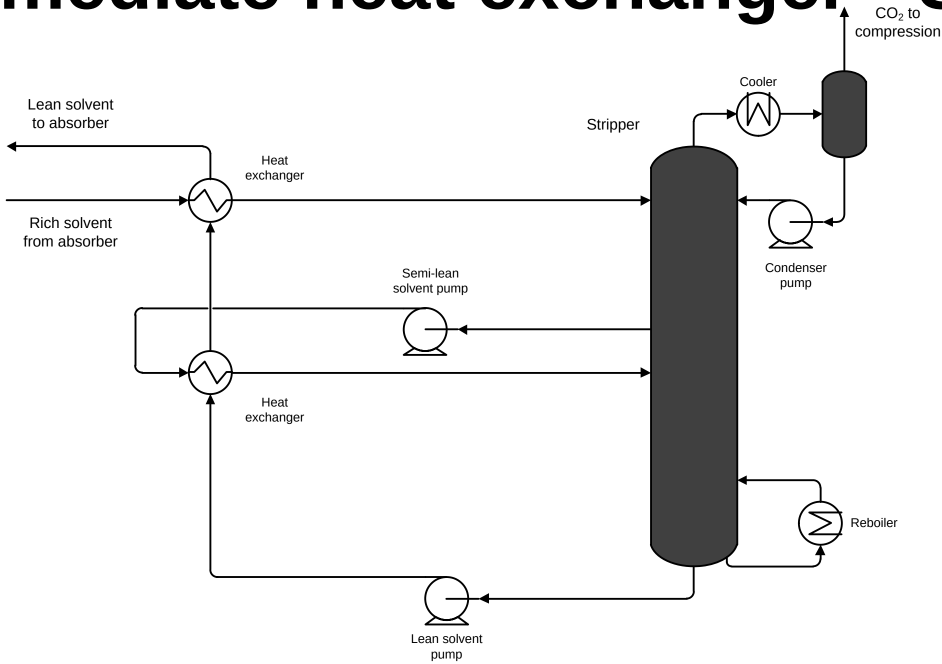
Reboiler duty	Heat Exchangers (HEX)	HEX total specific UA [a]	Cooling duty
[GJ_{th}/ton CO_2]	[number]	[(GJ_{th}/K)/ton CO_2]	[GJ_{th}/ton CO_2]
2.94	1	0.74	4.16

Electricity use

Capture [b]	Compression	Total	Total including reboiler [c]
[GJ_e/ton CO_2]	[GJ_e/ton CO_2]	[GJ_e/ton CO_2]	[GJ_e/ton CO_2]
0.13	0.32	0.45	1.18

[a] U is the overall heat transfer coefficient; A is the contact area in the heat exchanger. If U is considered constant, UA is proportional to the contact area.
[b] For this case, the electricity use for capture also includes the LVC compressor.
[c] Assuming 1 GJ_e = 4 GJ_{th}

Intermediate heat exchanger - Stripper



Reboiler duty	**Heat Exchangers (HEX)**	**HEX total specific UA** [a]	**Cooling duty**
[GJ_{th}/ton CO_2]	[number]	[(GJ_{th}/K)/ton CO_2]	[GJ_{th}/ton CO_2]
3.18	2	0.66	4.22

