



Energy research Centre of the Netherlands



CACarbon-free **E**lectricity by **SE**WGS:
AAdvanced materials, **R**Reactor-, and process design
CAESAR

Amsterdam, 29 September 2009



Roadmap for zero emission power plants

CO₂ avoided

ECN activities:

- NUON CO₂ CATCHUP
- PhD thesis on IGCC design
- SEQ support

1st generation CCS: solvent technologies

- **1st generation:** pilot and demo tests in power plants
- **Storage:** larger demo
- **2nd generation:** pilot tests

- **1st generation:** commercial plants
- **Storage:** fully integrated
- **2nd generation:** demo tests

- **1st generation:** zero emission power plants as standard
- **2nd generation:** implementation

- **1st generation:** R&D for commercial applications
- **Storage:** demo projects
- **2nd generation:** R&D on concepts

2nd generation CCS:
• Reduced investments
• Low energy demand

ECN activities:

- System assessment
- SEWGS
- Pd-membrane reactors
- OTM or MIEC membranes
- CaO as CO₂ sorbent

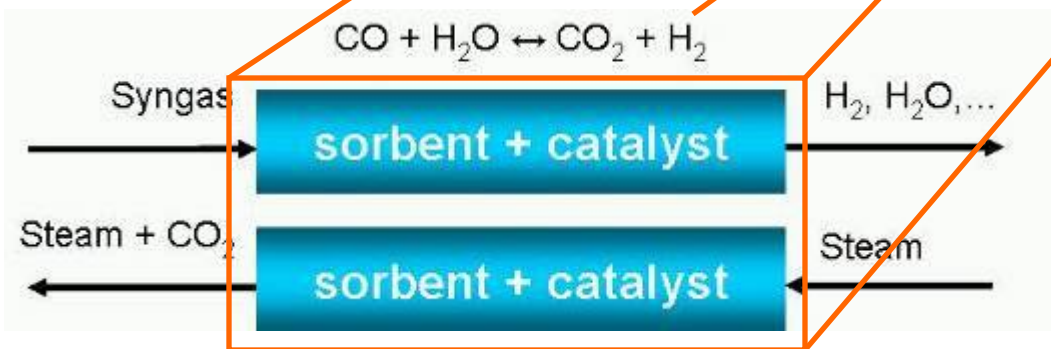
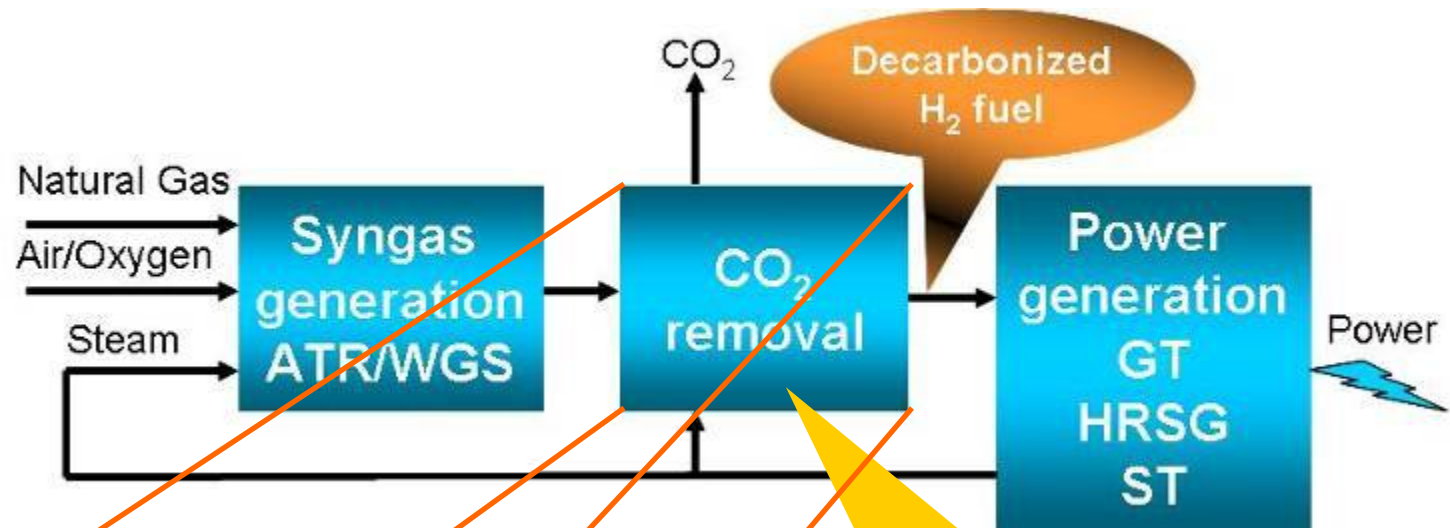
2010

2015

2020

2025

Sorption-Enhanced Water-Gas Shift (SEWGS)

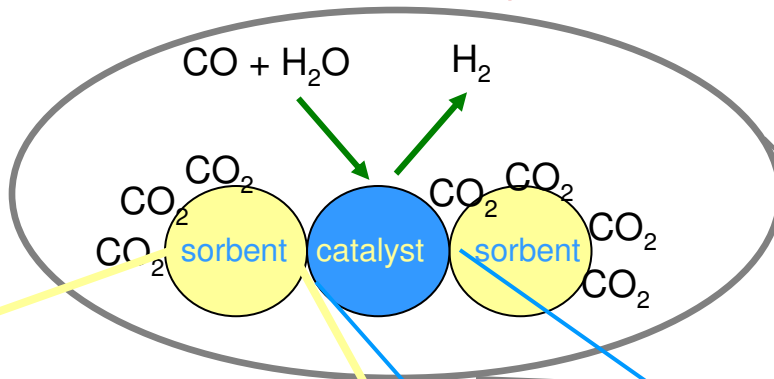


400 °C, 30 bar

Hot separation
 High H₂ recovery
 High CO₂/CO rejection

Materials

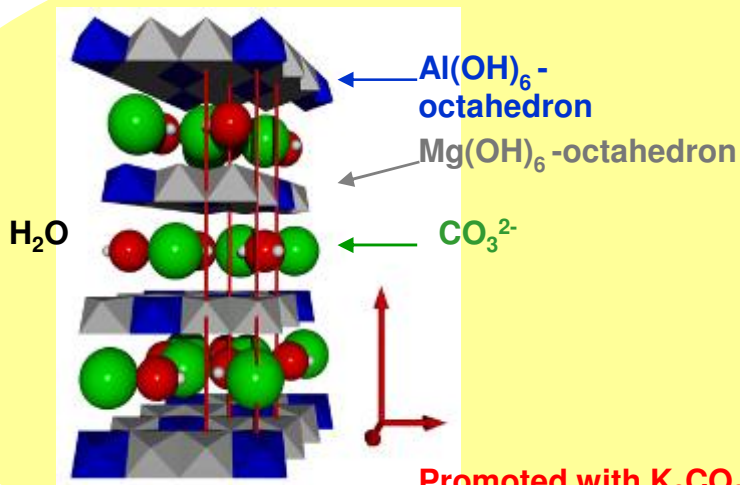
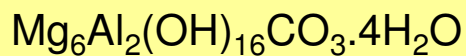
Le Chatelier's Principle



