CAESAR

CArbon-free Electricity by SEWGS

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SEVENTH FRAMEWORK PROGRAMME

CAESAR

CArbon-free Electricity by SEWGS

European conference on CCS Research, Development to implementation
ONE GREAT GEORGE STREET Conference centre

www.ecn.nl

CAESAR

- Small or medium-scale R&D focused FP7 project
- Builds on the SEWGS knowledge gained in CACHET
- Five partners involved:
    - AP (UK)
    - BP (UK)
    - ECN (NL)
    - SINTEF (No)
    - PTM (It)
- 4 years project, started 1 Jan 2008
- Budget 3,1 Meuro

The CAESAR project has received funding from the European Community's seventh Framework Programmme FP7/2007 -2013 under grant agreement no 213206.

CAESAR Introduction

ECN — Sorbent material design and development, PDU testing, coordination

SINTEF — Sorbent material development

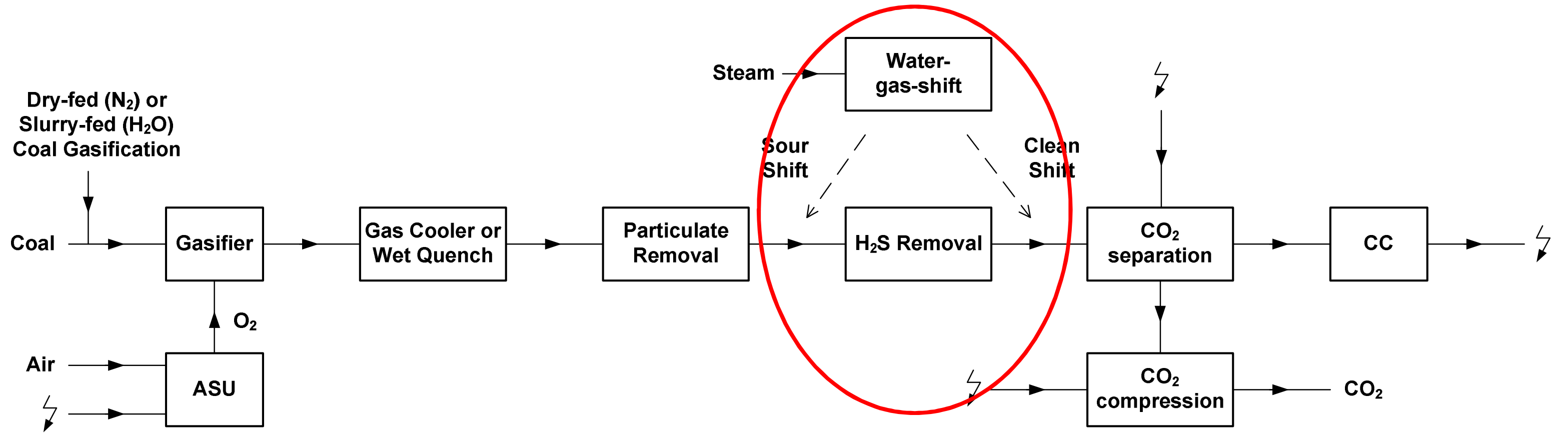
AIR PRODUCTS — Advanced process development and pilot plant design

