



ENCAP Integrated Project

Five years development of CO2 enhanced capture technologies

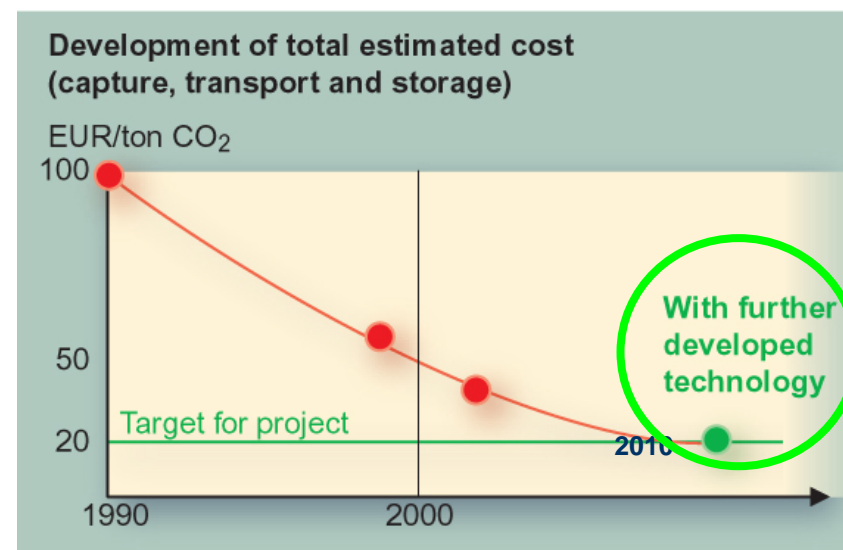
CO2Neteast Workshop CO2 Capture and Storage – Response to Climate Change
3-4 March 2009, Bratislava

Leif Brandels
Vattenfall AB, ENCAP Coordinator

ENCAP development Target

Develop and validate a number of pre-combustion technologies that in large Power Plants meets the target:

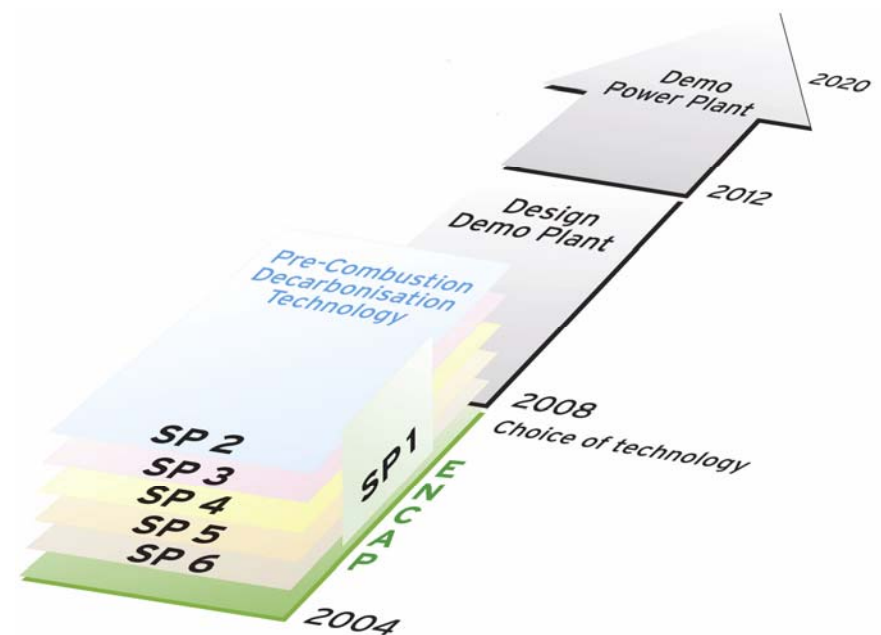
- 90% CO₂ capture rate and
- a cost of < 20 €/ton stored CO₂



Enhanced CO₂ Capture - ENCAP

A five year Integrated Project within the EC FP6
Total budget 22.2 MEuro
EC support 10.7 MEuro

Project period:
2004 March - 2009 February
(Requested extension August 2009)

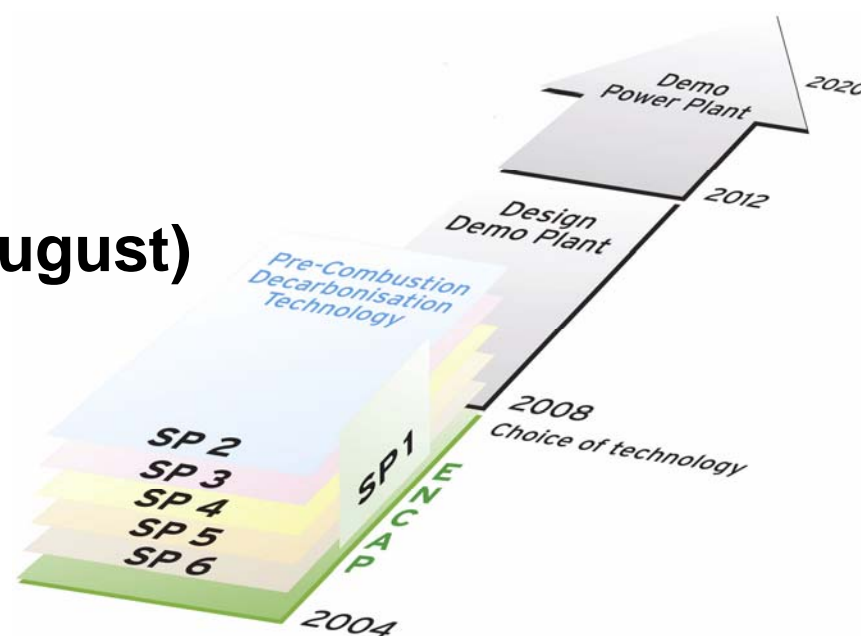


Enhanced CO₂ Capture - ENCAP

A five year Integrated Project within the EC FP6
Total budget 22.2 MEuro
EC support 10.7 MEuro

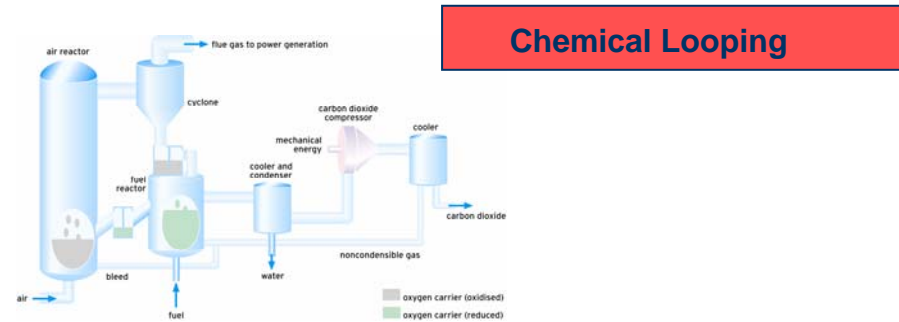
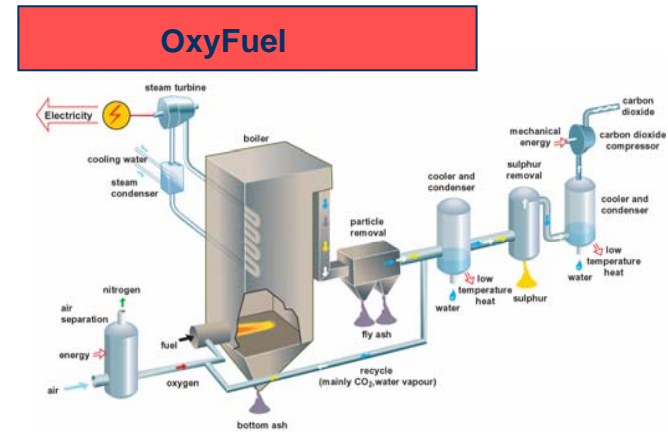
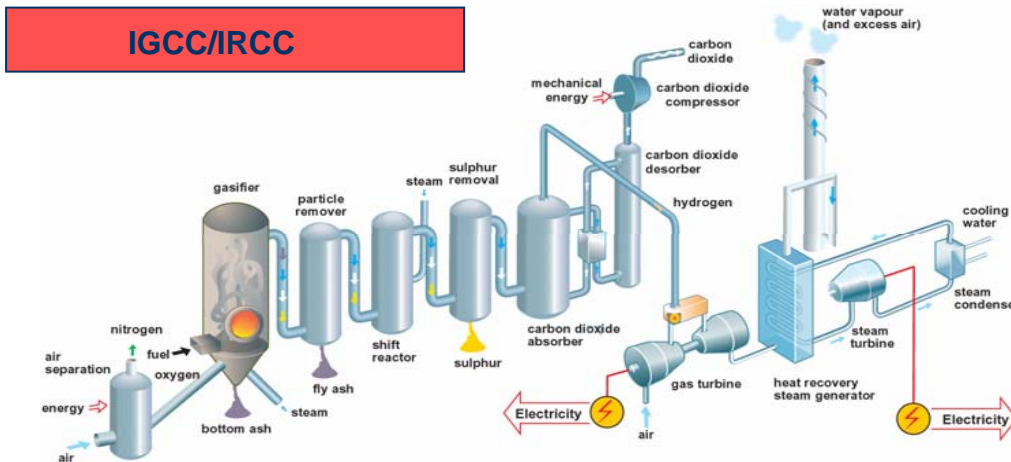
Project period:
2004 March – 2009 February (August)