1 cm



Fe-Cr



Promoted with K_2CO_3

Hydrotalcite (layered clay)

A Brief History of SEWGS

- SEWGS development initiated by Air Products in December 2002
- Developed by Air Products continued, with funding from the US DOE and the CO₂ Capture Program (CCP)
- Development by ECN on Sorption Enhanced Reforming started in CATO
- ECN work resulted in better understanding of the sorption process and new materials
- AP and ECN teamed up in 2006 for the process development in EU FP6 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.

CACHET Summary

- Objective: Develop technology to half cost of CO₂ at 90% capture rate
- Application to natural gas fired 400 MWe CCGT
- 4 main technology areas:
 - Advanced SMR
 - Chemical looping and One-step
 - Membranes
 - SEWGS
- Technical optimisation and economics (including state of art)
- 3 year project duration, ending 1st April 2009

CACHET Project Participants



CAESAR Introduction



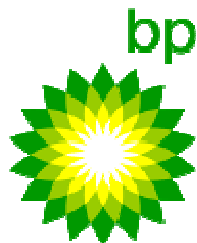
Sorbent Material Design and Development



Advanced Process Development
and Pilot plant design

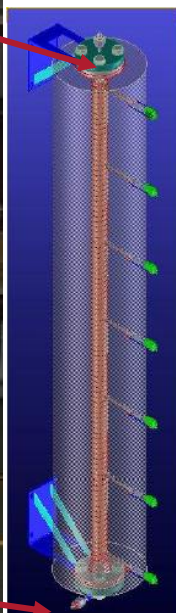


Application and process integration

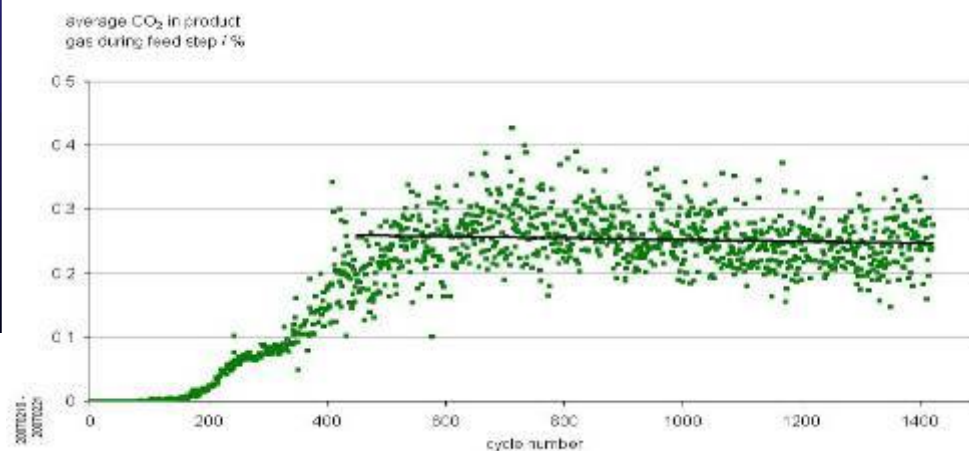


Pilot Plant design

CAESAR: Builds on CACHET SEWGS

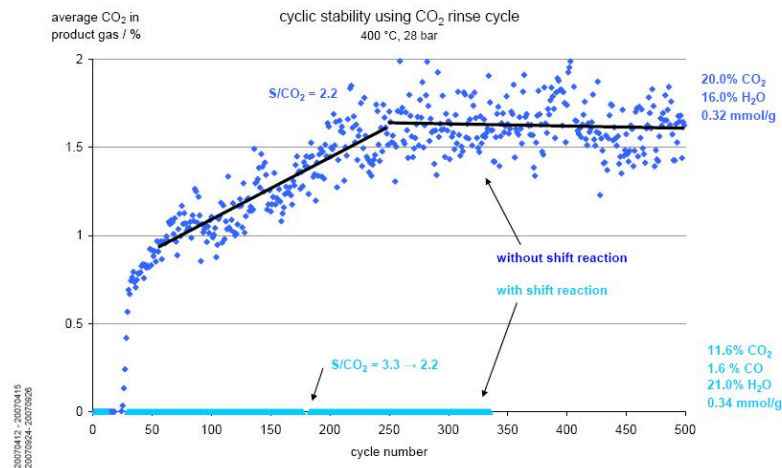
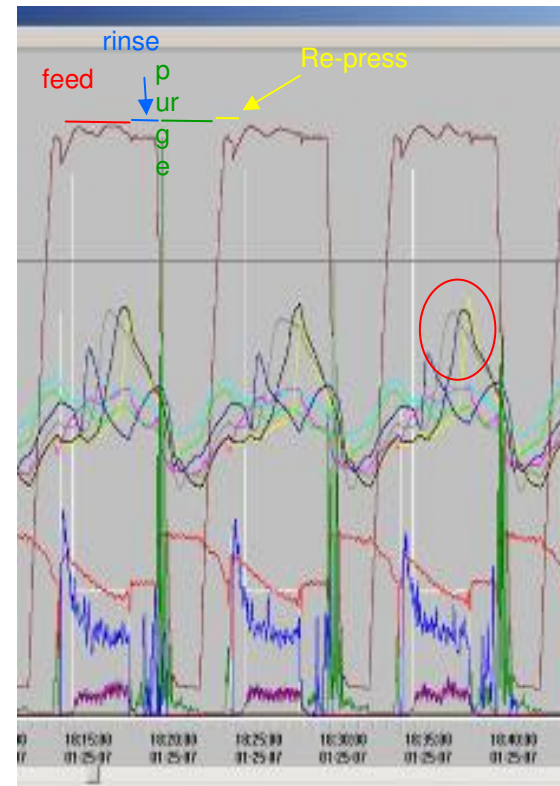


Process development
 Single column unit
 Test cyclic stability of sorbents
 under WGS conditions



