SP6 Public Summary Report

Based on:
Del 6.1.4 Evaluation of technologies and benchmarking based on reference cases
Del.6.2.1 Modelling, Design and Operational Analysis

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ENCAP SP6 aims at investigating prospective emerging pre-combustion capture technologies having a high potentiality for capture cost reduction while maintaining a high capture rate. A vertical, three-step approach by screening, modelling and verification was decided. This involved actions like world-wide screening of energy conversion technologies, generating new ideas on advanced power generation and cycle development, classification of emerging technologies by in-depth investigation - supported by modelling, conceptual design, novel techniques for experimental clarification of selected key elements, and economic ranking.

1. Evaluation of Technologies & Benchmarking

Within this framework substantial work has been carried out dealing with power cycle simulations in order to have a fair and extensive comparison of net efficiency and CO_2 capture rate of different power cycles concepts with CO_2 capture (Fig. 1, 2). There were separate comparisons of natural gas-fired cases and coal-fired cases (both lignite and hard coal). In the comparison between the oxy-fuel and the pre-combustion cycles, for the natural gas-fired cases, it should be taken into account that the pre-combustion cycles (except the air-blown auto-thermal natural gas reformer with combined cycle, ATR-CC case) include more innovative, not yet commercially available components (membrane reactors), compared with the oxy-fuel cycles. Additionally, the pre-combustion cycles have a larger number of cycle components compared with the oxy-fuel cycles. However, there are several unresolved issues for the oxy-fuel cycles, for example turbo-machinery that can operate with CO_2/H_2O working fluids. The cycles involving oxygen-transport membranes (Advanced Zero Emission power Plant -**AZEP**- and Oxy-fuel fired lignite cycle with integrated gas turbine and OTM module -**OTM**) involve technology that is not yet developed to a level where it can be applied in power plant operation. Considering the Chemical Looping Combustion (CLC) cycles, most of the components are state-of-the-art and commercially available except for the reactor system. Overall, the CLC cycles with the pressurised reactors (integrated in gas turbine cycles) pose a higher degree of novelty compared to the other cycles in terms of the key components design as well as plant control.

Table 1 Cycle considered for the evaluation

Integrated Brayton-Rankine Cycle – Water Cycle
Integrated Brayton-Rankine Cycle – Original Graz Cycle
Integrated Brayton-Rankine Cycle – S-Graz Cycle
Semi-closed Oxygen-Combustion Gas Turbine Cycle (SCOC-GT)
Semi-Closed Oxygen-Combustion Combined Cycle (SCOC-CC)
Pre-Combustion Cycle Siemens-1 – ATR Power Cycle with H2 Separation Membrane
Pre-Combustion Cycle Siemens-2 – ATR Power Cycle with H2 Separation Membrane
Pre-Combustion Cycle Siemens-3 – ATR Power Cycle with H2 Separation Membrane
Hygensys Cycle :
Pre-Combustion 1a with ATR O2-membrane and WGS H2-membrane
Pre-combustion cycle NTNU 1b with ATR O2-membrane reactor and WGS H2-membrane reactor
Pre-combustion cycle NTNU-2a with ATR O2-membrane reactor (high pressure) and WGS H2-membrane reactor
Pre-combustion NTNU-2b with ATR O2-membrane reactor (high pressure) and WGS H2-membrane reactor
Pre-combustion cycle NTNU-3a with ATR O2-membrane reactor and WGS CO2-membrane reactor
Pre-combustion cycle NTNU-3b with ATR O2-membrane reactor and WGS CO2-membrane reactor
Integrated Gasification Combined Cycle with CO2 Capture (IGCC-CA) – no ASU Integration
Integrated Gasification Combined Cycle with CO2 Capture (IGCC-CAASU) – 100% ASU Integration