In 2009 - Recommend
technology for
a 350 MWel Demo Plant



Enhanced CO₂ Capture - ENCAP

Development and validation of mainly three pre-combustion technologies:



Development of new air separation technologies

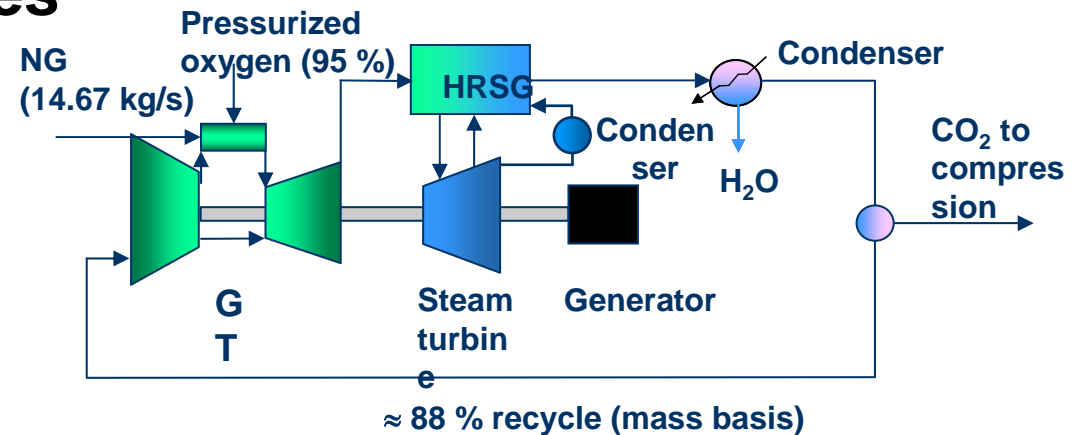
Development of 3 High-temperature oxygen generation technologies

- Oxygen separator membrane for power plant cycles
- High temperature oxygen adsorbent (CAR)
- Oxygen-transport membrane systems for power production

Oxygen-process integration into IGCC and OxyFuel Power Plants

Novel Capture Concepts

- Investigate prospective emerging technologies
- Oxy-fuel combustion cycles
 - Natural gas
- Pre-combustion capture cycles
 - Natural gas
 - Hard coal



ENCAP – a powerful consortium

The **ENCAP Consortium** gathers:

- 5 large European energy companies + Total France**
- 11 leading European technology providers**
- 12 high ranked research providers**

<p>DONG PPC RWE Power StatoilHydro Vattenfall +Total France</p>
--

<p>Air Liquide ALSTOM Power Boiler (Fr)(GE) ALSTOM Power Centrales ALSTOM Power Ltd (UK) ALSTOM Ltd (CH)</p>	<p>BOC Linde Lurgi Doosan Babcock Siemens</p>
---	--

<p>DLR SINTEF IFP TNO ISFTA</p>
--

<p>Chalmers NTNU University of Paderborn</p>	<p>University of Twente University of Stuttgart University of Ulster</p>
---	---

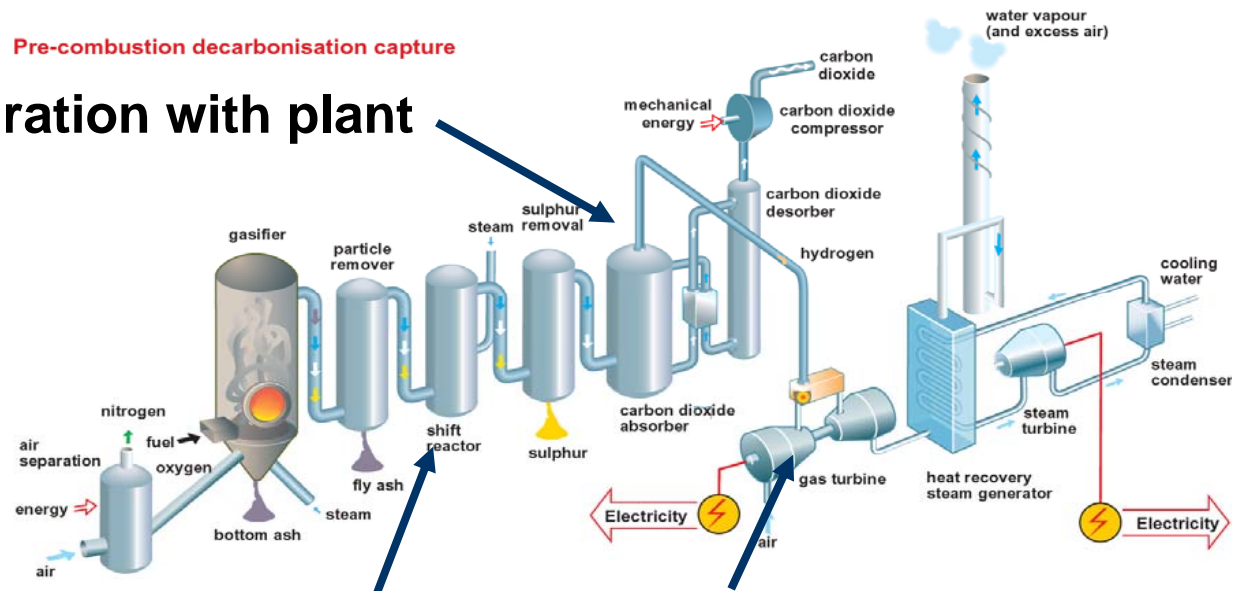
Pre-Combustion Decarbonisation Concept Development

Development of overall plant outline specification:

- 1000 MWeI Bituminous coal and lignite
- Natural gas-fired 400 MWeI Combined Cycle Gas Turbine