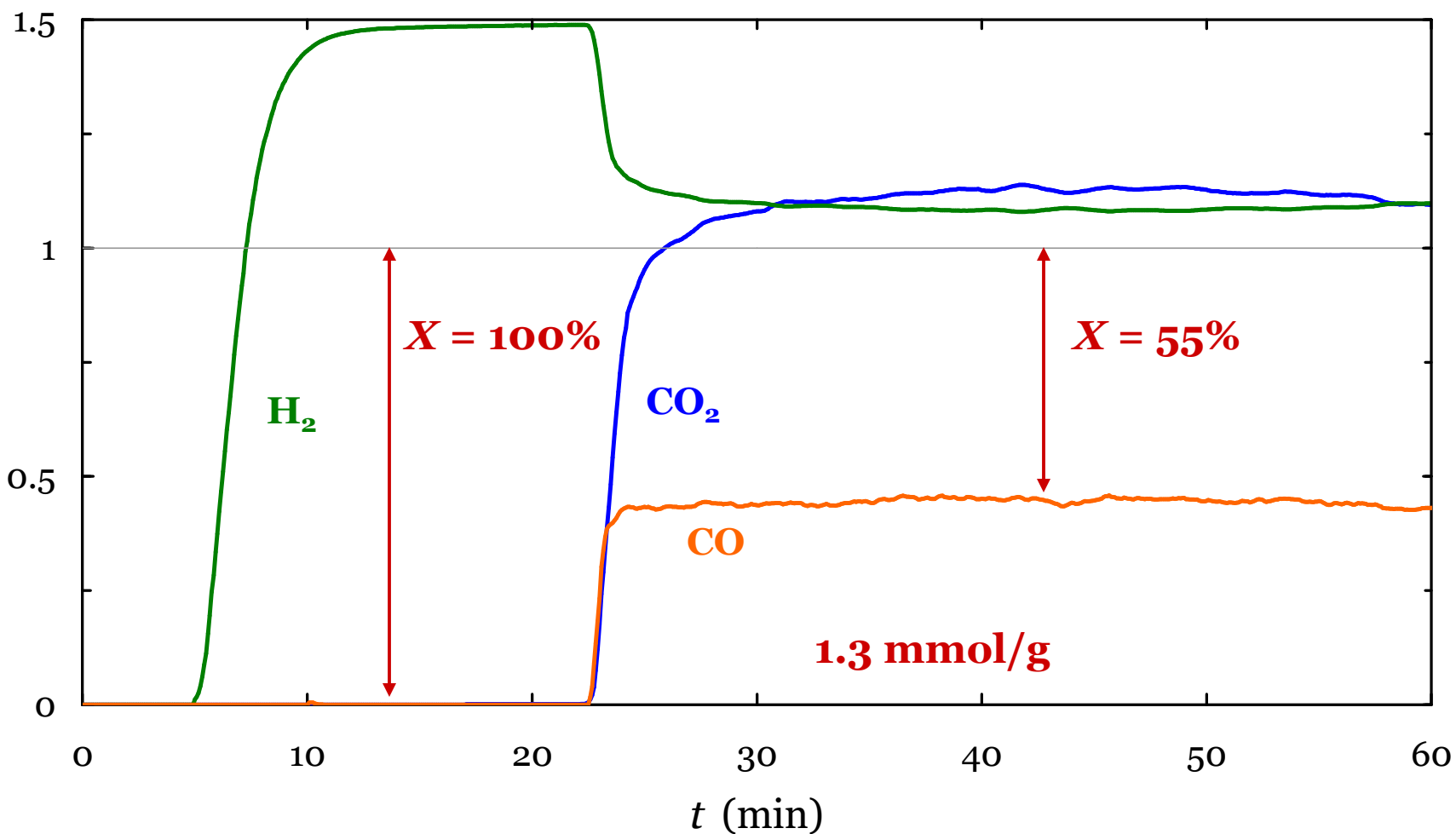
Single Column SEWGS Apparatus

- Breakthrough and cyclic testing
- HTC-only and HTC/catalyst combinations
- Rinsing with steam or CO₂
- Single column tests required to determine:
 - Adsorbent and catalyst are stable
 - Low CO₂ slip and high CO conversion can be achieved
 - Initial data for modelling/simulation