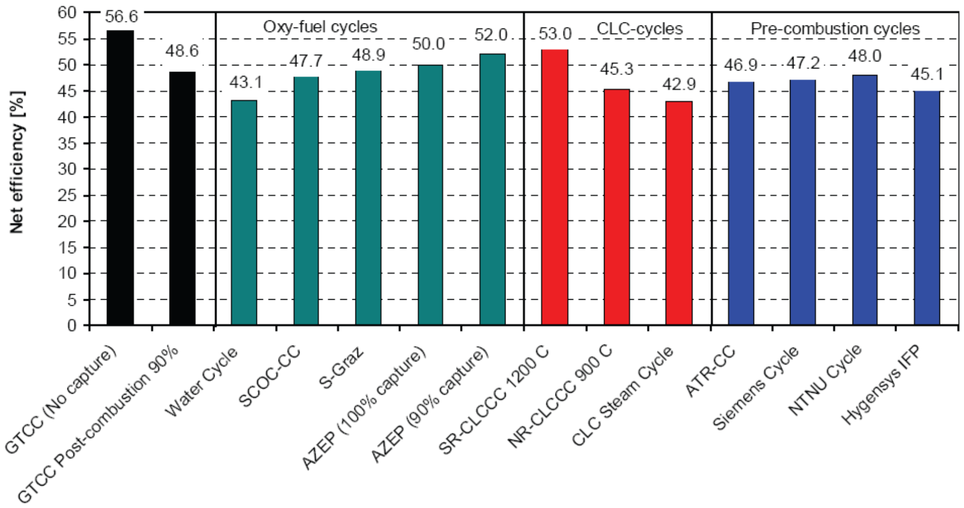

Figure 1: Net plant efficiencies of the natural gas-fired cycles

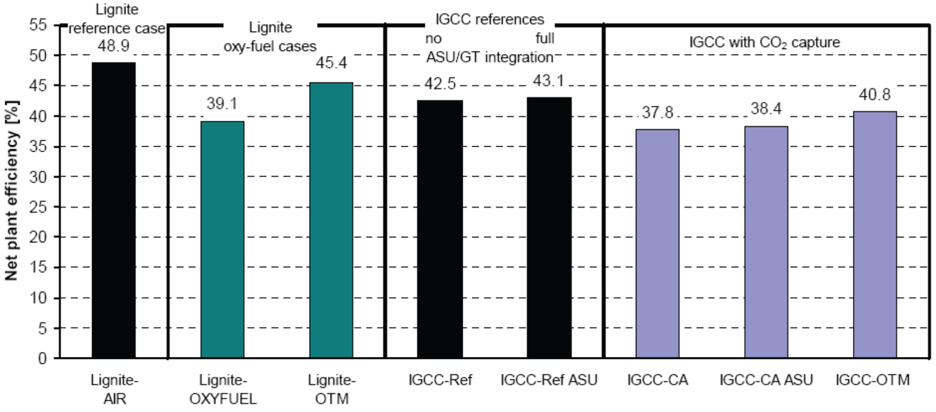

Figure 2: Net efficiencies of all coal-based cycles

2. Analysis of Cycle Components

Work package WP6.2 of ENCAP has the objective of identifying the potential difficulties of practical implementation of these cycles in real world power plants, from the point of view of the equipment manufacturers. The ultimate practical implementation in power plants will depend upon attributes such as capital cost, efficiency, reliability, availability, maintainability and life expectancy. These attributes of the whole electricity generation system will depend on the corresponding attributes of its components: compressors, turbines, combustors, heat exchangers and novel components. The mission is thus to examine the components of those cycles and to evaluate them with respect to those attributes. If it is assumed that each cycle has on average five critical components, the task would involve around one hundred components. As a detailed study of all components would not be practical within a reasonable timescale, a two-stage approach was adopted.

