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The Zero Emission Power Plant Concept

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Contents

Introduction

- In the assessment report of IPCC it is stated that most of the observed global warming over the last 50 years is likely to have been due to the increase in GHG concentrations in the atmosphere. The IPCC further concludes that the stabilisation of the atmospheric CO_2 concentration requires CO_2 emissions to eventually drop well below current levels.

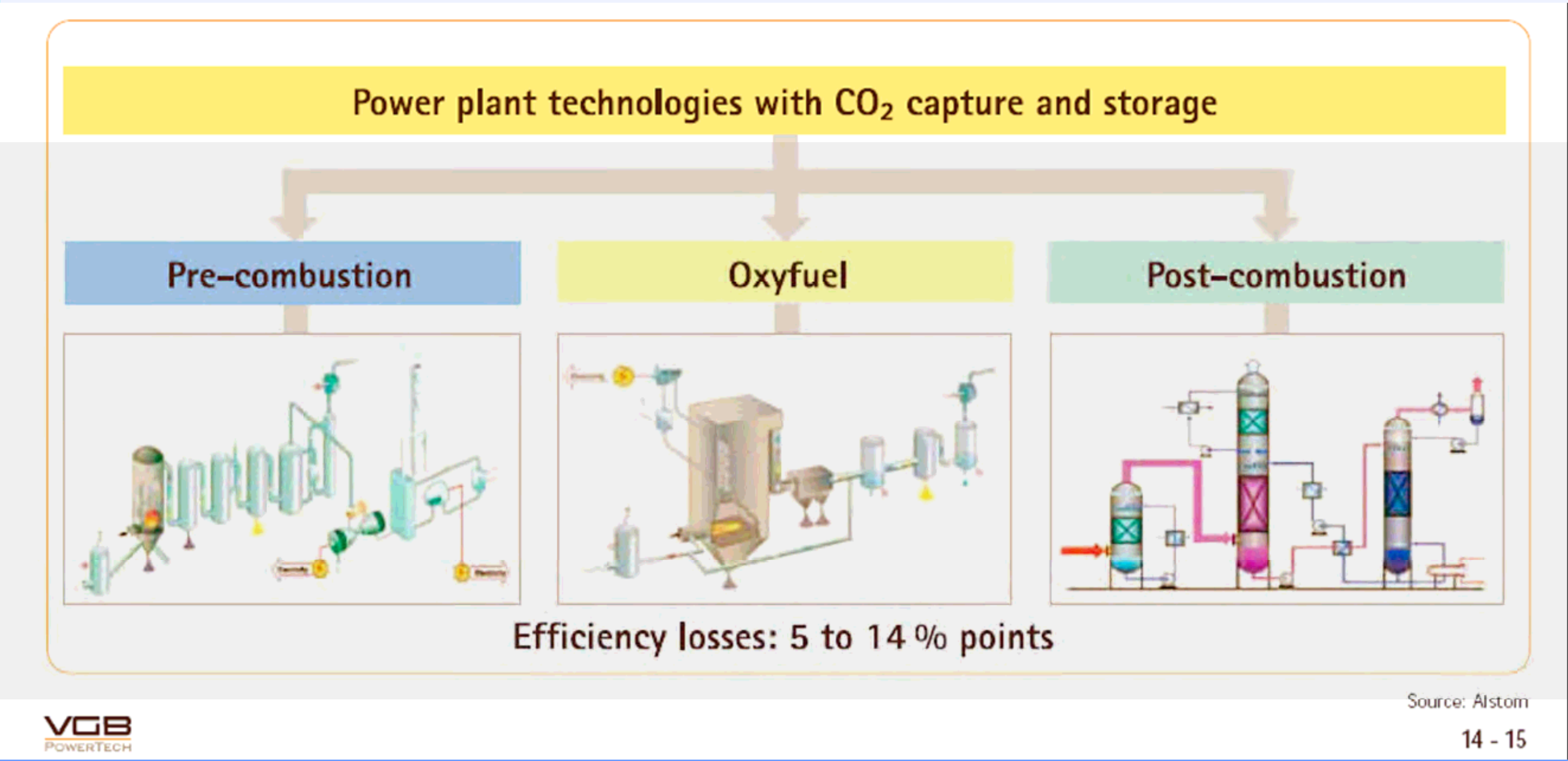
- In analysing CO_2 emissions reduction measures, it is concluded that none of the following measures alone is sufficient to stabilise CO_2 concentrations:
  - demand reductions and/or efficiency improvements
  - Increase of natural gas use
  - substitution among fossil fuels
  - switching to renewables or nuclear energy
  - CO_2 capture and sequestration
  - afforestation.