Capture unit integration with plant

Pre-combustion decarbonisation capture



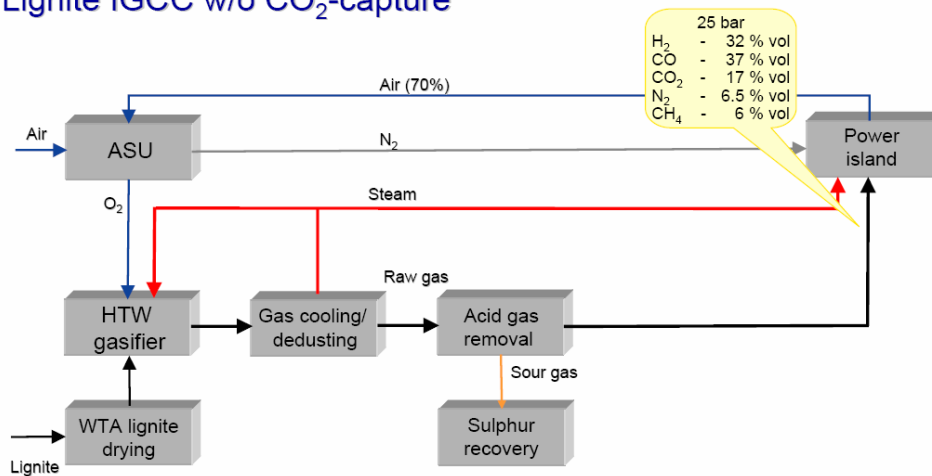
Optimising of CO-shift conversion

H2-rich combustion

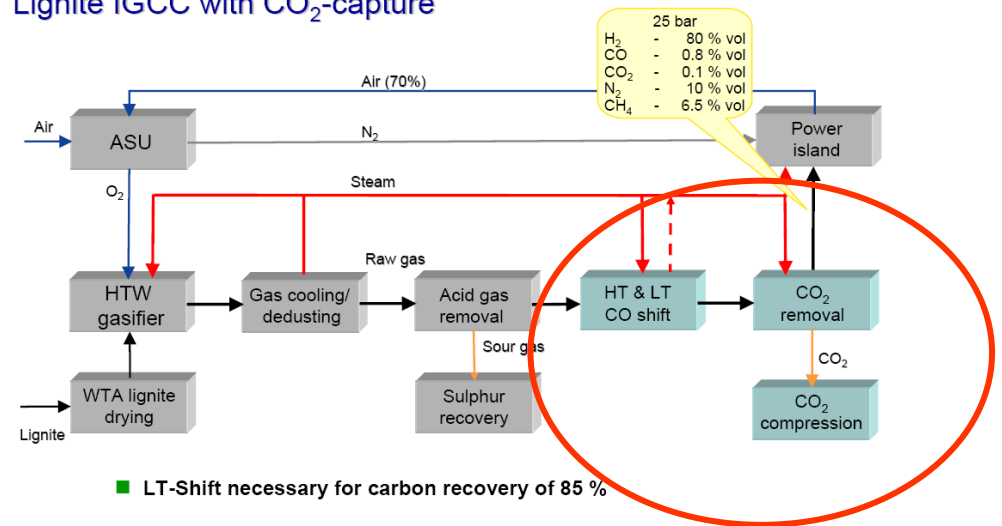
Pre-Combustion Decarbonisation Concept Development

Development of overall plant outline:

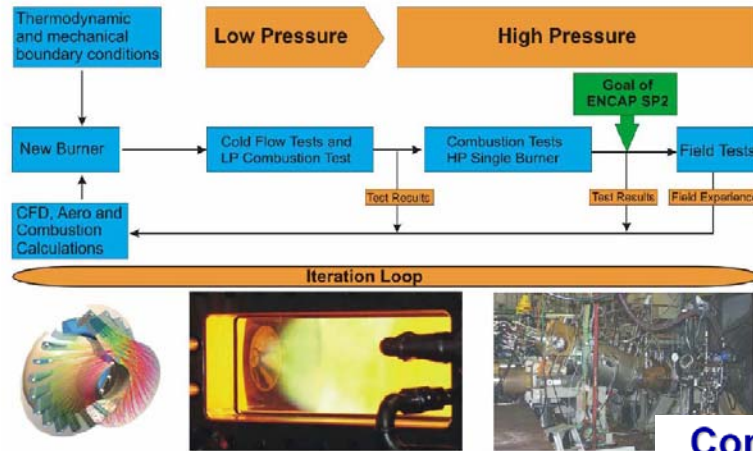
Lignite IGCC w/o CO₂-capture



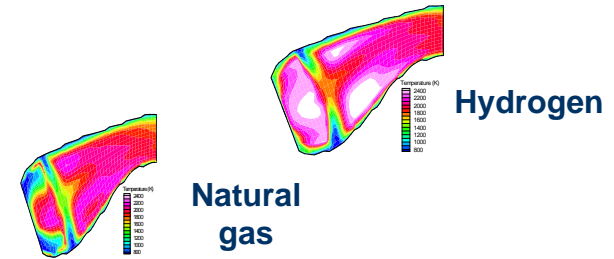
Lignite IGCC with CO₂-capture



Lean-Premixed Combustion of H₂-rich fuels :

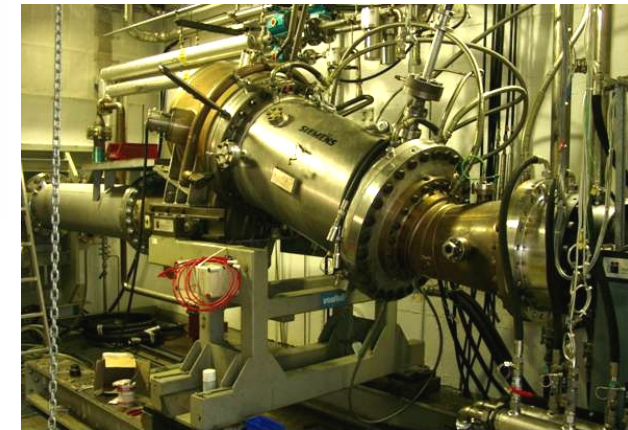
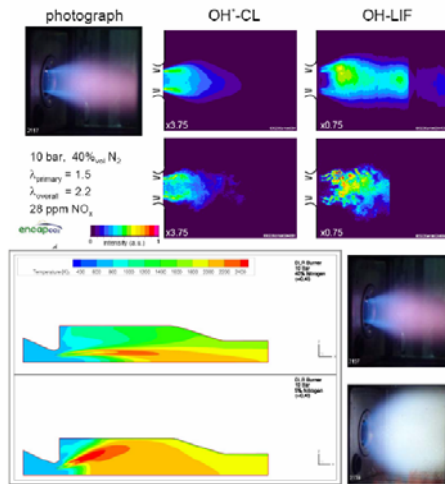
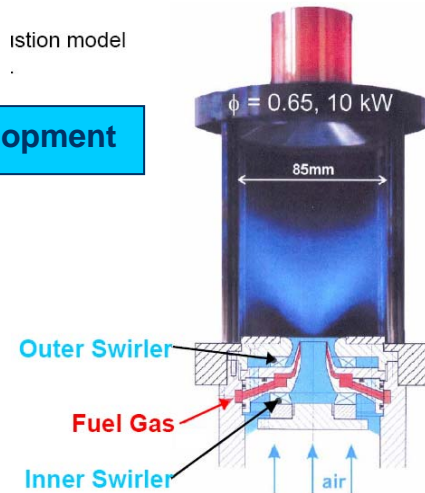


Simulations



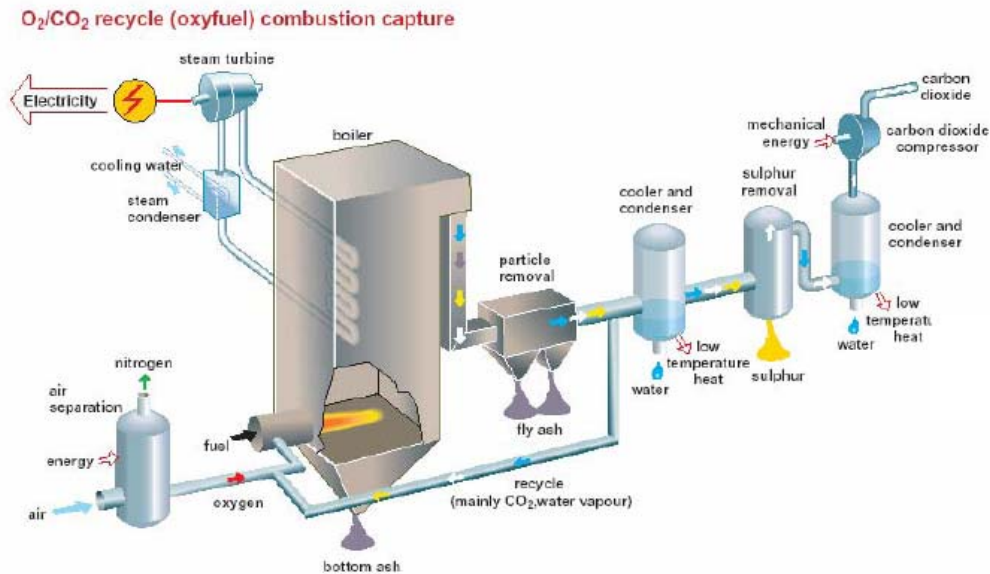
Combustion Modelling - Test data for code validation