Electricity use

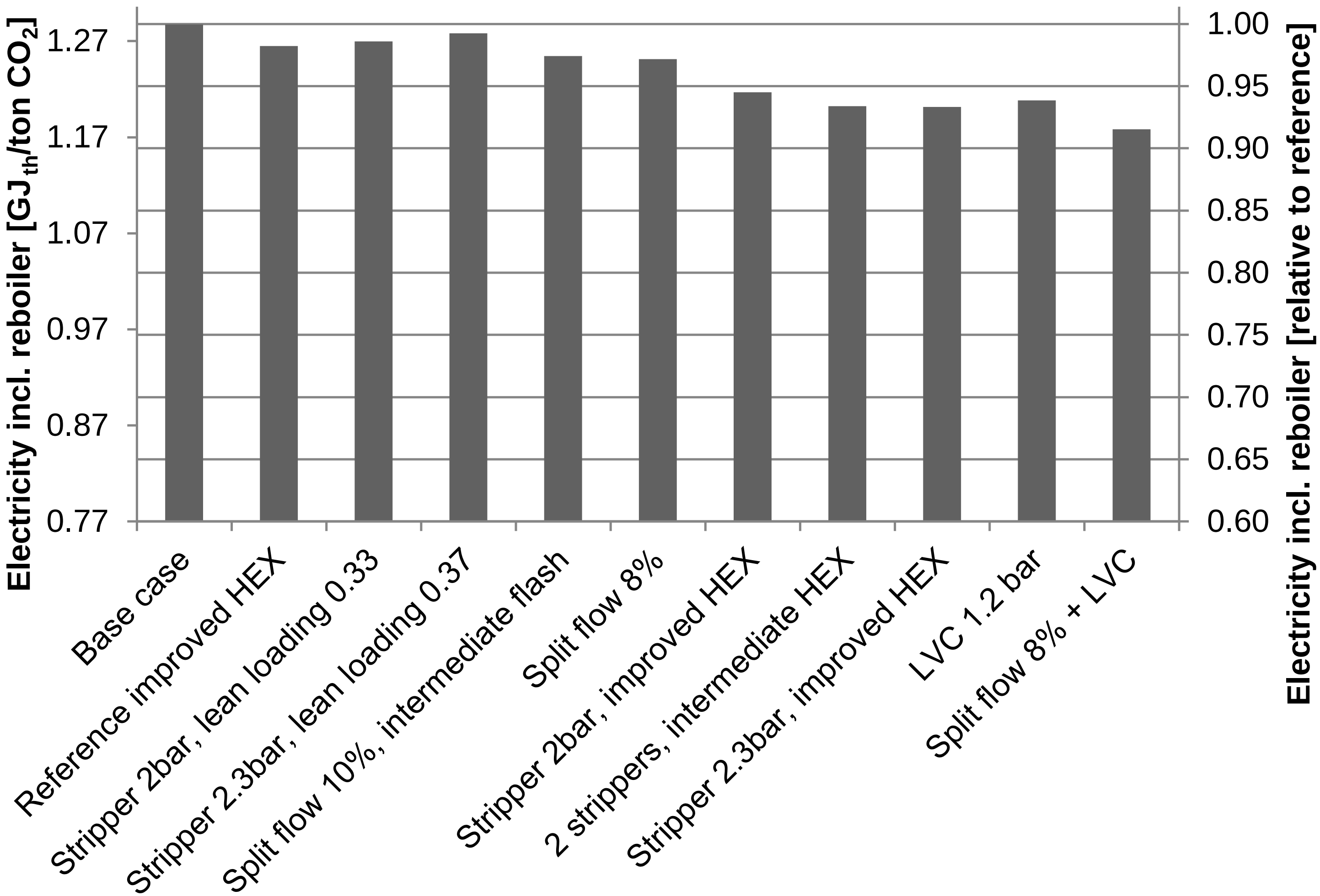
Capture [b]	**Compression**	**Total**	**Total including reboiler** [c]
[GJ_e/ton CO_2]	[GJ_e/ton CO_2]	[GJ_e/ton CO_2]	[GJ_e/ton CO_2]
0.10	0.32	0.41	1.21

[a] U is the overall heat transfer coefficient; A is the contact area in the heat exchanger. If U is considered constant, UA is proportional to the contact area. The UA is the sum of the two HEX used.

[b] For this case, the electricity use for capture also includes the extra semi -lean pump.

[c] Assuming 1 GJ_e = 4 GJ_{th}

Overview Capture Plant (2)



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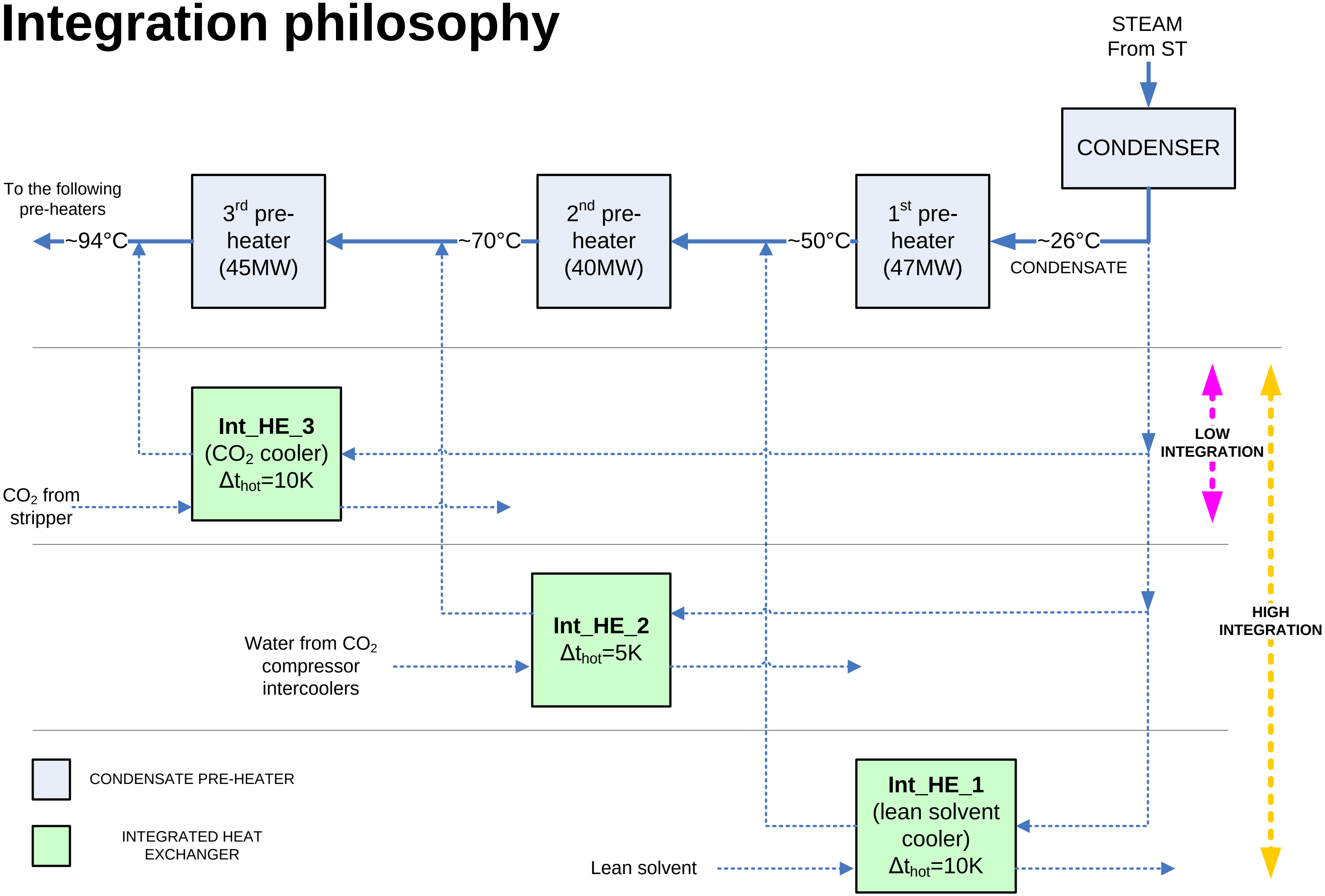
Integration philosophy