POLITECNICO MILANO — Application, process integration & economics EBTF

bp — (Pilot) Plant design and techno-economic assessment

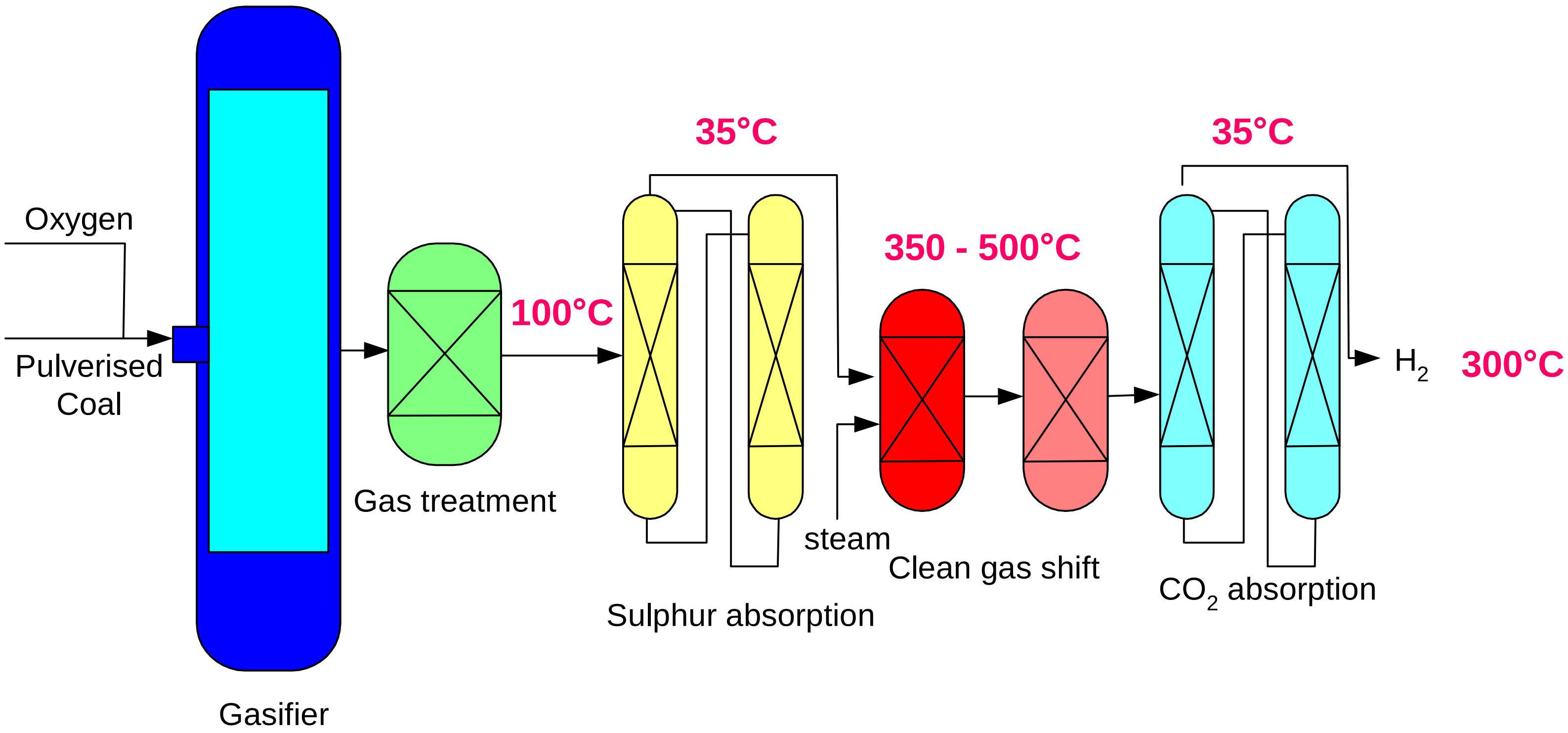
Pre combustion capture as of today

- In IGCC;
  - gas separation technologies commercial available
- In Natural gas combined cycles;
  - Reforming and gas separation technologies commercial available