New burners development



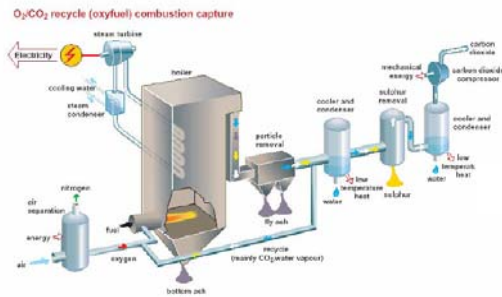
High pressure test rig DLR

OxyFuel Concept Development



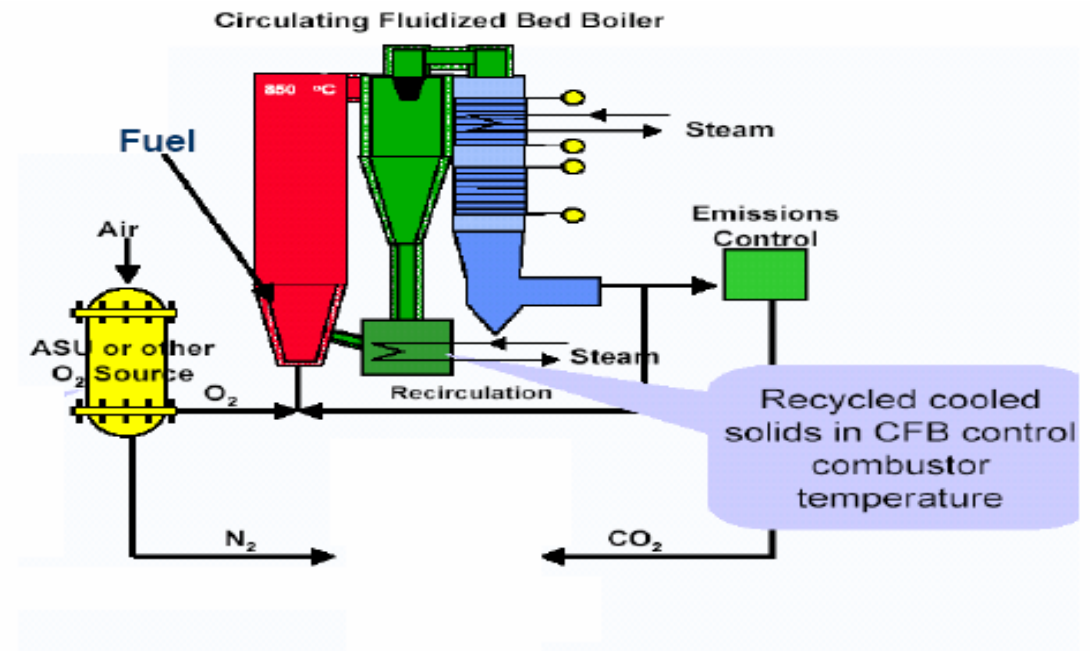
- 600 MWe Bituminous coal OxyFuel PF plant
- 1000 MWe German lignite OxyFuel PF plant
- 380 MWe Greek lignite OxyFuel PF plant

OxyFuel Concept Development



- 600 MWe (gross) Bituminous coal oxyfuel PF plant
- 1000 MWe German lignite oxyfuel PF plant
- 380 MWe Greek lignite oxyfuel PF plant

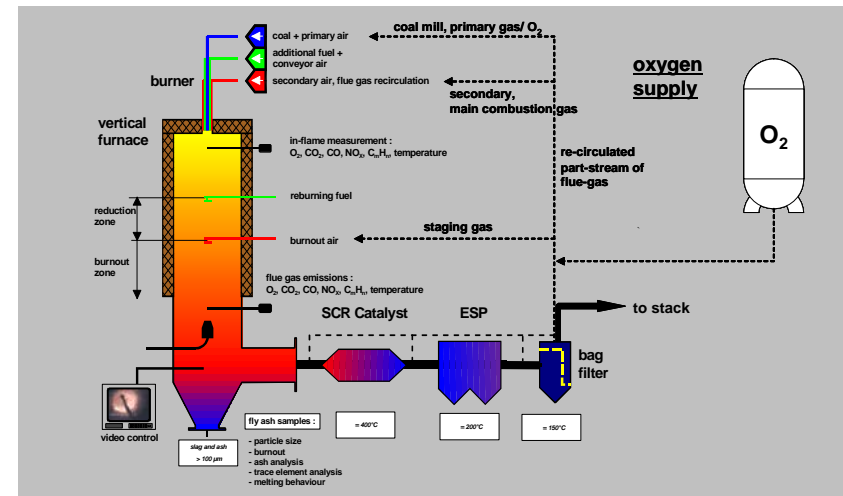
450 MWe Bituminous coal OxyFuel CFB plant



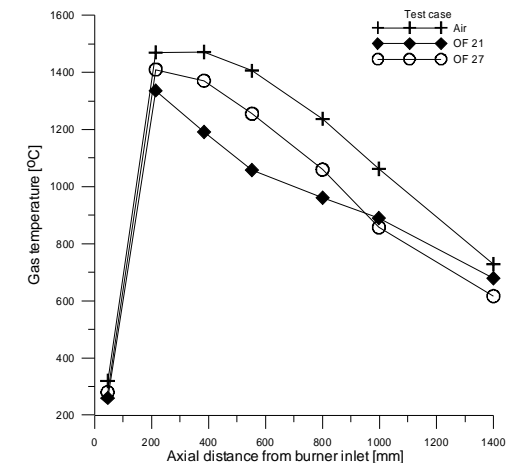
OxyFuel experimental work and pilot testing

- Experimental investigation of combustion fundamentals in
 - 10 kW IVD Stuttgart
 - 100 kW Chalmers Gothenburg
 - 500 kW IVD Stuttgart test rigs

- Phase 2 pilot testing:
 - 30 MW PF OxyFuel pilot plant Vattenfall Schwartze Pumpe

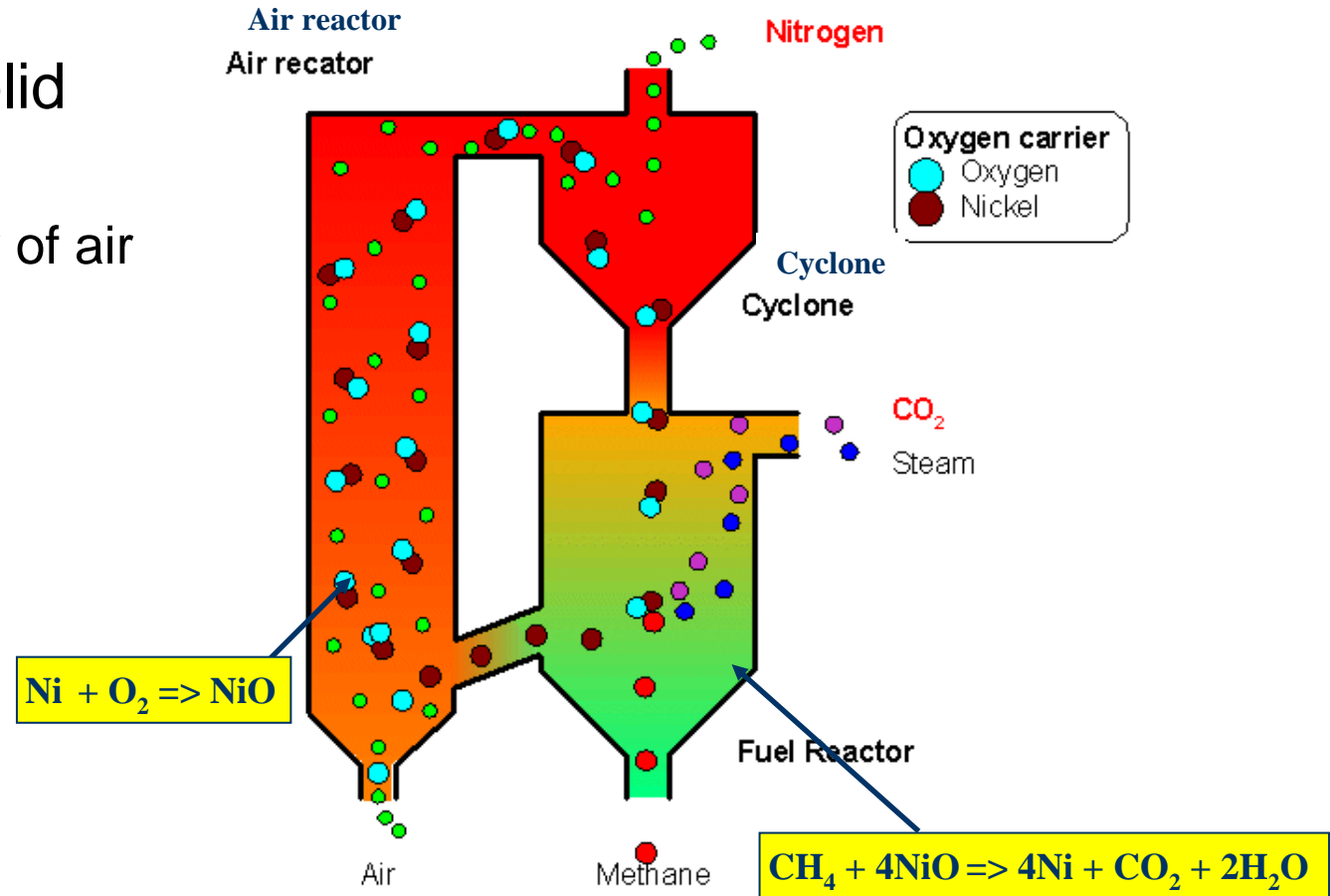


Centerline temperature profiles



Chemical Looping Combustion Development

- Combustion with a solid "oxygen carrier"
 - avoids energy penalty of air separation