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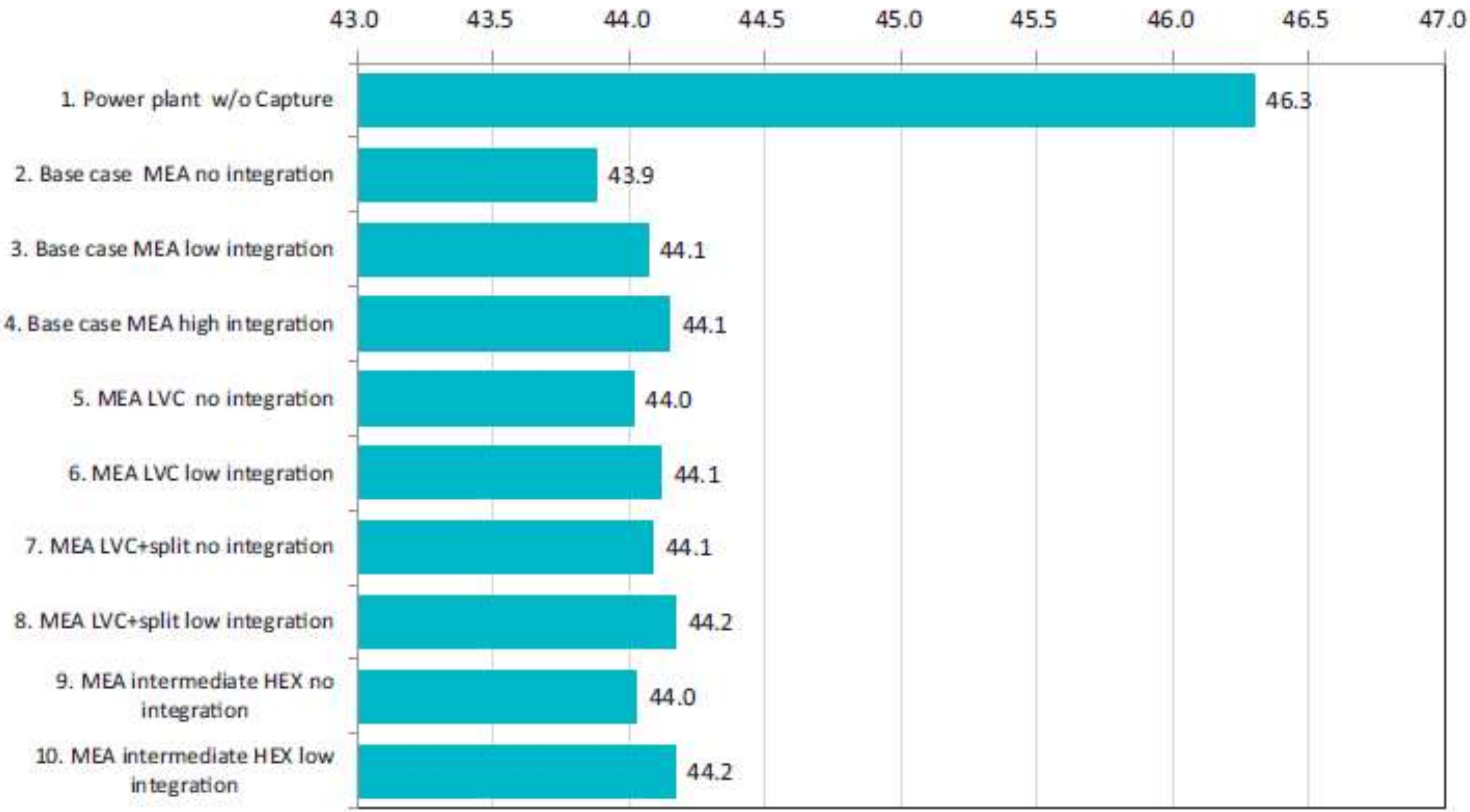