- At present, fossil fuels are the dominant source of the global primary energy demand, and will likely remain so for the rest of the century supplying over 85% of all primary energy, is spite of great efforts and investments made by many nations to increase the share of renewable energy to the primary energy demand and to foster conservation and efficiency improvements of fossil fuel usage.

- Capture and secure storage of CO_2 (CCS) allows the use of fossil fuels, while reducing atmospheric CO_2 emissions and mitigating global climate change.

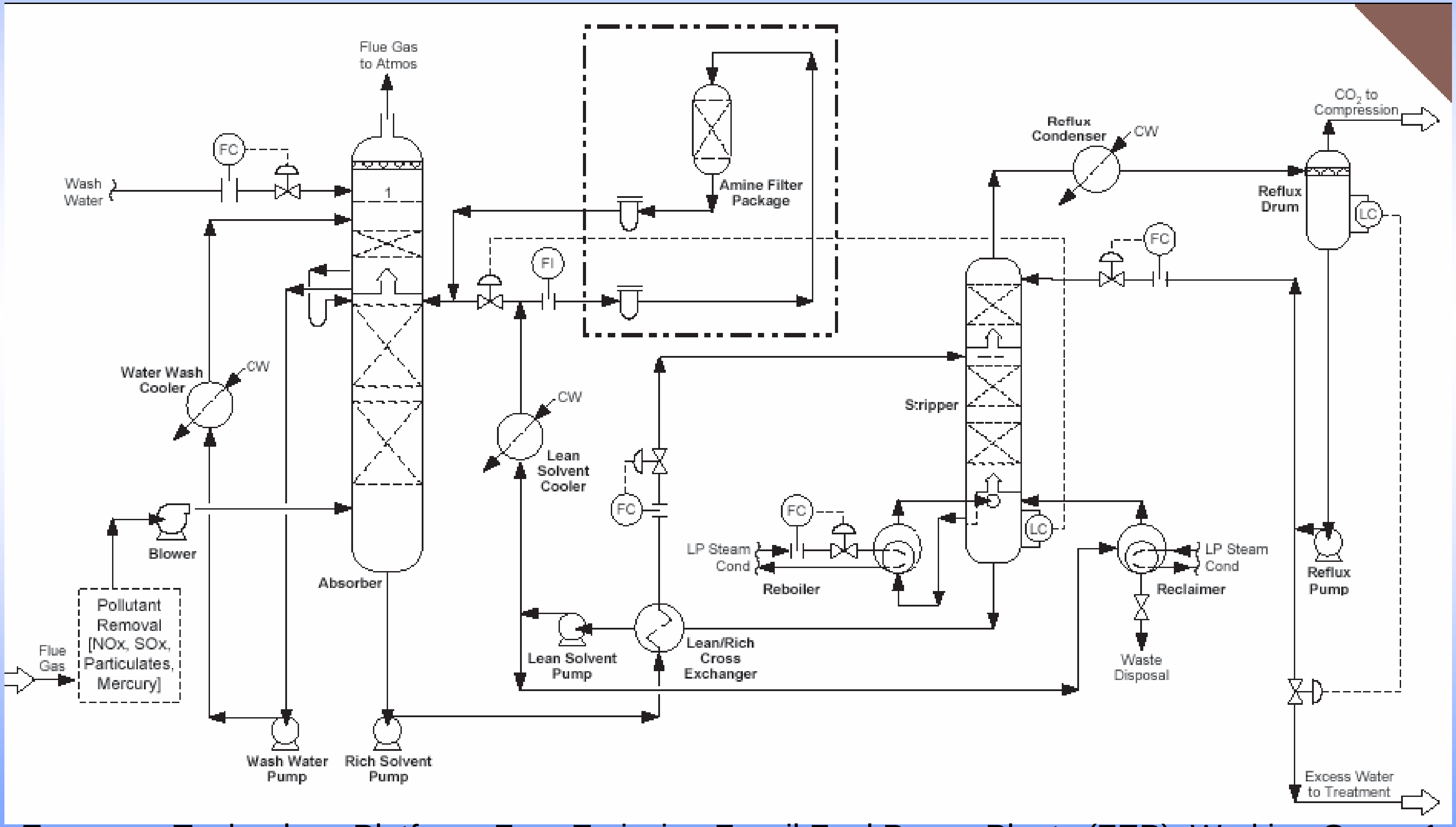
CCS Technologies in Thermal Plants 1/5

- The commercial or under development CO_2 sequestration technologies for coal-fired power plants can be divided into three broad categories:
  - Post combustion: separation of CO_2 from waste gas
  - Oxyfuel: combustion in O_2 instead of air
  - Pre-combustion: production of a carbon free fuel



CCS Technologies in Thermal Plants 2/5

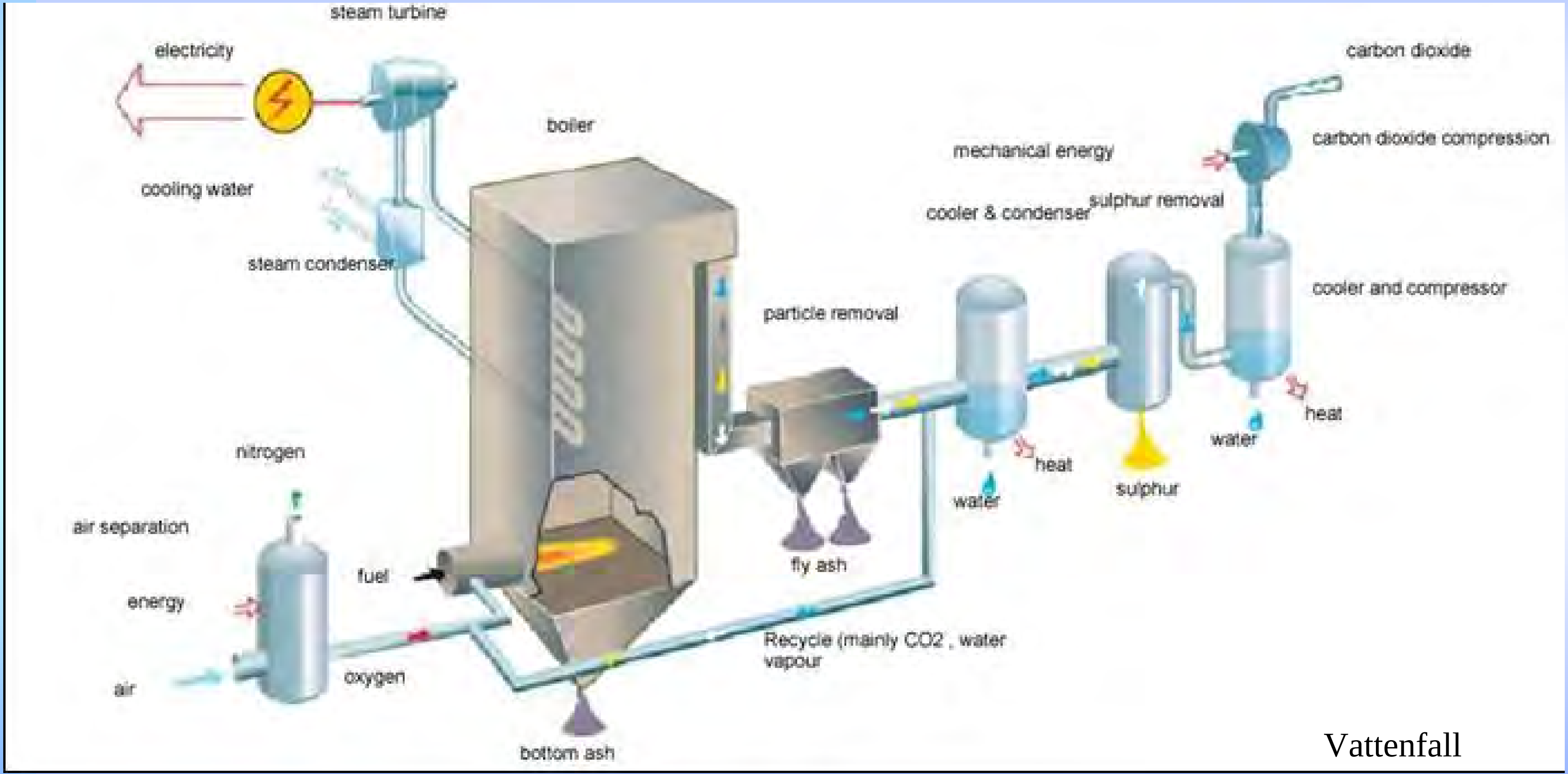
CO_2 scrubbing from flue gas using amine solution