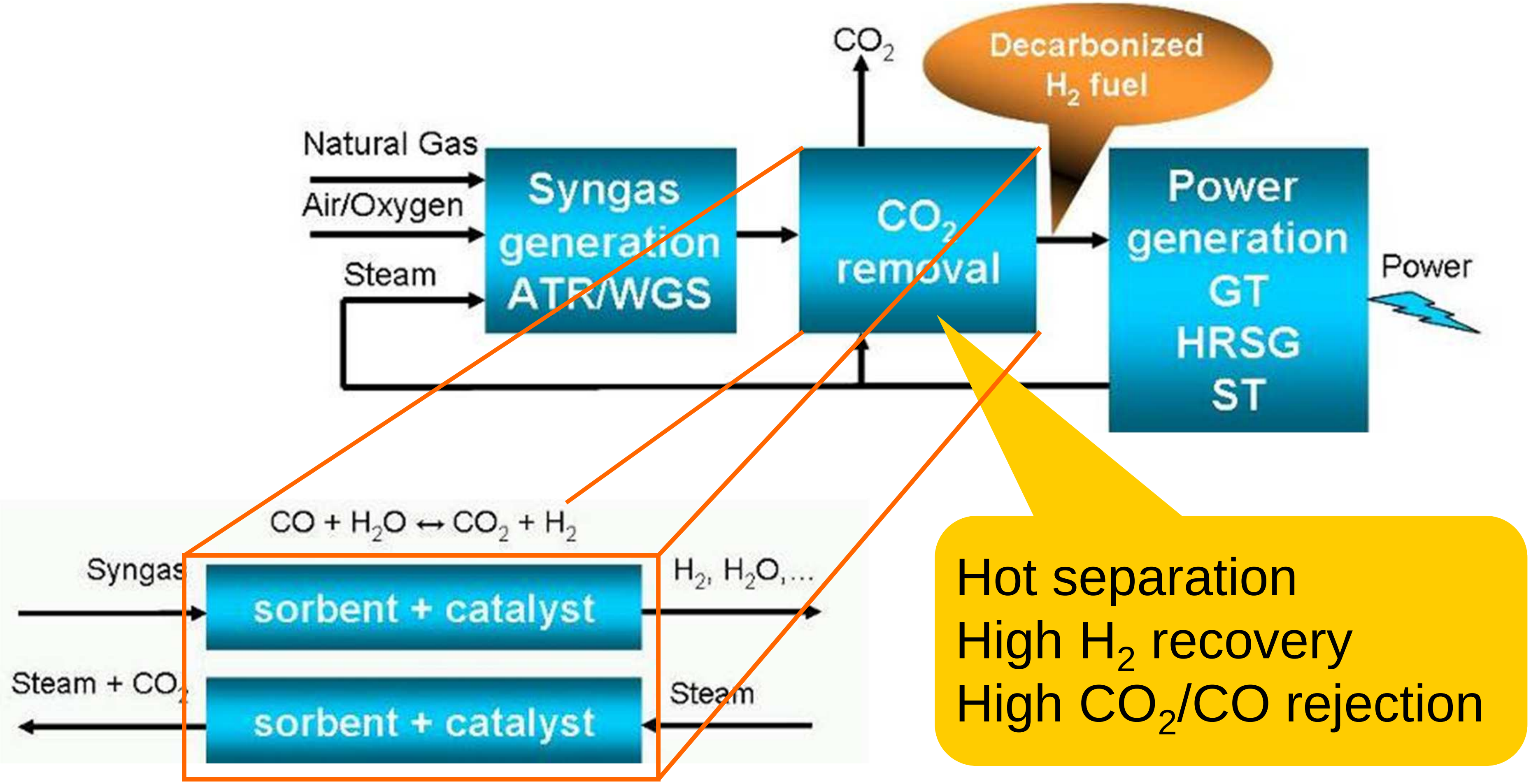


Pre combustion capture as of today

- Current plants use optimised shift followed by physical solvent separation process