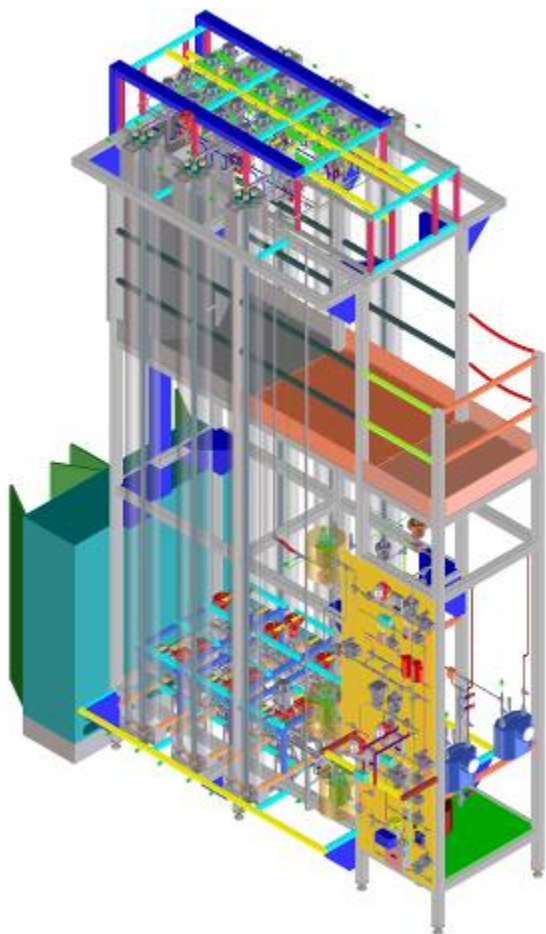


400 °C, 4.2 bar CO₂, 2.5 bar CO

$y_{i,out} / y_{i,in}$



CAESAR: Builds on CACHET SEWGS



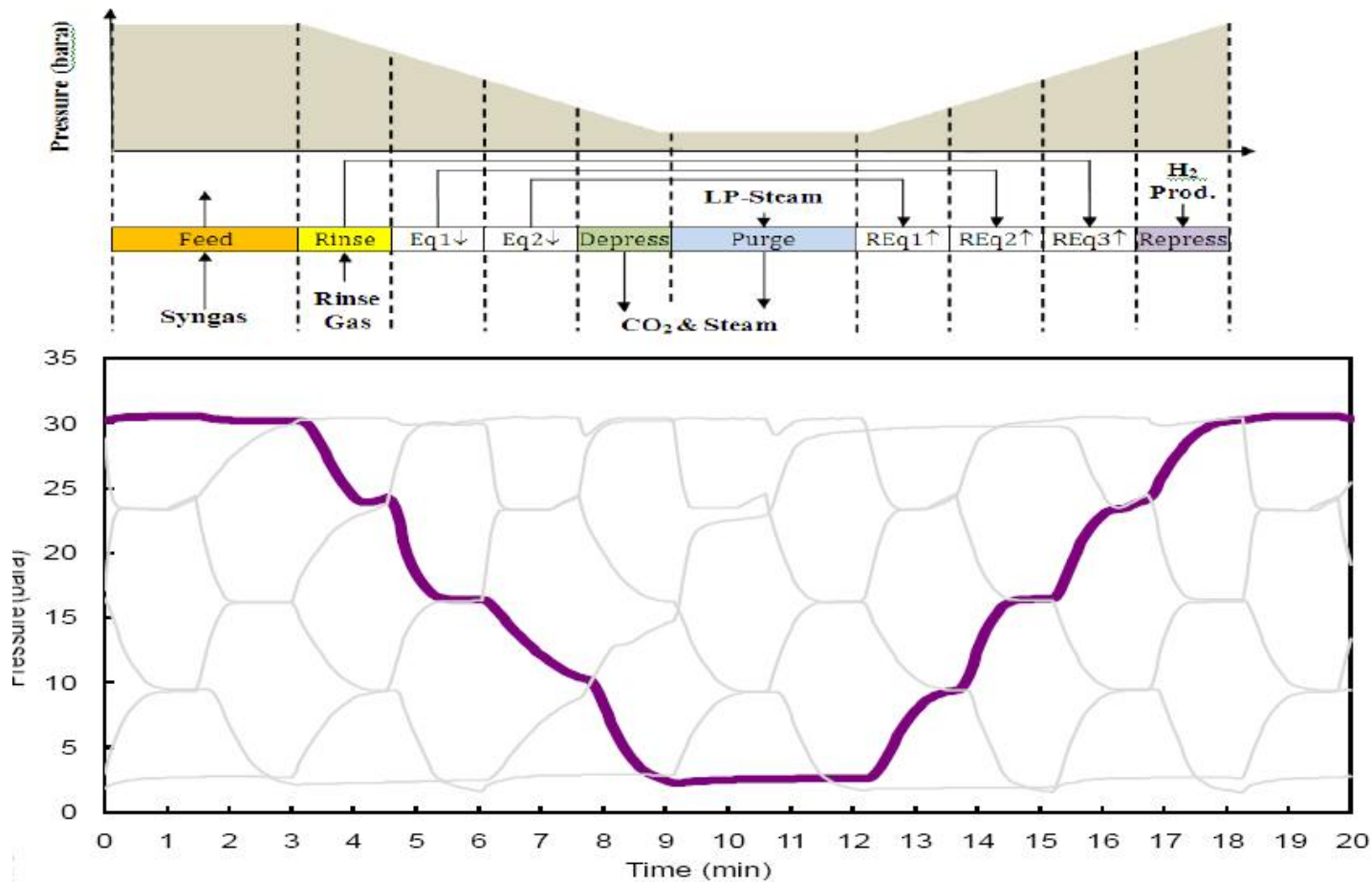
Multi-Column SEWGS Apparatus

Design

- Six 6 m high, 38 mm ID columns
- Columns insulated and filled with adsorbent + catalyst
- Design conditions:
 - Maximum bed temperature: 550 °C
 - Maximum pressure: 31 bara
- Feed gases:
 - CH₄, CO, CO₂, H₂, N₂, Steam