European Technology Platform, Zero Emission Fossil Fuel Power Plants (ZEP), Working Group 1, Power Plant and Carbon Dioxide Capture

CCS Technologies in Thermal Plants 3/5

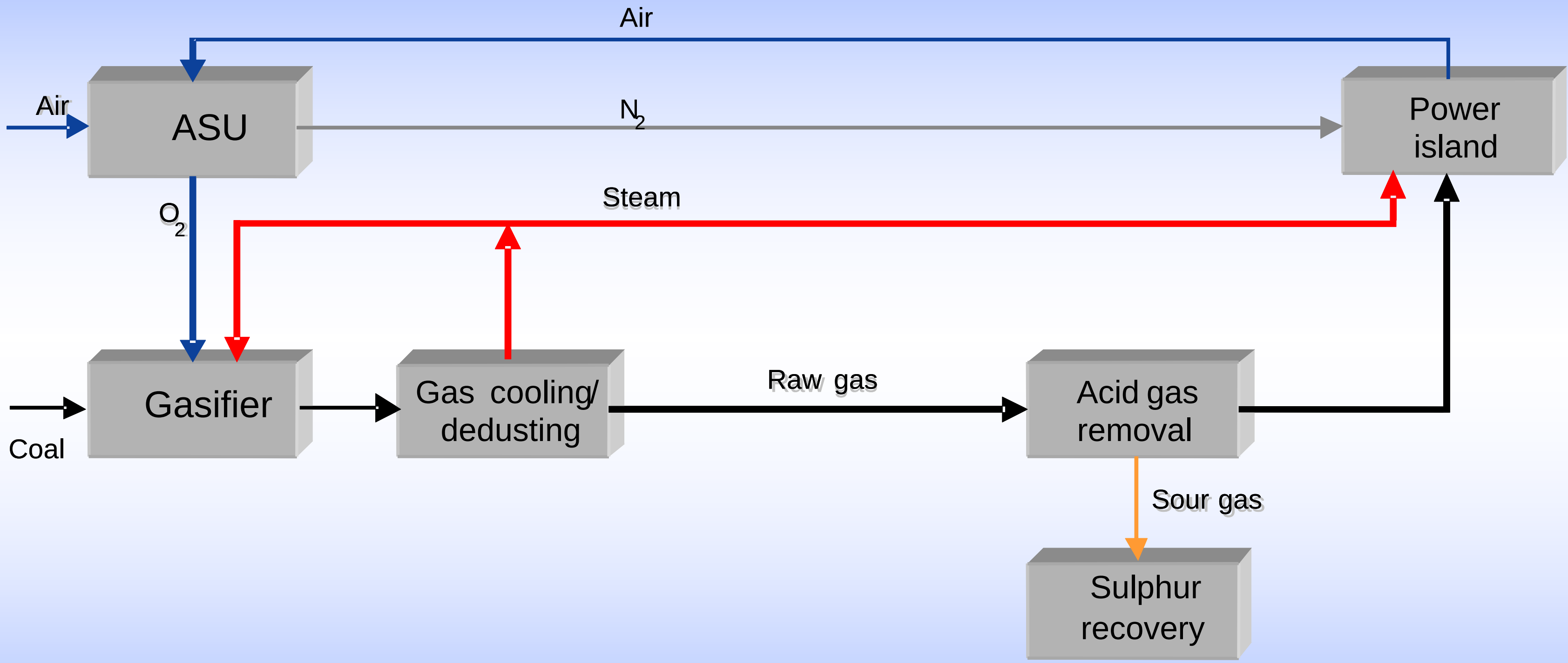
Oxyfuel combustion



Vattenfall

CCS Technologies in Thermal Plants 4/5

Production of a carbon free fuel



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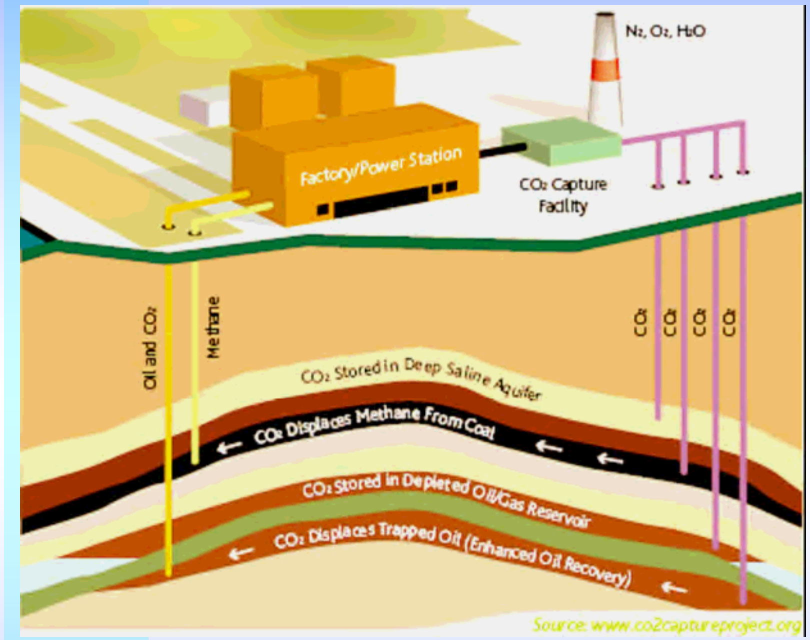
CCS Technologies in Thermal Plants 5/5



2006 2015 2020

Conceptual investigations	Laboratory Test	Pilot Plant	Demo-Plant	Commercial Plant