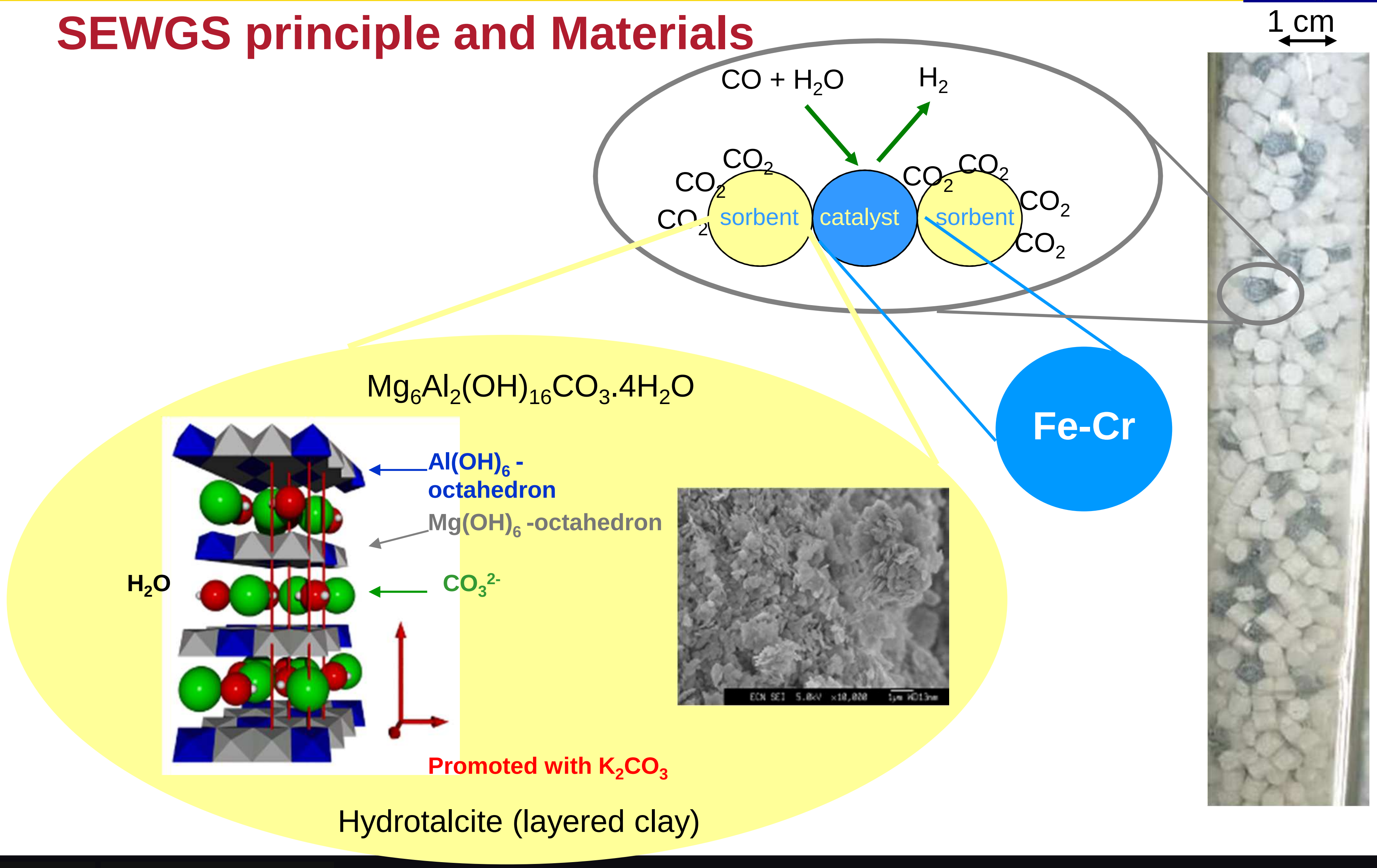
Sorption-Enhanced Water-Gas Shift (SEWGS)