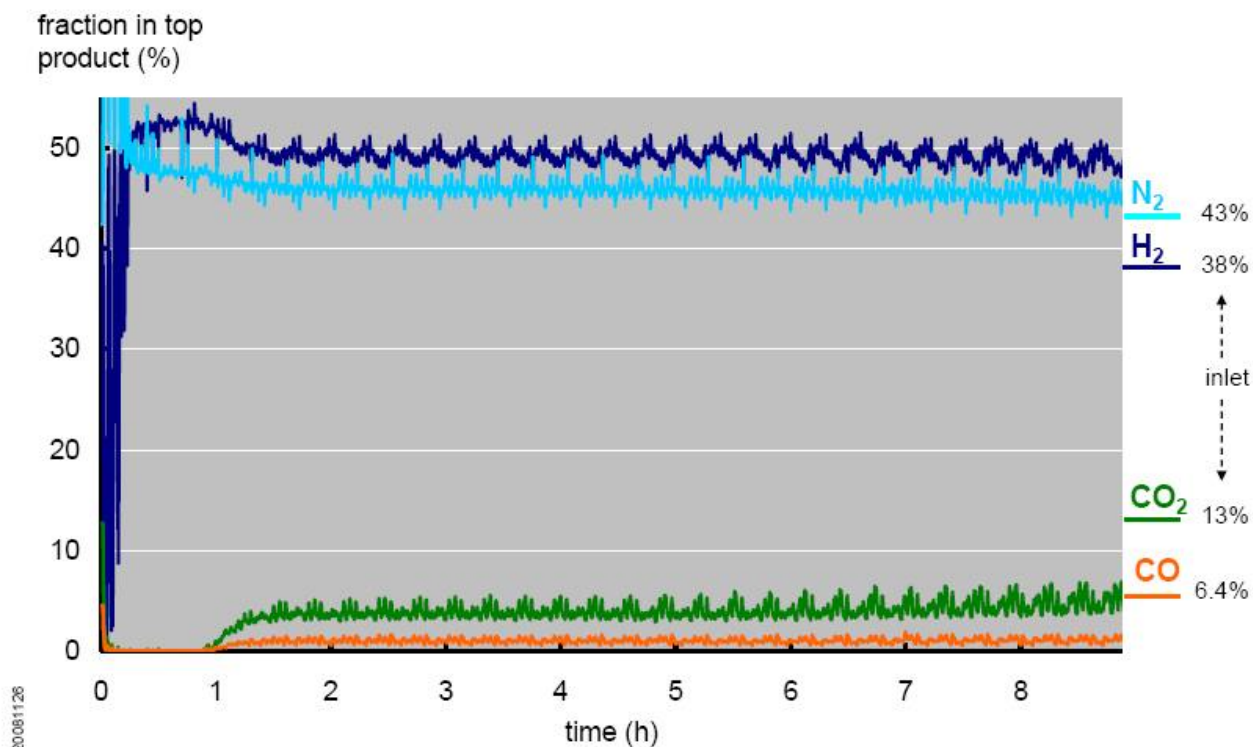


Multi-Column testing



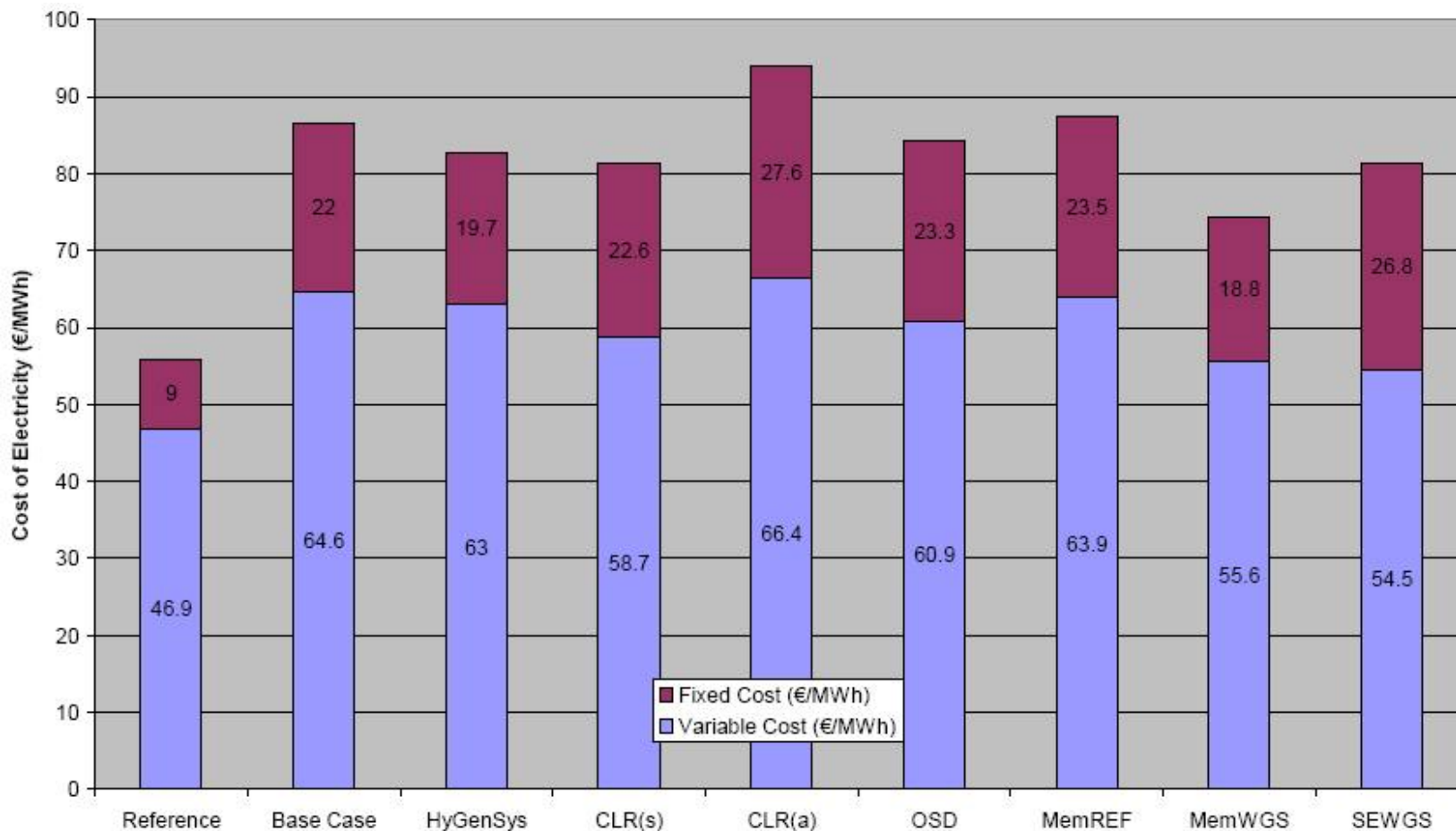
Multi-Column testing

- Multi-column test rig gave proof of the SEWGS process
- Minor sorbent capacity differences between each column