• Theoretical Research	• Research • Basic principles • Combustion characteristics	• Demonstration of the process chain • Interaction of components • Validation of basic principles and scale-up criteria • Long term charac-teristics • Non-commercial	• Verification and optimization of the component choice, the process and reduction of risks • Commercially viable incl. subsidies	• Competitive in the market at that time • No subsidies

CCS Technologies Time Frame

European Technology Platform, Zero Emission Fossil Fuel Power Plants (ZEP), Working Group 1, Power Plant and Carbon Dioxide Capture

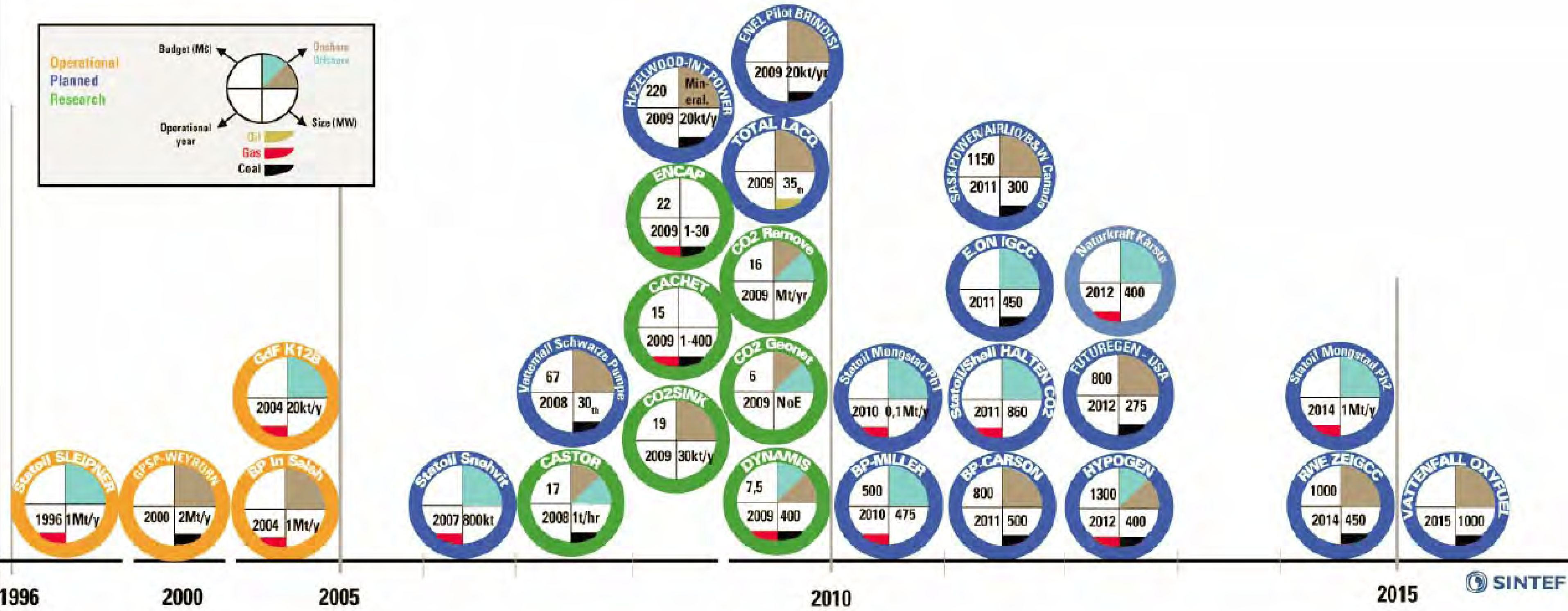
Research projects on the Zero Emission Power Plant