In the first stage, a so-called ‘component book’ was created, containing some basic information for each component:

- Inlet conditions: streams, compositions, mass flows, pressures and temperatures
- Power, polytropic and isentropic efficiencies, for turbo-machinery components
- Outlet conditions: streams, compositions, mass flows, pressures and temperatures

Expert opinion was then sought about the critical components, covering materials, gas turbines with or without cooling, compressors, combustors, steam turbines, heat exchangers and special reactors. The components were classified into three levels, technically and economically:

- Components involving available technology and current engineering practice (green)
- Components not within current engineering practice but not requiring new scientific developments (yellow)
- Components requiring completely new development or representing very high cost (red)

In the Table 2 below a summary of the general analysis of components of some selected cycles is shown. The general types of components considered are compressors, turbines, combustors and other reactors and heat exchangers. Colour classification corresponding to the most critical component of each type is shown for each cycle, with brief highlights of the problems observed.

Detailed Analysis of combustors, compressors and turbines

In the second stage a more detailed numerical analysis of selected components was made. At the time of writing this report, they were combustors, a compressor and a turbine and were chosen from the most promising cycles studied within the project. The analysis has proven that even the least complex cycles may require significant component design changes with respect to commercially available equipment, which will lead to substantial product development and tests. The examples of the preliminary design of a turbine and a compressor for the Semi-closed Oxy-fuel Combustion Combined Cycle are given below.

The working fluid of the SCOC-CC compressor necessitates the design of a radically different compressor from those currently in use in 50Hz power generation gas turbines. The working fluid results in the need for more stages at lower exit radius. Fig. 3 shows the compressor profile. As compared to the compressors of conventional power generation gas turbines, this compressor is longer. This implies a complete and probably costly re-design, not within current engineering practices. Ways of reducing the overall length of the compressor should be investigated. Provided the above does not result in the need to modify the selected compressor parameters significantly, high efficiencies should be attainable in line with the values currently assumed in the cycle calculations.

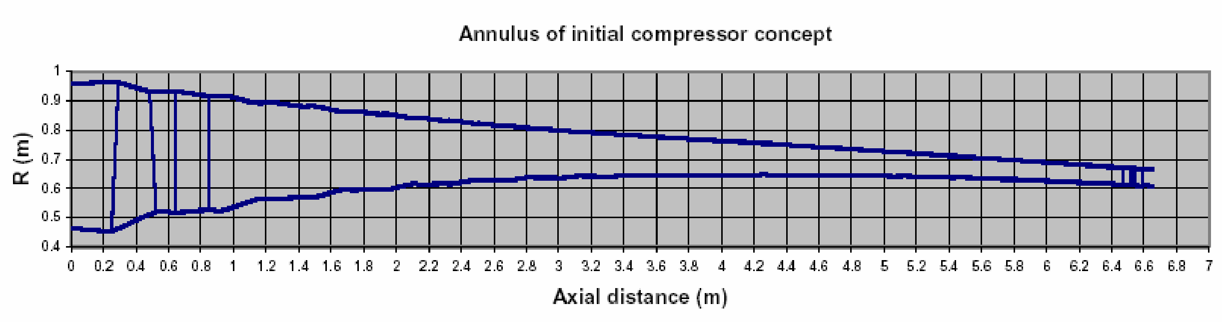

Figure 3. Initial design of CO_2/H_2O compressor annulus

The working fluid of the SCOC-CC turbine dictates that a new turbine is required, i.e. existing power generation turbines would not be suitable. Fig. 4 shows the turbine profile.