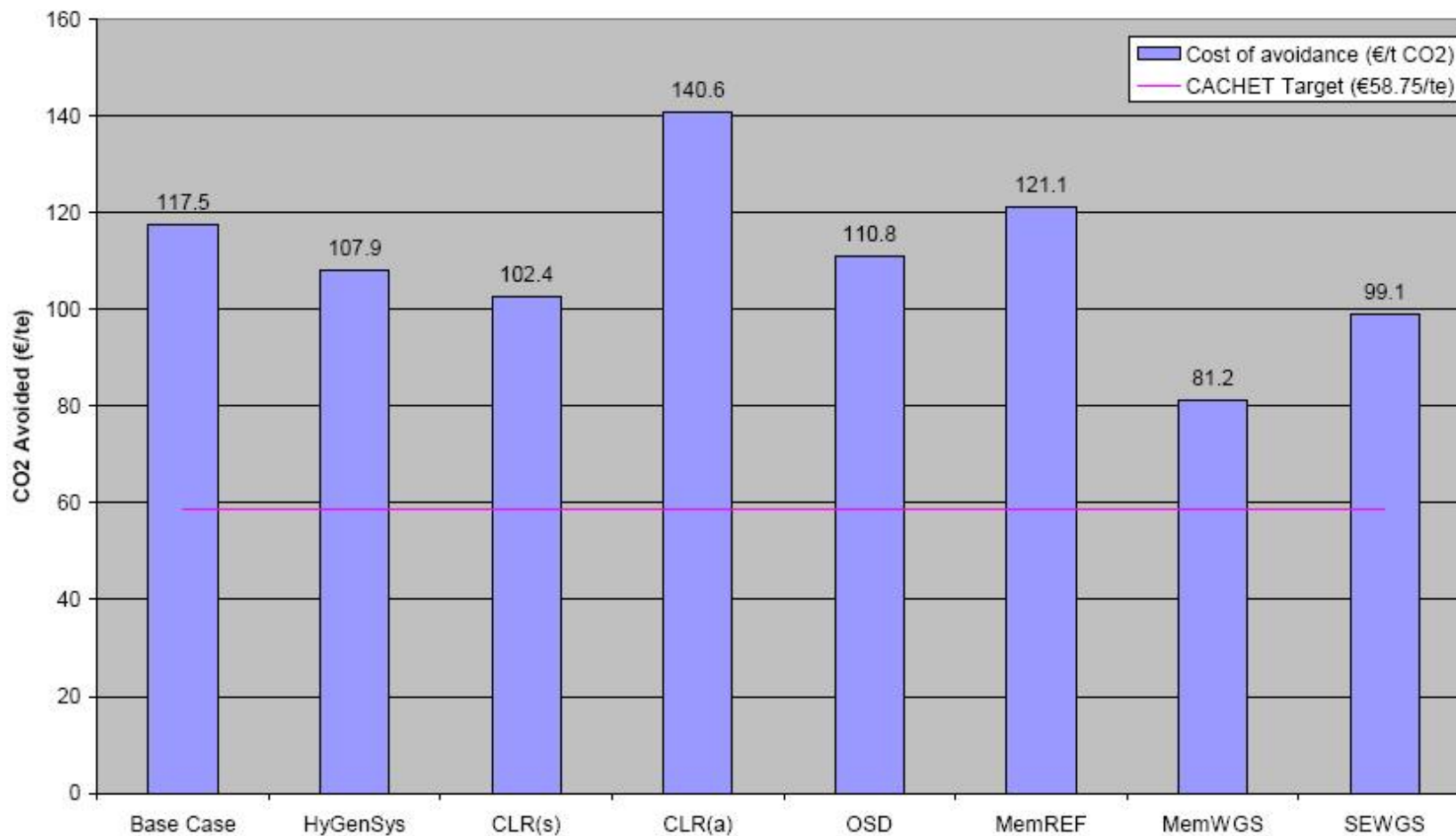


- CO conversion 83% and carbon capture 73%

Cost of Electricity of the CACHET technologies



Avoided cost for the CACHET technologies



Why CAESAR?

CACHET results showed that:

- Novel/improved sorbents are needed for low-cost CO₂ capture with SEWGS;
 - Improved chemical and mechanical stability
 - Improved sorbent capacity
- Reactor modelling is essential to develop novel reactor concepts and to for optimisation of full cycle operation
- Improve integration in order to improve efficiency
- The SEWGS process should also be made suited for **other applications** i.e. IGCC and industrial processes (belts furnace gas)

Mechanical Stability

- Hydrotalcite is a soft clay
 - Higher calcination temperature degrades performance