400 ℃, 30 bar

Hot separation
High H_2 recovery
High CO_2/CO rejection

SEWGS principle and Materials



A Brief History of SEWGS

- SEWGS development initiated by Air Products in 2002
  - Development by Air Products continued, with funding from the US DOE and the CO_2 Capture Program (CCP)
- Development by ECN on Sorption Enhanced Reforming started in **CATO-1**
  - ECN work resulted in better understanding of the sorption process and new materials
- AP and ECN up in 2006 for the SEWGS process development in the EU FP6 project **CACHET.**
  - ECN constructed two test rigs (2007 and 2008)
  - PoC of SEWGS process finalised the CACHET project
- 2008, Process development continued in FP7 **CAESAR** project.
  - Improvements in sorbents and process economics. other applications

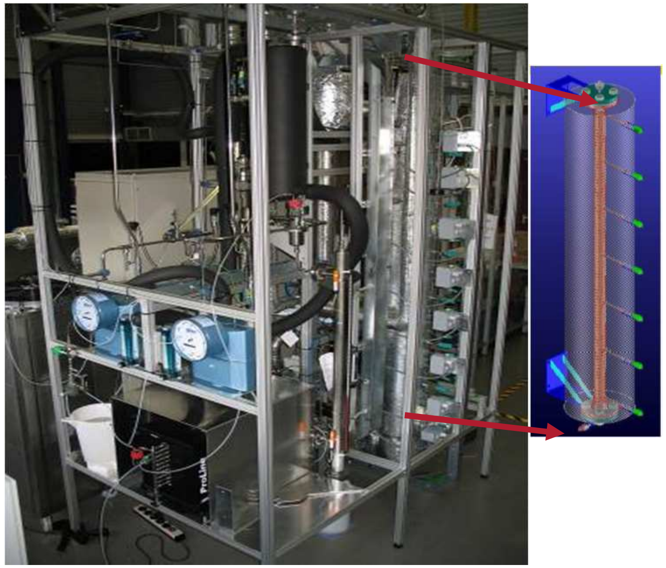
Why CAESAR?

- **CACHE: *Efficiency 45% and Capture costs 100 €/t for NGCC***
- Novel/improved sorbents are needed for low-cost CO_2 capture with SEWGS;
  - Improved chemical and mechanical stability
  - Improved sorbent capacity
  - reduced steam demand during regeneration
- Reactor modelling is essential to develop novel reactor concepts and for optimisation of full cycle operation

  See presentation (APL Wednesday 11:30 – 11:55)
- Improve integration in order to improve efficiency

  See presentation (PTM Wednesday 11:55 – 12:20)
- The SEWGS process should also be made suited for other applications i.e. IGCC and industrial processes (blast furnace gas)