Emission reduction

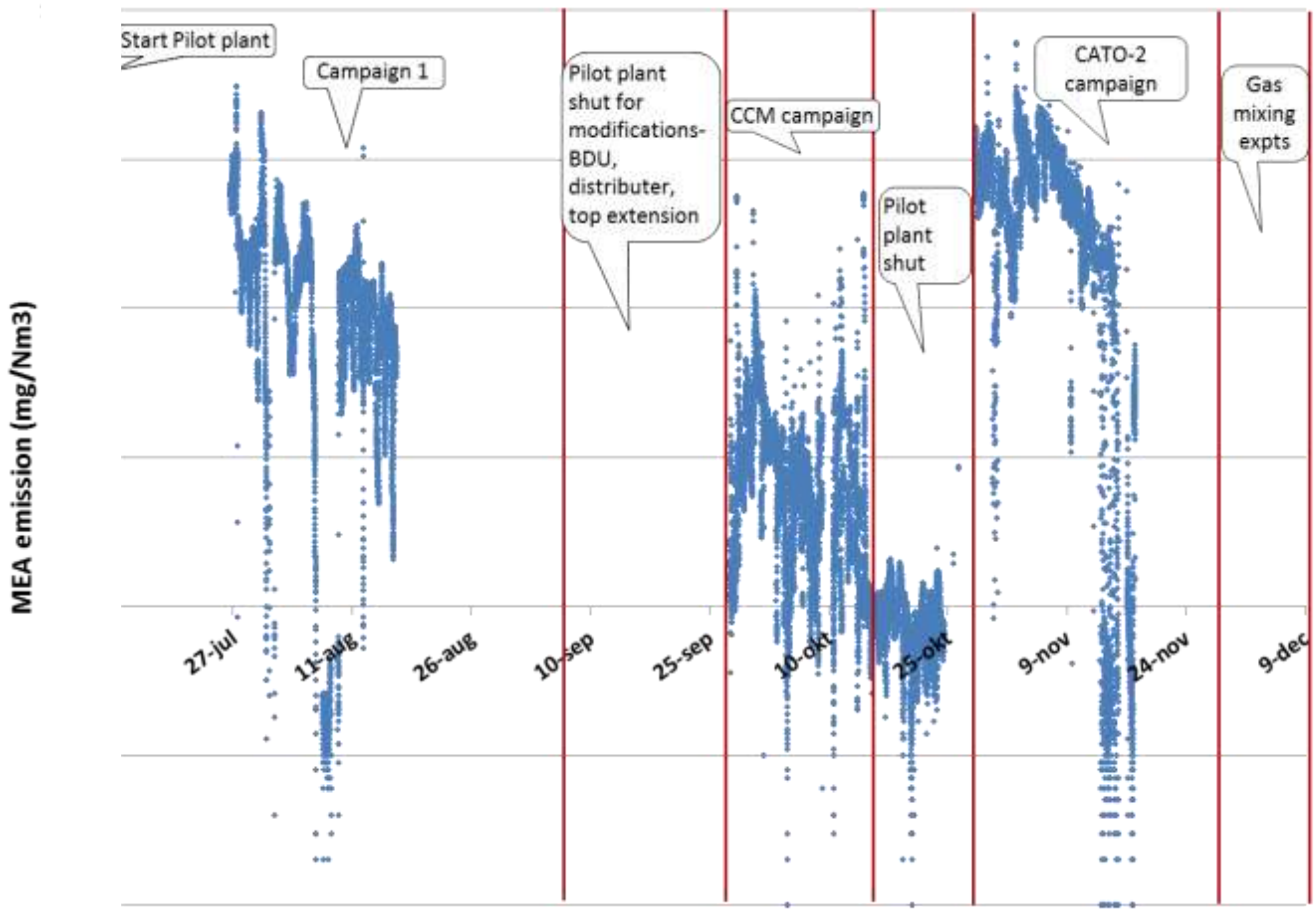
- Aerosol formation
- Mechanical entrainment
- Nitrosamine


TNO's pilot plant at the Maasvlakte

Capacity:
250 kg CO2//hr
1000 Nm3 /hr flue gas

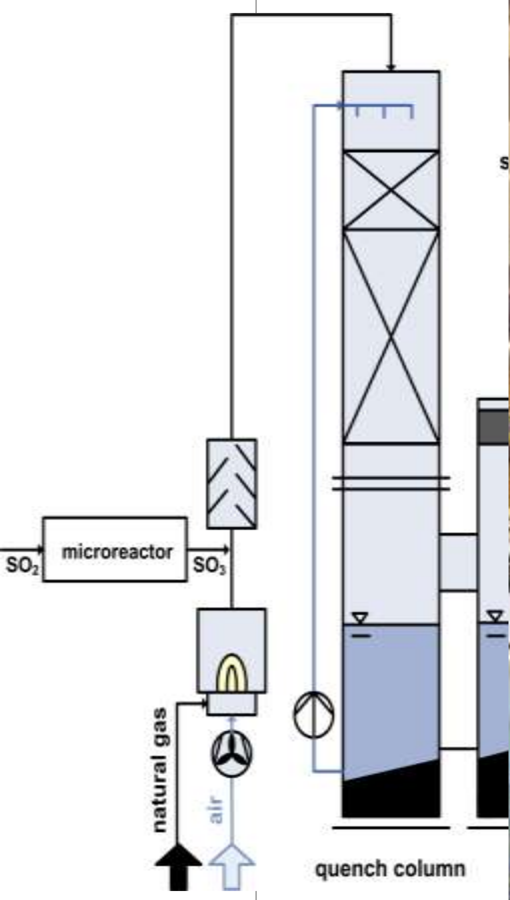
Connected to the COAL fired powerplant of E.ON