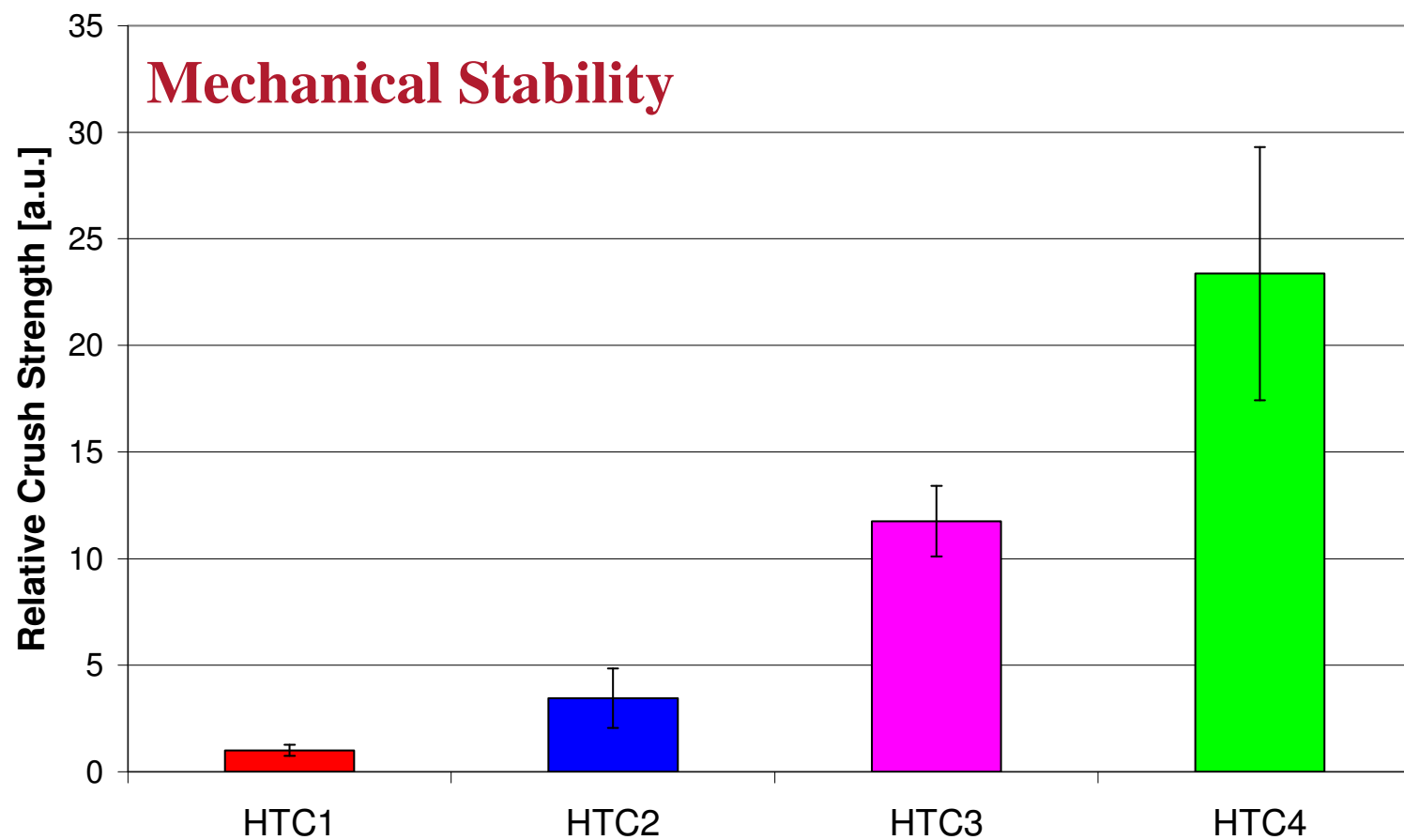


MgO 89 mmol/cm³



MgCO_3 35 mmol/cm³

Sorbent development in CAESAR



Sorbent development in CAESAR



Old sorbent
Before



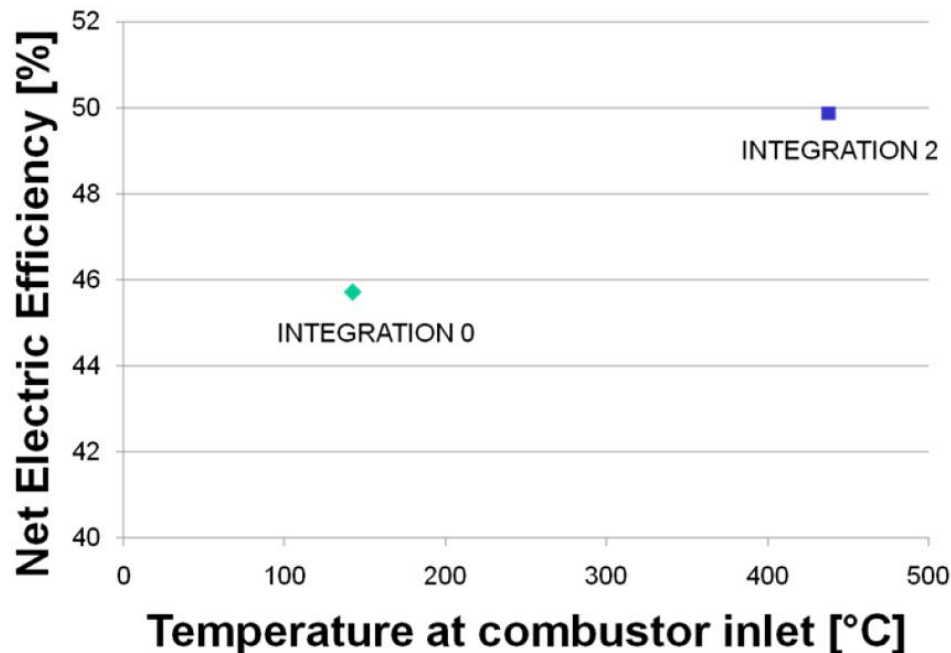
After test



New sorbent
After test

SEWGS integration in NGCC

- Different levels of SEWGS integration in the HRSG (heat recovery steam generator) of a NGCC have been assessed.
- Efficiency performances can vary from 46% up to 50% depending on integration level, with a carbon avoided of 94%;



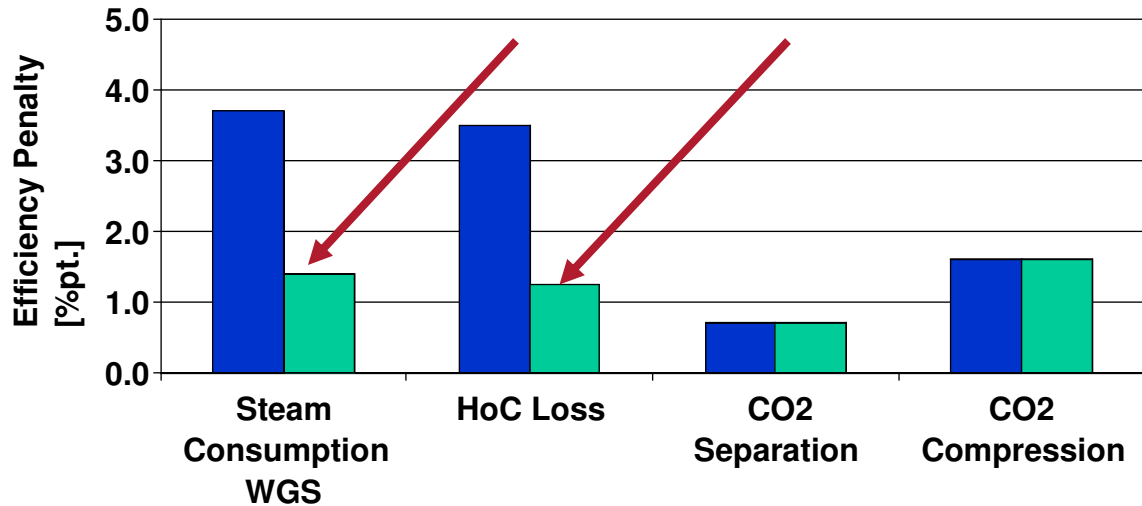
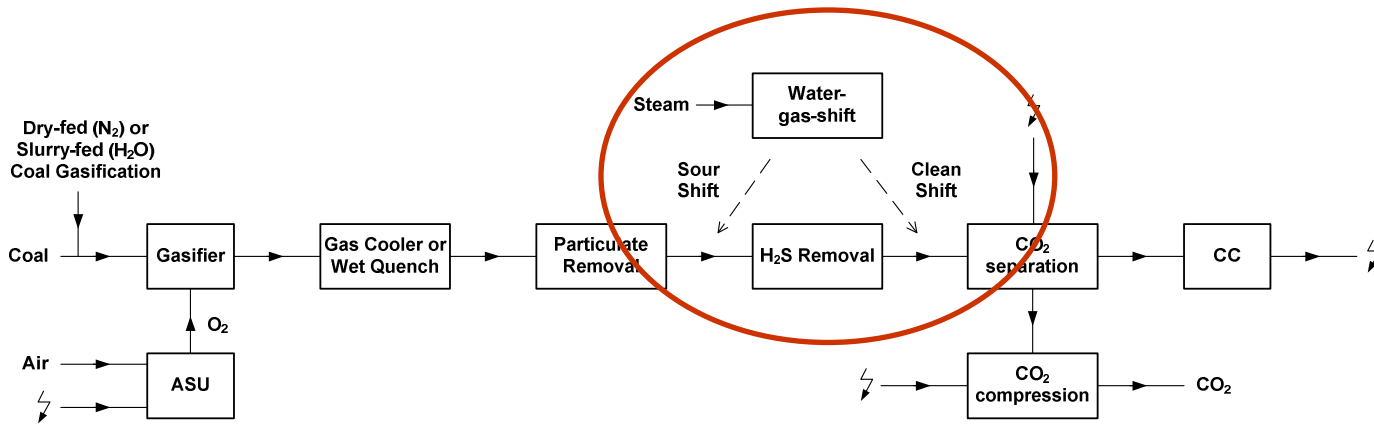
Level 0: The hydrogen island (ATR+SEWGS) and the heat recovery steam cycle are almost decoupled.

Level 2: A full integration of ATR + SEWGS in the NGCC

SEWGS integration in NGCC: Results

	NGCC w/o capture	NGCC with SEWGS (lev 0)	NGCC with SEWGS (lev 2)
Gas Turbine, MW	281.5	323.6	287.2
Steam Cycle Net Power, MW	140.8	136.9	126.2
Auxiliaries, MW	-3.8	-65.8	-26.6
Net power Output, MW	418.5	394.7	387.4
Thermal power input, MW	717.8	863.7	776.8
Net Electric Efficiency, %	58.3	45.7	49.9
Emissions (g _{CO2} /kWh _{el})	346	18.9	19.6
CO ₂ avoided, %	N/A	94.5	94.3