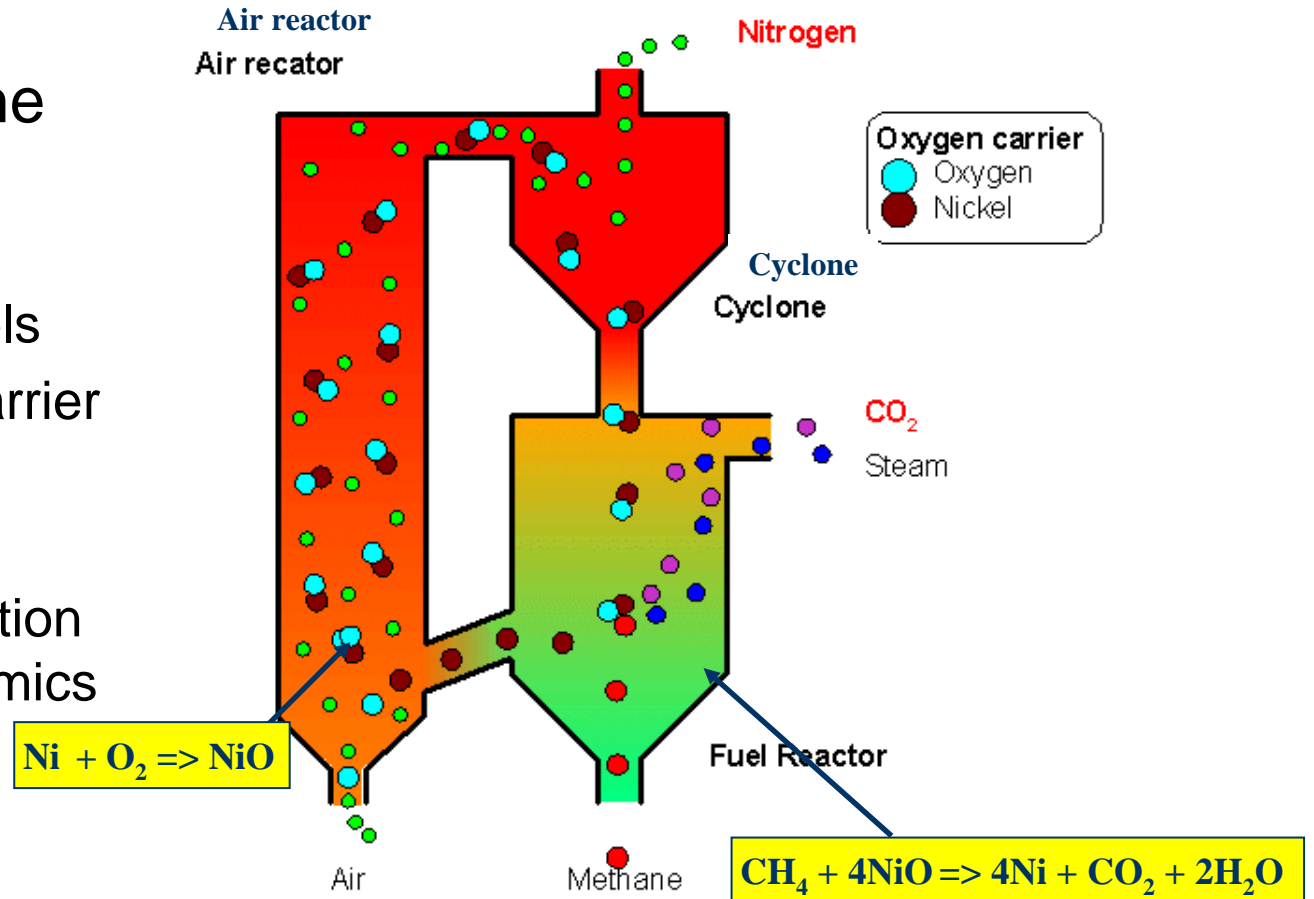


Courtesy Jens Wolf, Vattenfall Utveckling AB

Chemical Looping Combustion Development

■ Developments within the ENCAP project

- Chemical looping combustion for solid fuels
- Evaluation of oxygen carrier materials
- Novel reactor concepts
- Process design, integration optimisation and economics



Courtesy Jens Wolf, Vattenfall R&D AB

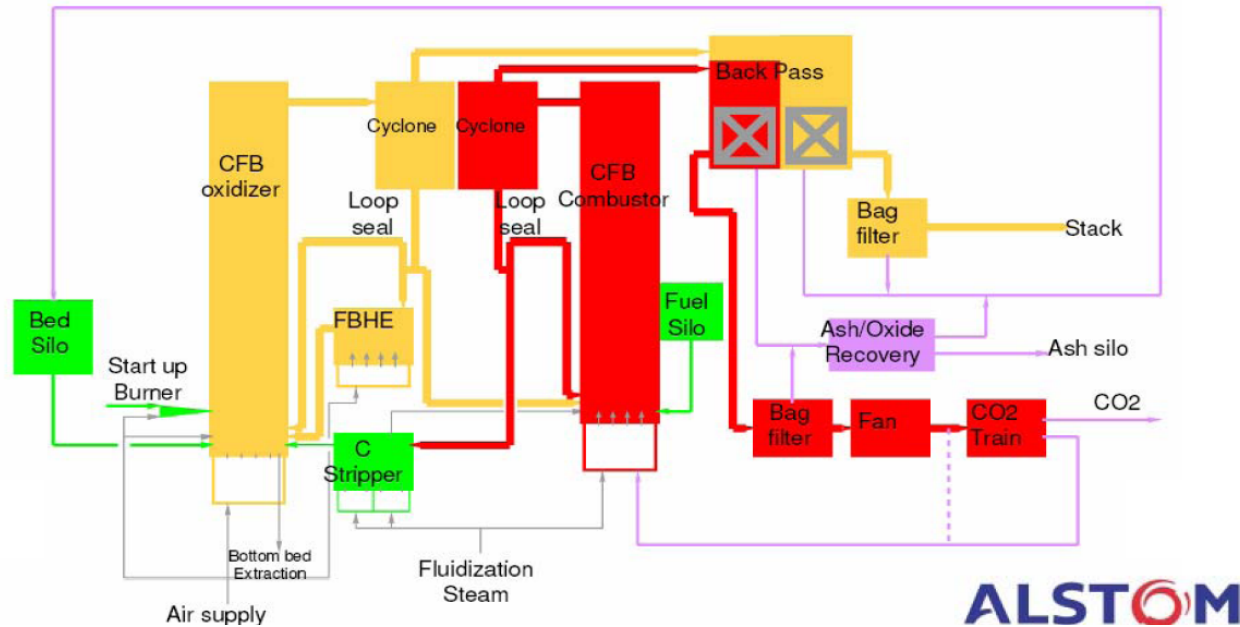
Chemical Looping Combustion Development

Concept design:

455 MWe CFB design :

Net cycle efficiency reduced from 43.5% to 41.5% (low penalty)

CO2 avoidance cost lower than 10€/ton



Testing:

Coal tests in CLC CFB 10 kW
Prototype at Chalmers

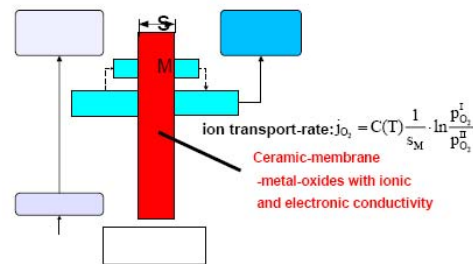


Air separation: Development within the ENCAP project

- High temperature oxygen separation with ceramic materials
 - oxygen transfer membranes
 - high temperature oxygen adsorbent (CAR)