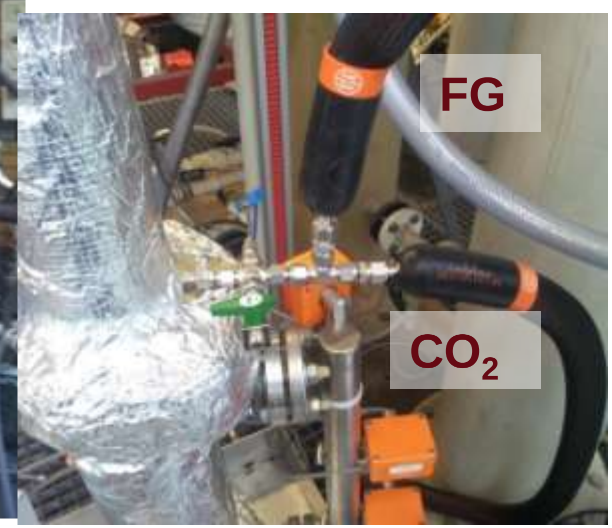
Pilot campaign 2011



Significant emission observed much more than expected based on simulation and previous experience

Test Equipment





Collaboration with Karlsruhe Institute of technology, Laborelec, E.on

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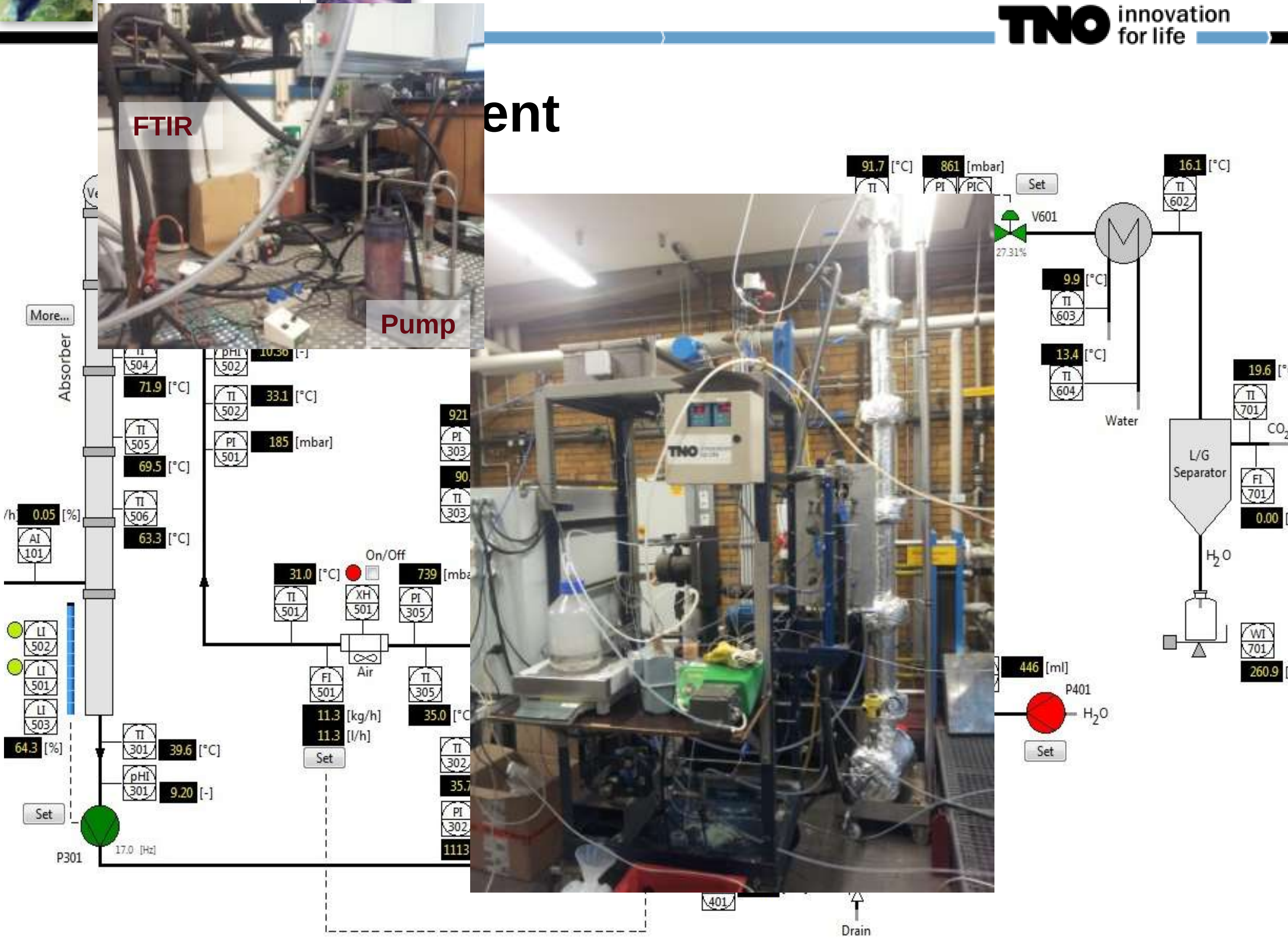
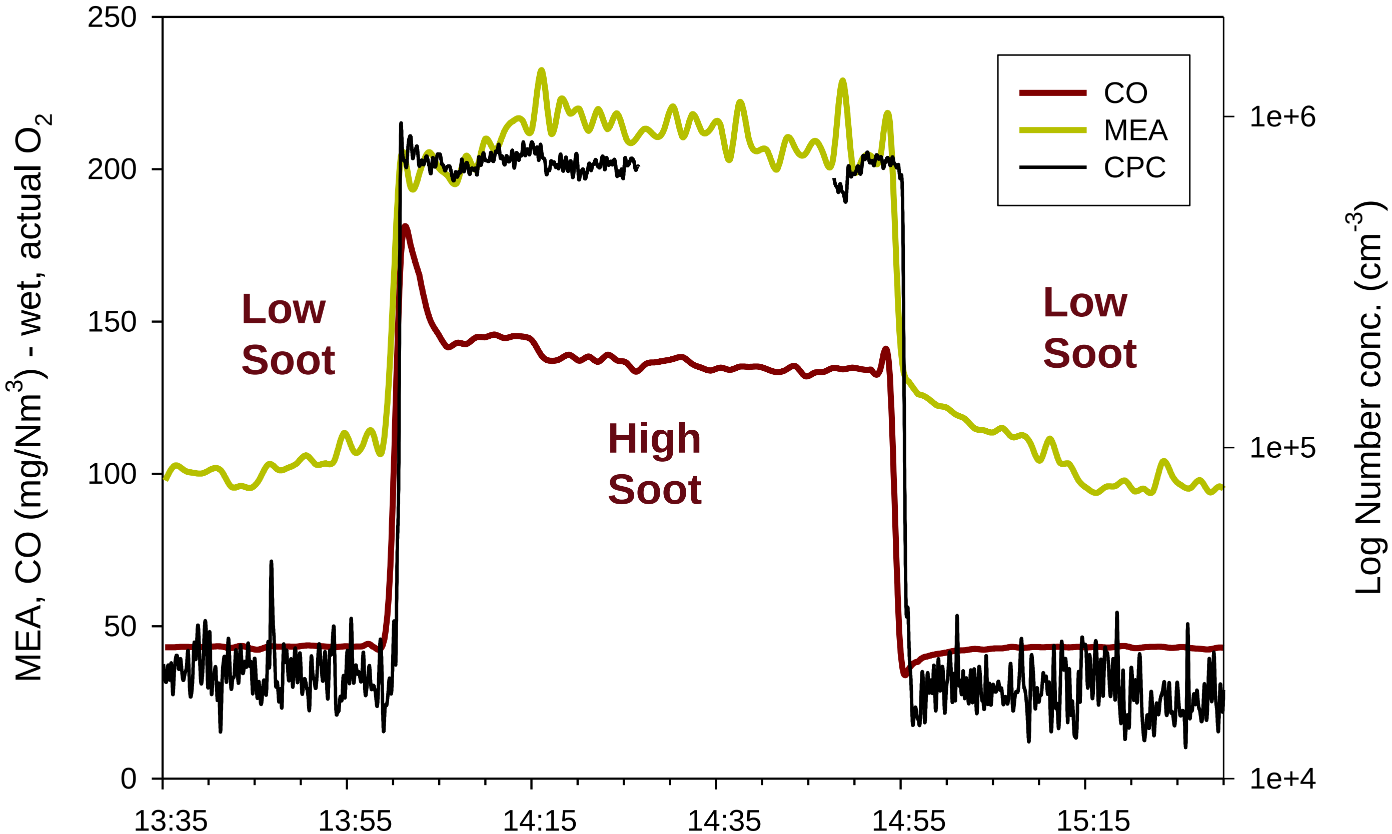