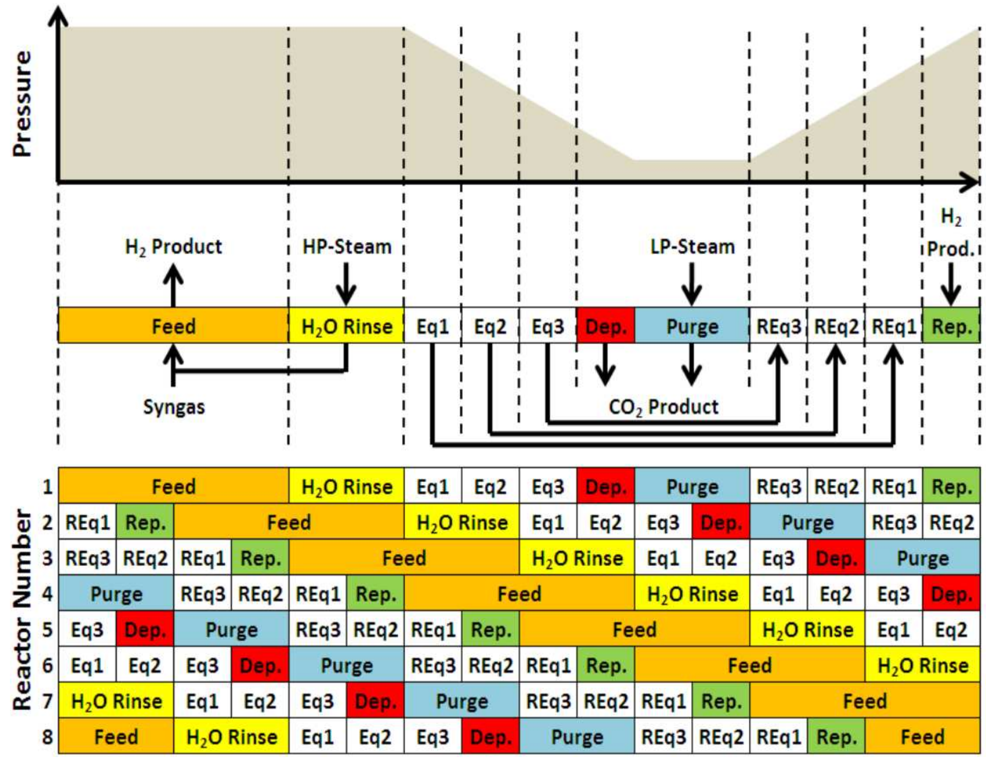
Test Rigs

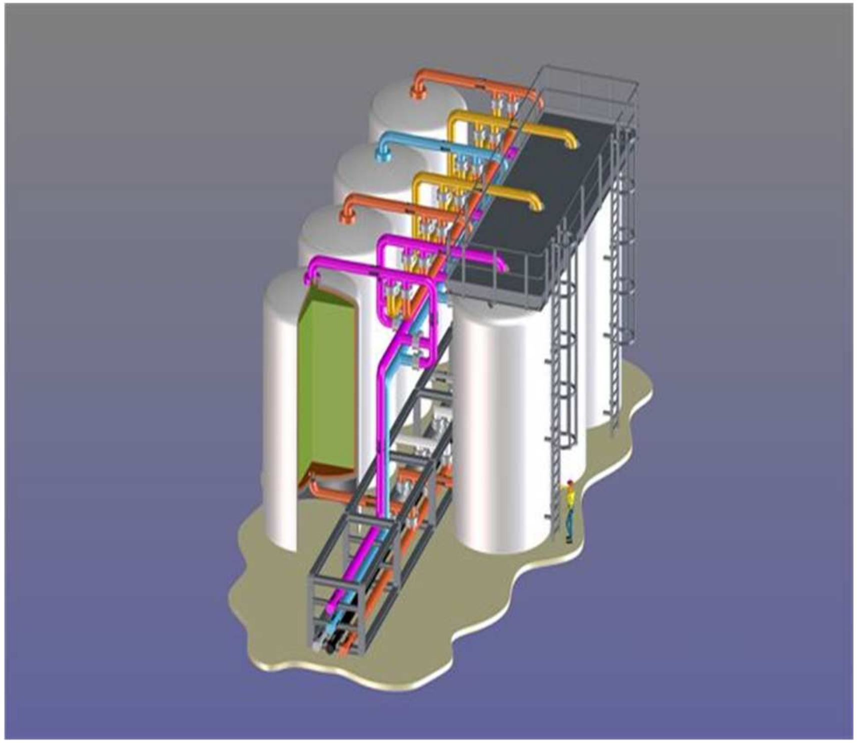


2 m single column, 38 mm ID
Design conditions:
    Tmax: 550°C
    Pmax: 31 bara
Feed gases:
CH_4, CO, CO_2, H_2, H_2S, N_2, Steam

Six, 6 m high,
38 mm ID columns
48 valves

The SEWGS process





Sorbent development in CAESAR
Mechanical Stability

- Hydrotalcite is a soft clay
- Key was to develop a sorbent that does not form $MgCO_3$ under the relevant process conditions