- Development of materials, cost, integration into power plant

O₂-production by a pressure-driven ceramic membrane



O₂-production by CAR process



Air separation: Development within the ENCAP project

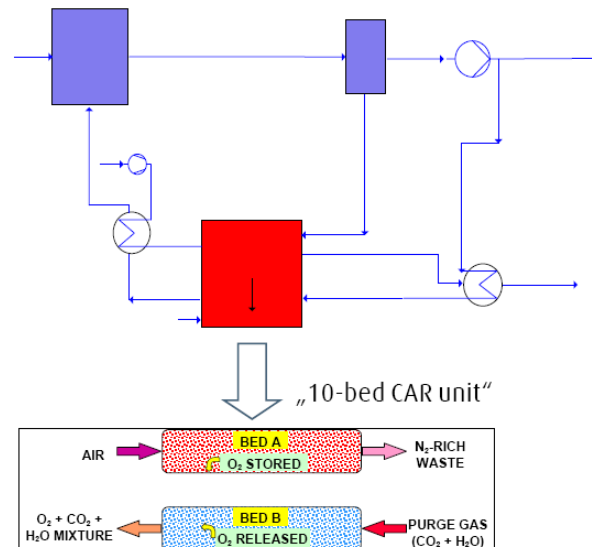
Concept design:

Option selected by SP5 group: CAR Unit in oxyfuel PF-boiler power plant (WP5.3)

Net electricity: 713 MW

Net efficiency: 38%

CO₂ capture: 96%



Material development and testing:



Novel Capture Concepts

- A large number concepts have been classified and evaluated

Around 20 have been further developed including:

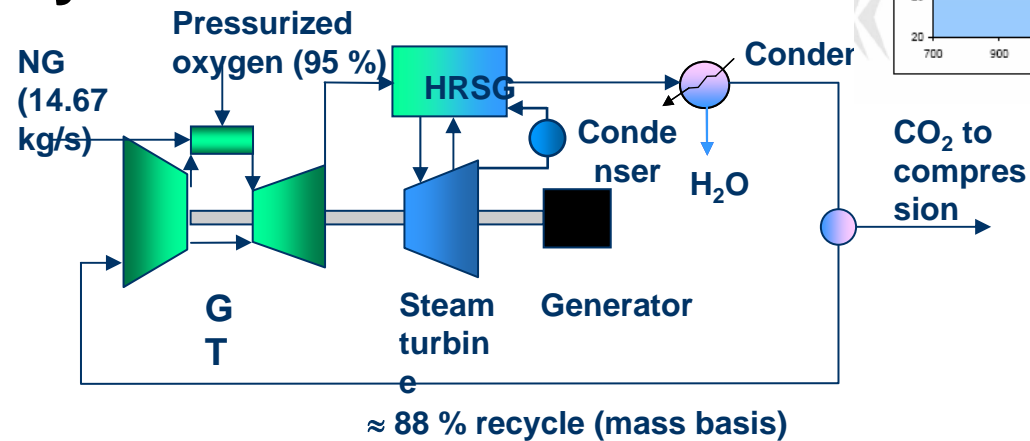
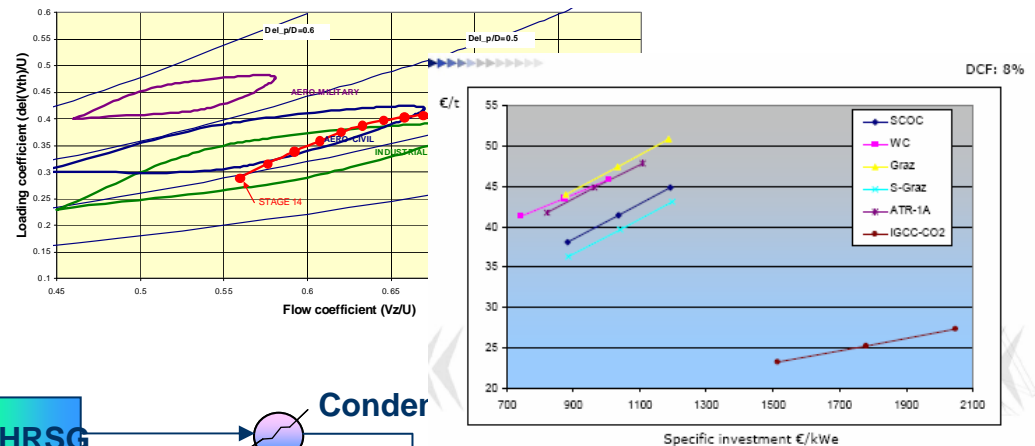
- Oxy-fuel combustion cycles

- Natural gas

- Pre-combustion cycles

- Natural gas
- Hard coal

Location of S-Graz C1 compressor stages on the flow coefficient / loading coefficient diagram



ENCAP Sub Projects

- ❑ **Pre-combustion Technologies for Development and validation**
 - SP2 Pre-Combustion Decarbonisation Concept Development
 - SP3 OxyFuel Concept Development
 - SP4 Chemical Looping Combustion Development
 - SP5 High Temperature oxygen separation technology development
 - SP6 Novel Concepts

- ❑ **Benchmarking of ENCAP developed concepts and recommendation of technology for 350 MW Demo Plant**
 - SP1 Power System evaluation

Reference cases and guidelines for ENCAP technology concepts

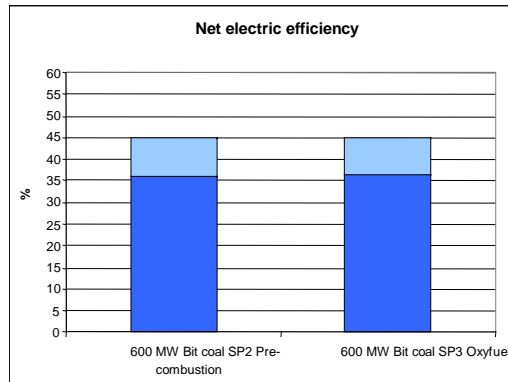
A common framework is established to define:

- State of the art reference power plants without CO₂ capture
 - Natural gas-fired 400 MWe Combined Cycle Gas Turbine (Statoil / Siemens)
 - Hard coal / pet coke-fired 445 MWe Circulating Fluidised Bed (Alstom)
 - Hard coal-fired 600 MWe PF (Mitsui Babcock)
 - Lignite-fired 1000 MWe IGCC/PF (RWE / Vattenfall)
 - Lignite fired 380 MWe PF (PPC).
- Boundaries for economic analysis
- Procedure to evaluate power plants with CO₂ capture
- Design scenarios for CO₂ purity

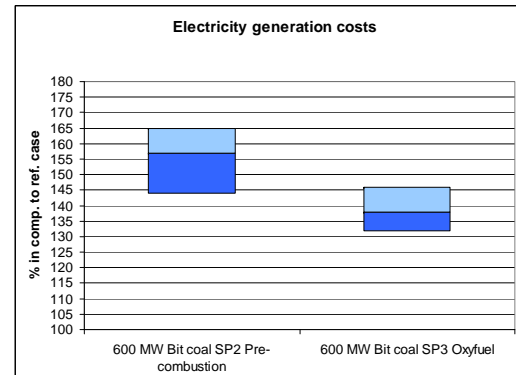
■ This has enable consistency in the benchmarking of CO₂ capture alternatives

Benchmarking in ENCAP

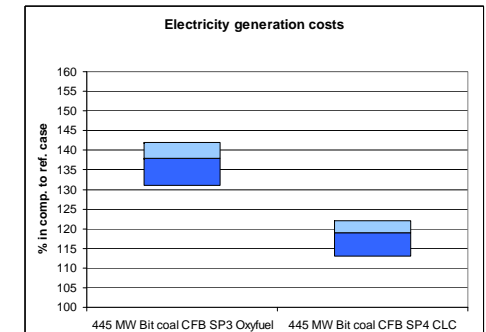
PF 600 MWel gross reference case



PF 600 MWel gross reference case



CFB 445 MWel gross reference case

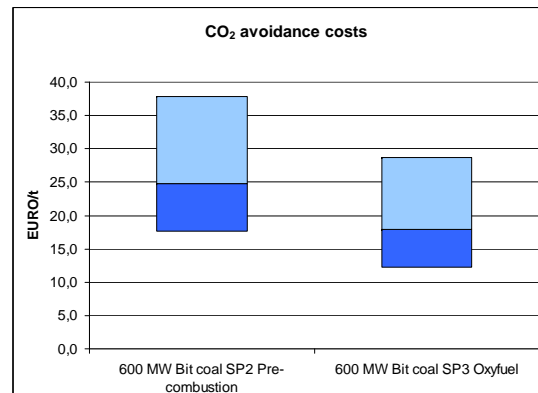


Net electricity reduced with capture:
 6-9 % for IGCC, OxyFuel PF , CFB hard coal
 15 % IRCC natural gas