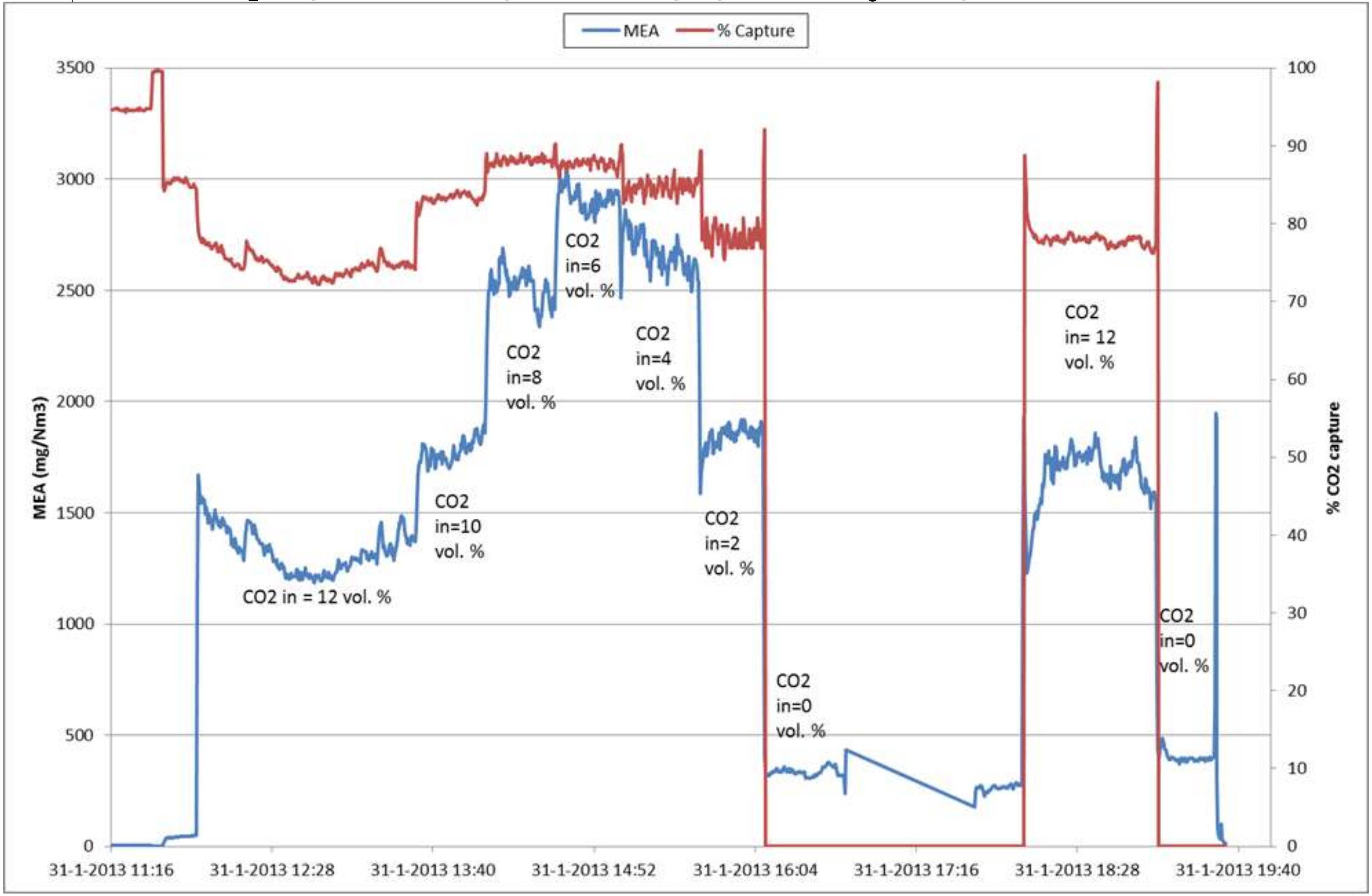
Effect of soot



Air +12 % CO_2 → MEA ~40-50 mg/Nm^3

Effect of capture plant parameters

Effect of CO_2/ capture rate/temperature bulge (Middle SO_3 conc.)



Nitrosamine

Emission results (gas fired conditions)

In BDU Gas conc.	**MEA**		**86,6**	**128,8**	**156,9**	**173,2**	**86,1**	**158,6**	**145,7**	**176,7**	**255,7**
	NDELA	**ng/Nm^3 dry gas**		**13,5**				**11,0**	**28,1**	**47,0**	
	NDMA			**7,3**					**9,9**	**8,3**	
	NMOR			**4,8**				**6,9**	**36,3**	**22,0**	
Out BDU Gas conc.	**MEA**	**mg/Nm^3 dry gas**	**1,2**	**1,0**	**1,2**	**2,1**	**4,4**	**1,3**	**1,9**	**4,0**	
	NDELA	**ng/Nm^3 dry gas**		**16,3**						**20,5**	
	NDMA			**6,5**						**11,1**	
	NMOR			**2,4**						**4,0**	

Nitrosamine content in the order of 10 ng/m3
NDELA is partly present in aerosols

Measurements performed at TNO's pilot plant
Analysis performed by SINTEF

Nitrosamine from post combustion capture plant → implications

Typically, treated flue gas will be emitted via stacks (> 150 meter height)

Dispersion factor 500.000 to 1.000.000

Concentration NA capture plant will be in order of 10^{-13} to 10^{-14} g/Nm3

NDMA recommended maximum limit is in the order 10^{-11} g/Nm3

Caveat is amine degradation in the air

Carbon capture:

from dream

<u>via demonstration</u>

to realization

Demonstration activities within OCTAVIUS

TNO pilot plant / 0.25 tCO_2/h
(Maasvlakte- NL)