MgO
89 mmol/cm^3

$MgCO_3$
35 mmol/cm^3

Sorbent Development

CACHET CO_2

Before

After

Sorbent development in CAESAR

The consortium developed a new HTC sorbent: ALKASORB

- We demonstrated the cyclic stability of ***ALKASORB*** using two different SEWGS cycles. The material was shown to be chemically and mechanically stable over 2000+ cycles.
- No formation of undesirable $MgCO_3$ was observed, which is important since formation of $MgCO_3$ can lead to mechanical failure of the sorbent pellets and can decrease the carbon capture ratio.
- Moreover, it was demonstrated that the cyclic capacity of ***ALKASORB*** is higher and that it needs substantially less steam is required for its regeneration.
- Using data collected from numerous sources (Rubotherm at SINTEF, breakthrough data at ECN in the single-column, and TGA data from Air Products), combined CO_2 and H_2O isotherms for ***ALKASORB*** were created.

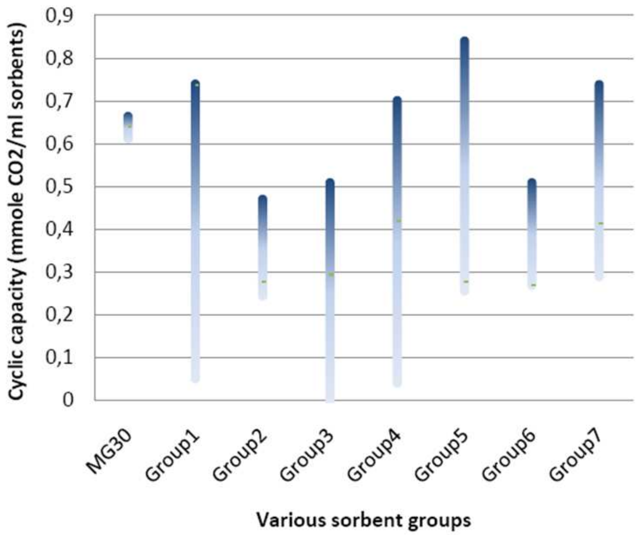
Catalyst screening in CAESAR

The ALKASORB sorbent can work without shift catalyst.

- A stability test showed the stability of the working capacity as well as shift activity of **ALKASORB** during 2000 cycles, at a minimal steam to carbon ratio (2 mole/mole).
- Hence, it was demonstrated that the SEWGS process does **not require a shift catalyst**, which brings substantial economic and technical benefits.
- **ALKASORB** captures also H_2S along with the CO_2 without significant loss of capacity.

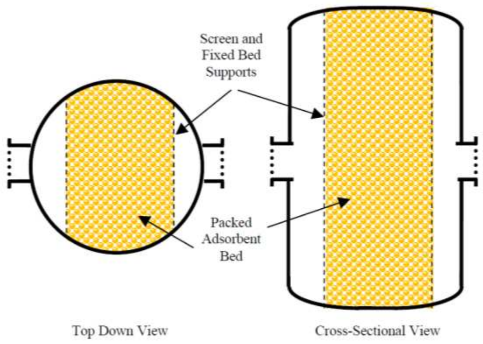
Sorbent development in CAESAR

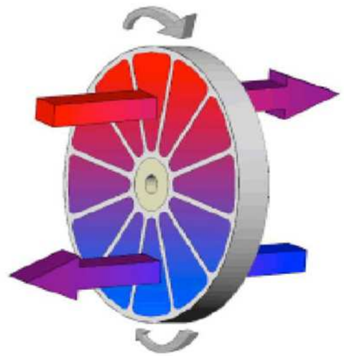
- High throughput techniques have been applied in the search for even more efficient sorbents for the SEWGS process.
- From the 400+ sorbents tested by high-throughput screening, we selected the four most promising for further testing.
- These four sorbents were bench marked against **ALKASORB.**
- Not one of these four sorbents performed sufficient to scale up the sorbent for testing in the single-column and multi-column test rigs.



Alternative reactor designs in CAESAR

- Alternative fixed vessel flow arrangements other than vertical
- Mechanical improvements to fixed vessel designs
  (e.g. rotating beds, internal heat exchangers etc.)