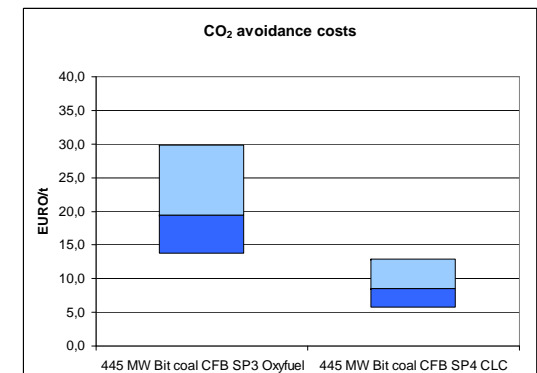
Electricity cost with capture increased:
 30-60% for developed technologies

CO2 avoidance cost:
 18-24 €/t IGCC
 13-17 €/t OxyFuel
 6-8 €/t CLC

PF 600 MWel gross reference case



CFB 445 MWel gross reference case



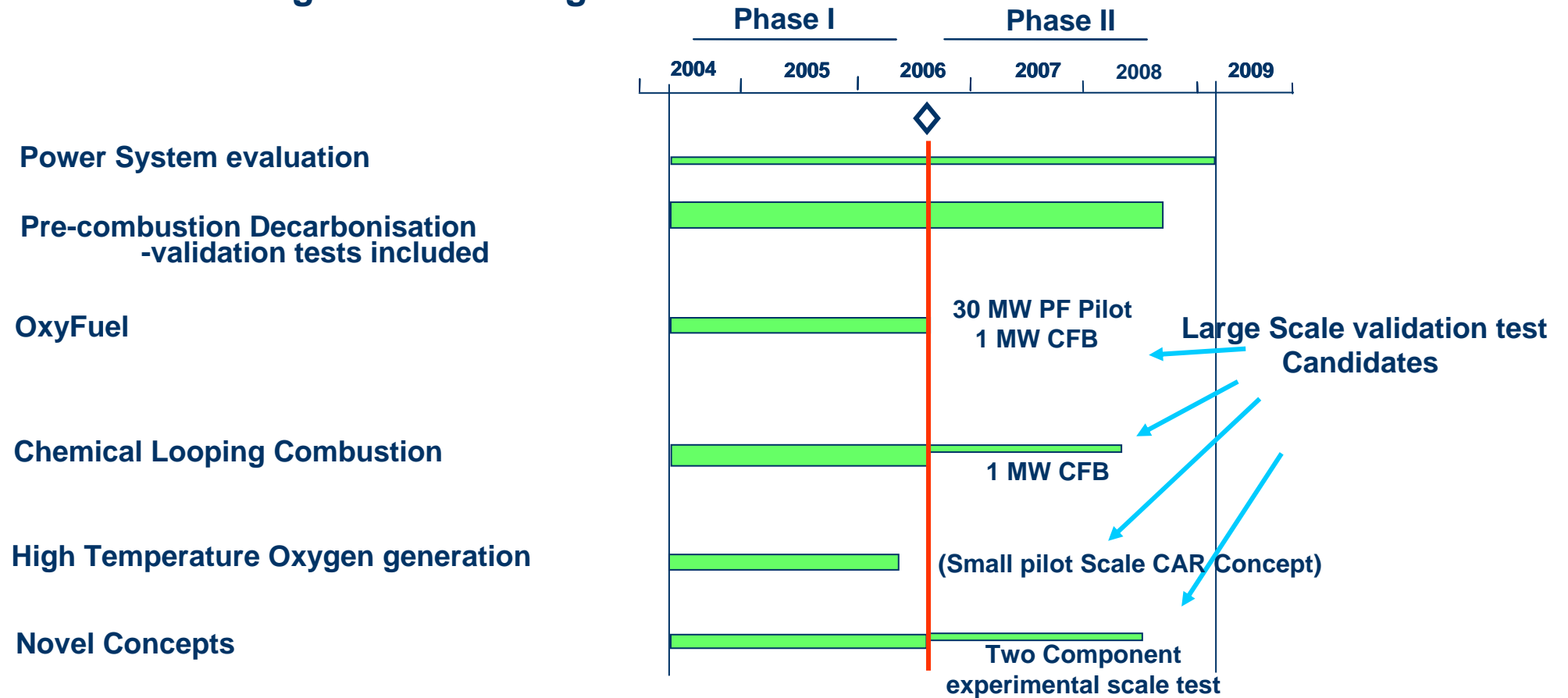
Cost base: Year 2005

ENCAP Integrated Project

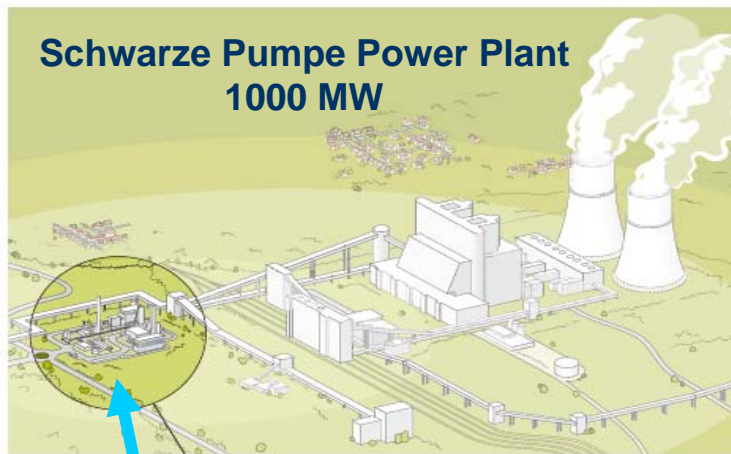
A two phase approach in the development and validation of pre-combustion technologies of capture of CO₂

ENCAP 5 year project – Planned in two phases

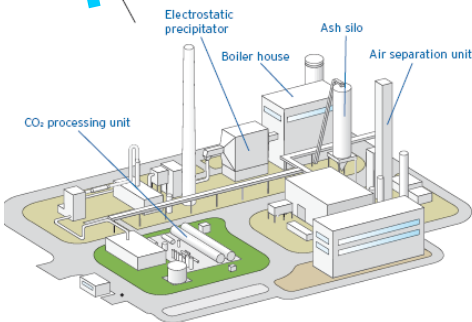
Selection of Large Scale Testing candidates 2006:



Vattenfall 30 MW PF OxyFuel Pilot in Germany



Pilot Plant

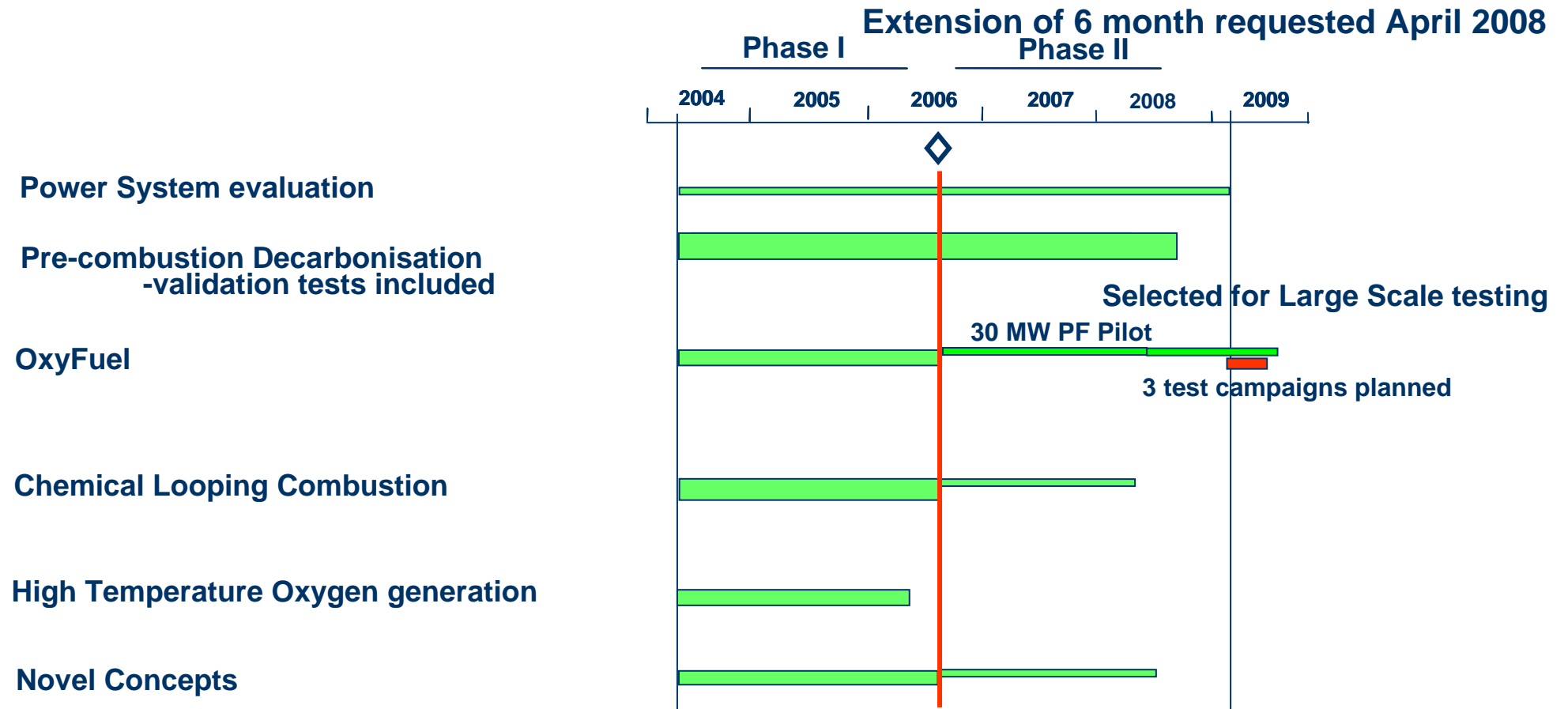


First pilot including the whole chain/components:

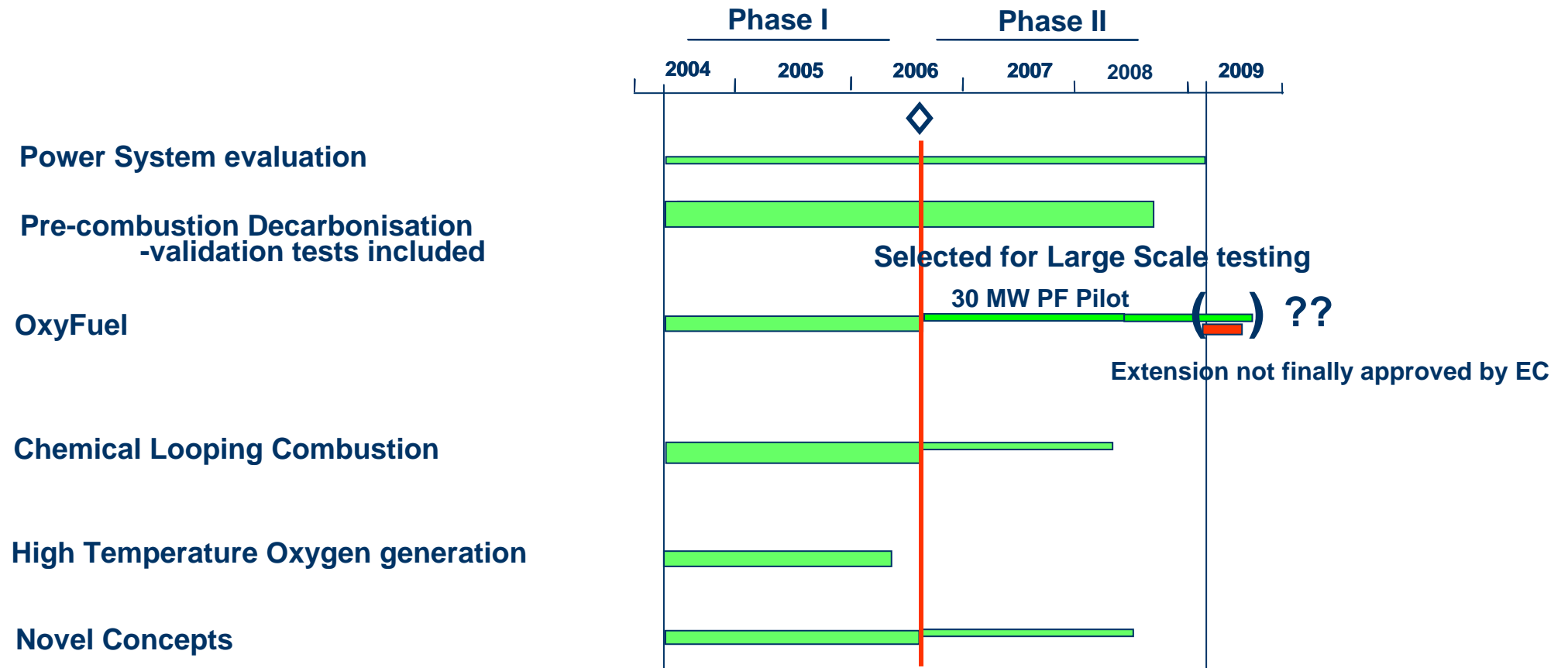
- Air separation
- Boiler 30 MWth
- Ash treatment
- Electrostatic precipitator
- CO₂ processing unit



ENCAP 5 year project – Planned in two phases



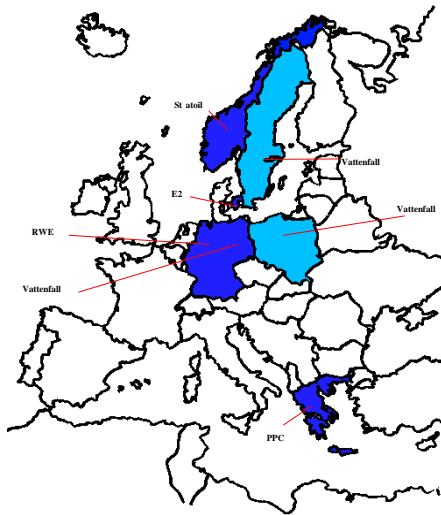
ENCAP 5 year project – Planned in two phases



Thanks for the attention

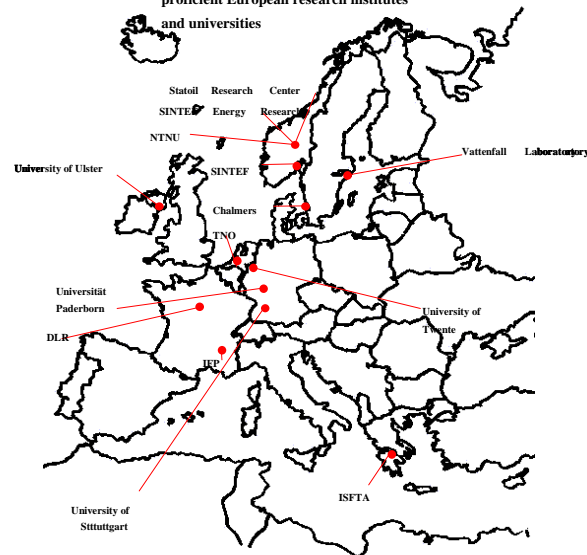
Energy providers

Main operating areas
Power & fossil fuel suppliers



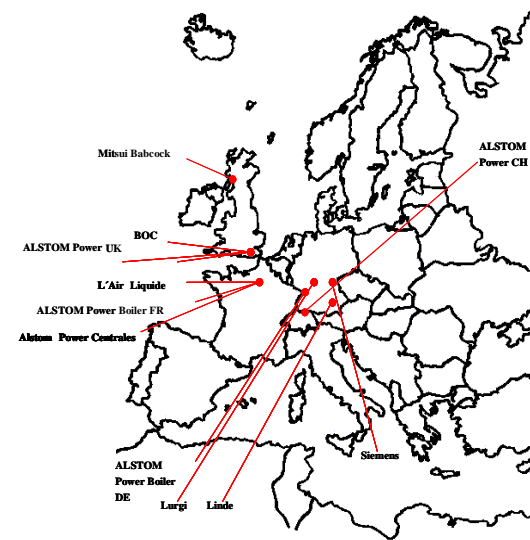
RTD Providers

proficient European research institutes
and universities



Technology providers

leading European manufacturers



the ENCAP consortium