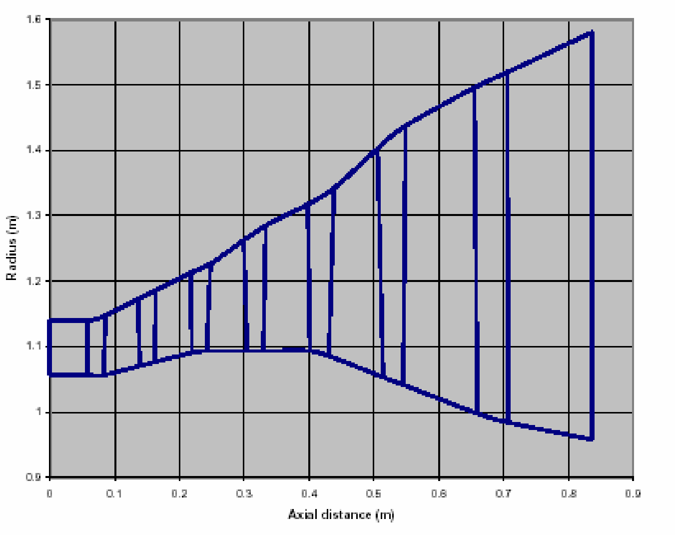

Figure 4. Initial design of turbine annulus

The main difference between this turbine and conventional air turbines is in the first stage, where the hub/tip ratio is higher than that of conventional turbines. This may cause high losses, affecting the turbine efficiency. Also the implications of CO_2 as the cooling fluid should be assessed.

These two examples show that detailed analysis is necessary for a deeper understanding of the difficulties and costs to develop the components of the most promising cycles and to integrate them in power plants.

More information can be found under :

Flavio J. Franco, Theo Mina, Gordon Woollatt, Mike Rost, Olav Bolland, "Characteristics of Cycle Components for CO_2 Capture", Proceedings of the GHGT8, 19-22 June 2006, Trondheim, Norway.

Table 2: Summary of the general analysis of components for some cycles

General type of component	Oxy-fuel Water Cycle		Oxy-fuel Original Graz Cycle		Oxy-fuel Steam Graz Cycle		Oxy-fuel SCOC-GT		Oxy-fuel SCOC-CC		Pre-Combustion Siemens 1	
	4		5		6		7		8		9	
	Tech	Eco	Tech	Eco	Tech	Eco	Tech	Eco	Tech	Eco	Tech	Eco
Compressors			Very high volume flow rate (860 m^3/s). Potential corrosion problems. Unknown corrosion effects of CO_2 and steam in the cycle concentrations.	Two units in parallel required. Complex design.	CO2 + Steam. Potential corrosion problems.	Cost of materials development.	Mixture of CO2 and Steam. Potential corrosion.	New design due to properties of CO2.	Working fluid is a mixture of CO2 and Steam.	New design due to working fluid.	Large fractions of CO2 and steam. Potential effects on materials.	New design due to working fluid.
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Turbines	Very high pressure ratio = 138. Potential sealing problems. Steam cooling. Turbine inlet temperature is 1254 °C after mixing with coolant. Working fluid is 87% steam + 12% CO_2.	Completely new design due to working fluid and pressure ratio.	Steam cooling. CO2 + Steam. Potential corrosion problems with inlet temperature 1247 °C.	High power output (470 MW). High development costs.	Slow pressure uncooled turbine for 10% CO2 and 89% steam. Exit gas below dew point temperature (32.54 °C). Corrosion potential problems.	Completely new design due to working fluid.	Mixture of CO2 and Steam. Potential corrosion.	New design due to working fluid.	Mixture of CO2 = Steam. Corrosion to be investigated.	New design due to working fluid.		
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Combustors and Other Reactors	High pressure (92 bar). Extensive development required. Desired temperature may be achieved by mixing steam to O_2.	High development cost.	Need to cool combustor with water & ex. gas.	Some cooling development cost.	Steam to be added for temperature control.	Cost of development of cooling system.	O2 to be mixed with CO2 for combustor temperature.	New design for CO2 circulation.	O2 to be mixed with CO2 for combustor temperature.	New design due to circulation.	Syngas splitting with H2 permeable membrane.	High development cost and unknown capital cost. Unknown reliability and effectiveness.
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Heat Exchangers	Very low pressure. Low heat transfer coefficient.	Large size equipment: high capital cost.			Low pressure condenser for CO2 & steam. Corrosion in condensation section.	Very low heat transfer coefficient.Exit pressure very low. Large size and capital cost.	Corrosion may be a problem in condensation section.		Corrosion may be a problem.		High temperature / multiple media.	Development costs and capital cost.
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