SEWGS for IGCC



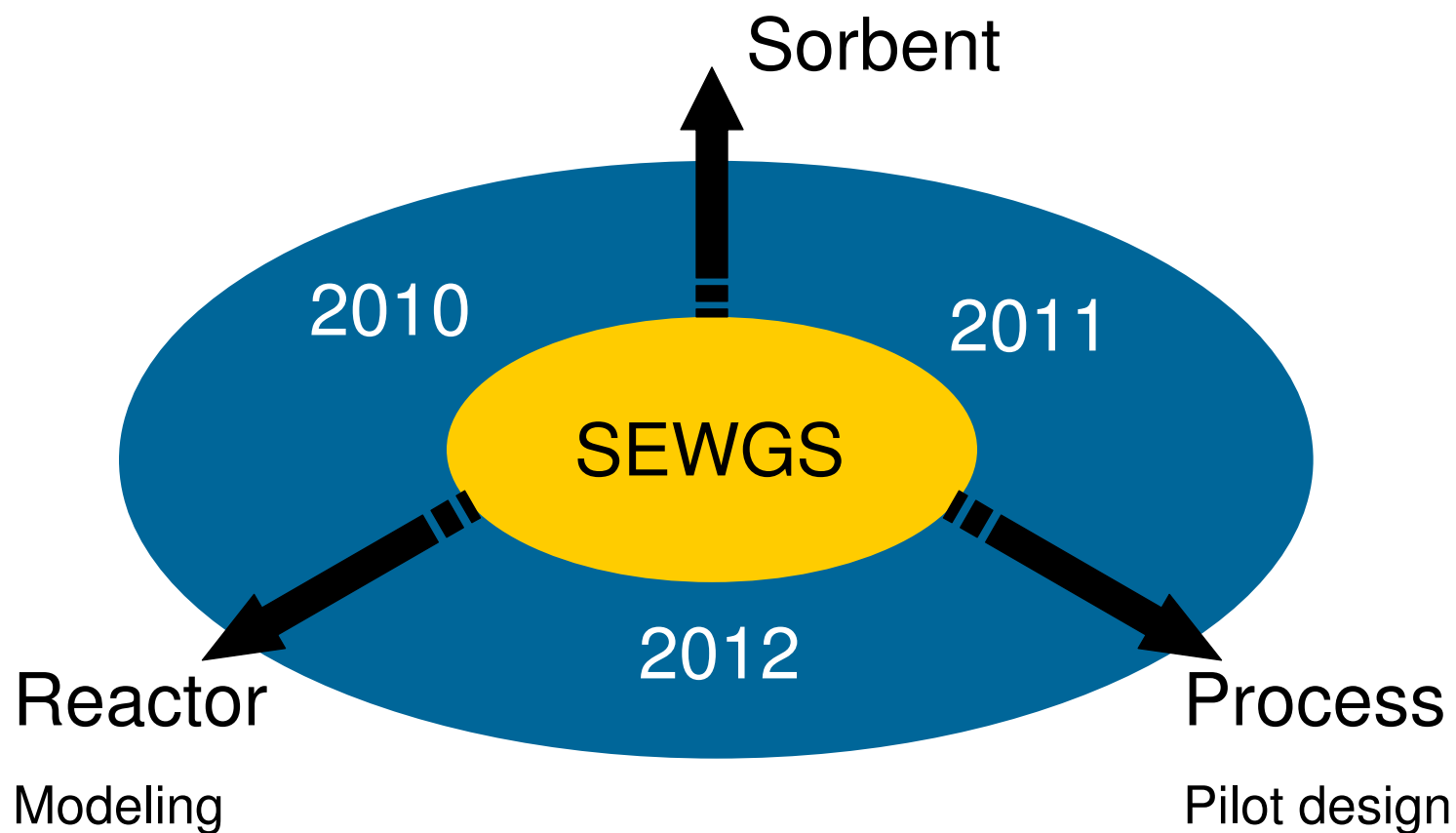
■ Base Case
■ SEWGS

SEWGS in IGCC

- HTC sorbents are capable of simultaneously removing CO_2 and H_2S from coal based syn gas.
- Preliminary efficiency calculations indicate electrical efficiencies above 37% points (LHV). This is comparable to conventional CO_2 capture in IGCC.
- Optimal system and process configurations for sour SEWGS not yet identified.
- Bench scale testing in the SEWGS-1 for clean and sour CO_2 removal in IGCC in progress.

Future work

Objective : Pilot plant design in 2014



Recap

- CAESAR project builds on CACHET SEWGS
- First 12 month of CAESAR emphasis on sorbent development and process feasibility for NGCC and IGCC
- Improved sorbent capacity demonstrated
- Improved mechanical strength demonstrated
- Proper integration of the SEWGS process in NGCC will improve power generation efficiencies

More info on SEWGS

www.cachetco2.eu

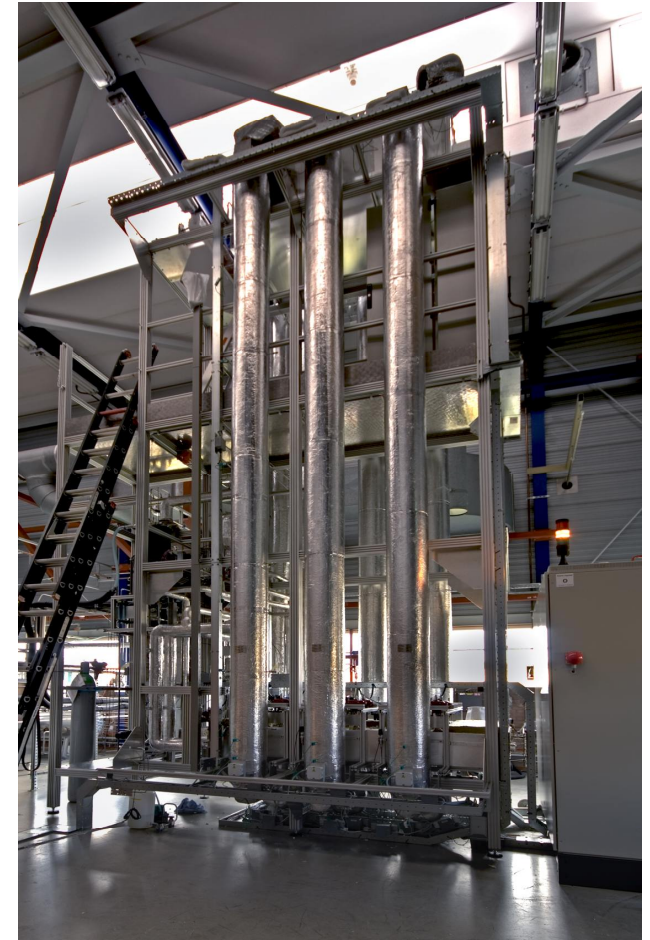
<http://CAESAR.ecn.nl>



AIR PRODUCTS 



CO₂ Capture Project



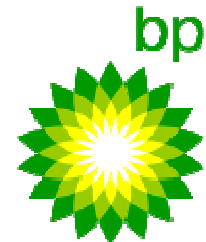
The CAESAR project has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement no. 213206

CAESAR Introduction

- Builds on the SEWGS knowledge gained in CACHET

Five partners involved:

- AP (UK)
- BP (UK)
- ECN (NL)
- SINTEF (No)
- PTM (It)



- Small or medium-scale R&D for project
- 4 years project, started 1 Jan 2008
- Budget 3,1 Meuro