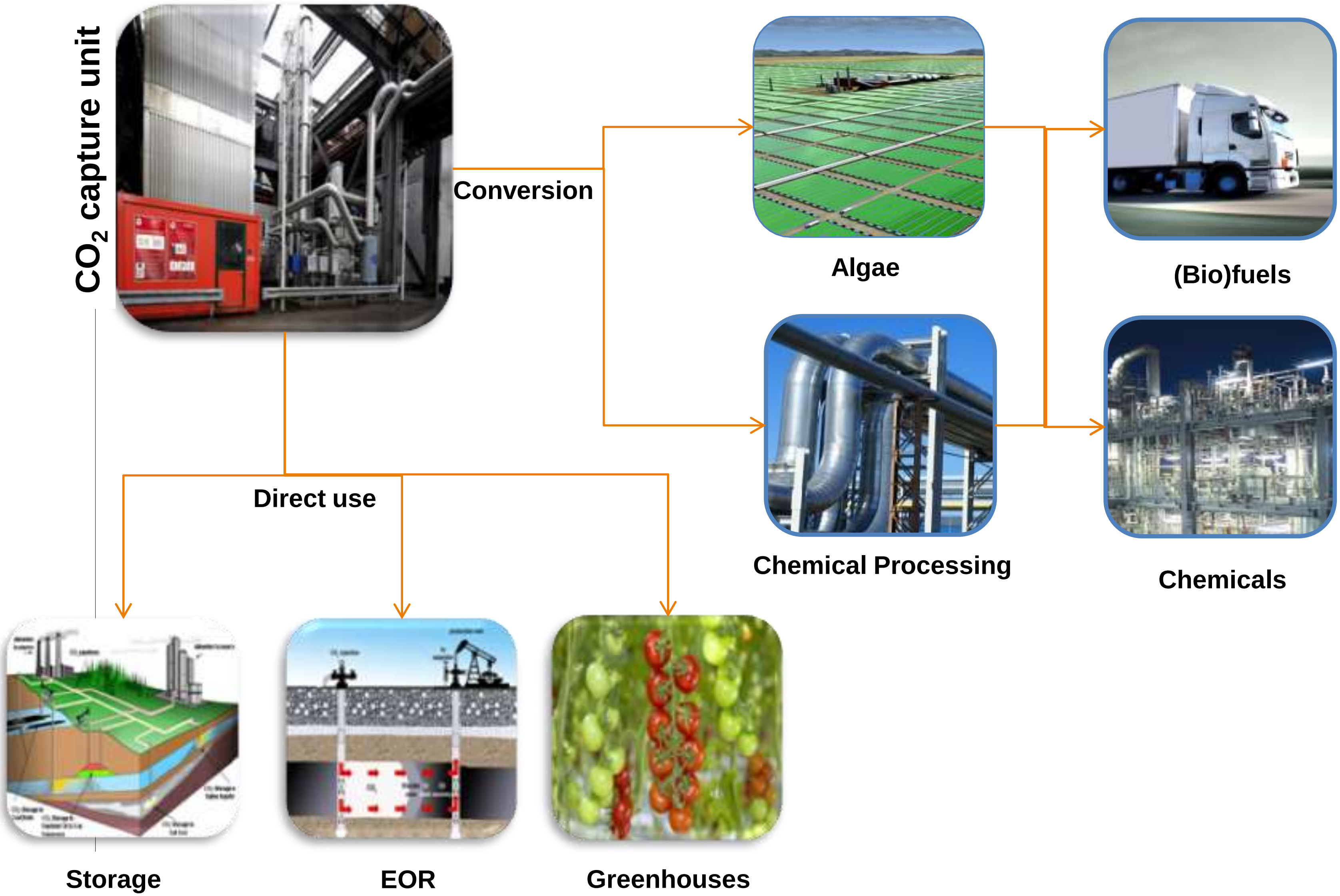
EnBW pilot plant / 0.3 tCO_2/h
(Heilbronn - G)

ENEL pilot plant / 2.25tCO_2/h
(Brindisi - I)

ROAD 1 Million ton/yr storage – from source to sink

One million tonnes of CO2 per year: world's first and largest commercial scale coal-fired CCS project ($1.24 billion)

Carbon capture, utilization and storage (CCUS)



Acknowledgements

CATO2

OCTAVIUS
Optimisation of CO2 Capture Technology Allowing Verification and Implementation at Utility Scale

Seventh Framework Programme

CESAR
Enhanced Separation & Recovery

iCap CO2

ALSTOM

IFP Energies nouvelles

BASF The Chemical Company

NTNU
Det skapende universitet

DONG energy

polymem Membrane Manufacturer

ΔEH Public Power Corporation S.A.

DOOSAN Doosan Babcock Energy

RWE The energy to lead

CNRS

SIEMENS

SINTEF

e.on

VATTENFALL

Statoil

Technische Universität Kaiserslautern

Thank you!