- Moving beds versus fixed beds

The main finding was that the current SEWGS fixed bed PSA design will most likely be the best arrangement. We will concentrate on improving fixed bed cycles

SEWGS Assessments for NGCC

	NGCC	NGCC MDEA	SEWGS integration 2	SEWGS int2 + exp
Net Power Output, [MW]	829.5	830.0	777.9	791.8
Thermal Power Input$_{LHV}$, [MW]	1422.6	1651.0	1556.5	1556.5
Net Electric Efficiency (LHV base), [%]	**58.3**	**50.3**	**50.0**	**50.9**
Emissions [g_{CO2}/kWh_{el}]	351.8	29.8	17.1	16.8
CO_2 avoided, [%]	**-**	**91.5**	**95.1**	**95.2**
SPECCA (MJ_{LHV}/kg_{CO2})	**-**	**3.07**	**3.08**	**2.70**
Investment costs [€/MWe]				
COE [€/MWh]	54.2	76.37	74.17	73.33
Cost of CO2 avoided [€/t_{CO2}]	**-**	**68.9**	**58.9**	**56.4**

CACHET results for NGCC: Efficiency 45% and Capture costs 100 €/t

ECN

EWGS Assessments for IGCC

	IGCC	SELEXOL	Sour SEWGS	ADV Sour SEWGS
Net Power Output, [MW]	425.7	383.5	388.0	393.6
Thermal Power Input$_{LHV}$, [MW]	888.8	1053.5	1032.7	1032.7
Net Electric Efficiency$_{LHV}$, [%]	47.48	36.4	37.6	38.2
Emissions, [g_{CO2}/kWh_{el}]	726	98	22	22
CO_2 avoided, [%]	-	86.6	96.9	97.0
SPECCA (IGCC), (MJ_{LHV}/kg_{CO2})	--	3.67	2.84	2.65
COE, [€/MWh]		?	?	?
Cost of CO_2 avoided, [€/t_{CO2}]		?	?	?

SEWGS Assessments for blast furnace

- Steel industry accounts for 10-15% of industrial CO_2 emissions;
- Balst furnace gas has a concentration of CO and CO_2 of 20% each.

	No Cap	MEA cap	SEWGS cap
Net Electric Efficiency (LHV base), [%]	**51.3**	**37.8**	**32.8**
Emissions [g_{CO2}/kWh_{el}]	1366	958	345
CO_2 avoided, [%]	--	30	75
SPECCA (MJ_{LHV}/kg_{CO2})	**--**	**6.10**	**3.9**

Recap

- We demonstrated the cyclic stability of ***ALKASORB*** using two different cycles. The material was shown to be chemically and mechanically stable over 2000+ cycles.
- It was demonstrated that the cyclic capacity of ***ALKASORB*** is higher and that it needs substantially less steam for its regeneration.
- ***ALKASORB*** can work without shift catalyst.
- **ALKASORB** captures also H_2S along with CO_2 without significant loss of capacity.
- Over 400 sorbents have been screened in a dedicated high throughput set up.
- The four most promising sorbents have been selected for further analysis and testing. Unfortunately, not one of these four sorbents performed sufficient to scale up the sorbent for testing in the single-column and multi-column test rigs.

Recap

- For the NGCC application, the energy use for SEWGS systems is lower compared to a conventional MDEA process.
- Moreover, SEWGS system allows a system components reduction and gives higher carbon capture ratios and the CO_2 avoidance cost are lower for the SEWGS process.
- SEWS in the IGCC applications reduces the energy use substantially compared to the SELEXOL process outlining its very good potential.
- The carbon capture rate is higher and the CO_2 avoidance costs are lower than for Selexol.
- SEWGS in blast furnace application showed reduced efficiency penalties compared to reference plant with MEA CO_2 capture;

More info on SEWGS

http://caesar.ecn.nl/home/

www.ecn.nl

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