- CCS technologies in thermal PPs will contribute significantly in the mitigation of the GHG effect since thermal PPs account for ca. 1/3 of the total CO_2 atmospheric emissions. This fact explains the intense research activities aiming at the achievement of viable solutions in the medium term.

- Within FP6, the FENCO project aims at the development of the critical infrastructure for solid fuels, so that the EU technology remains competitive in the international market.

- The following are a number of important EC CCS projects with Greek partnership (NTUA - PPC):
  - ENCAP (Pre-combustion and oxyfuel technologies for solid fuels)
  - CASTOR (Post-combustion CO_2 capture)
  - CACHET (Post-combustion CO_2 capture for gaseous fuels)
  - ISSC (Production of a carbon-free gaseous fuel from solid fuels using CaO and pre-combustion CO_2 capture)
  - C2H (Production of a H_2-rich from solid fuels using CaO)

CCS pilot, demo and commercial projects



CCS in the European energy market 1/3

Coal		Reference Unit	Unit with pre-combustion capture	Unit with post-Combustion capture	Oxyfuel
Power output	MW	556	737	460	470
Efficiency	%	46	36	36	36
CO_2 capture	%	-	92	85	91
EPC Capital cost	Euro/kW	918	1577	1446	1447
Lignite		**Reference Unit**	**Unit with pre-combustion capture**	**Unit with post-Combustion capture**	**Oxyfuel**
Power output	MW	920	717	731	760
Efficiency	%	43	41	39	41
CO_2 capture	%	-	85	85	90
EPC Capital cost	Euro/kW	1065	1556	1683	1671
Natural Gas		**Reference Unit**	**Unit with pre-combustion capture**	**Unit with post-Combustion capture**	**Oxyfuel**
Power output	MW	420	755	662	325
Efficiency	%	58	41	47	48
CO_2 capture	%	-	93	85	100
EPC Capital cost	Euro/kW	410	763	742	1124

Financial and other Boundary Conditions		Natural Gas	Hard coal plant	Lignite plant
Economic life time	years	25	25	25
Depreatiation	years	25	25	25
Fuel price	EUR/GJ (LHV)	5,8	2,3	1,1
Fuel price escalation	% per year	1,5%	1,5%	1,5%
Operating hours per year	hours per year	7500	7500	7500
Standard Emission factor	t/MWh_{th}	0,210	0,344	0,402
Common Inputs				
O&M cost escalation			2%	
Debt /Equitiy ratio	%		50%	
Loan interest rate	%		6%	
Interest during construction	%		6%	
Return on Equity	%		12%	
Tax rate	%		35%	
WACC			8%	
Discount rate	%		9,0%	

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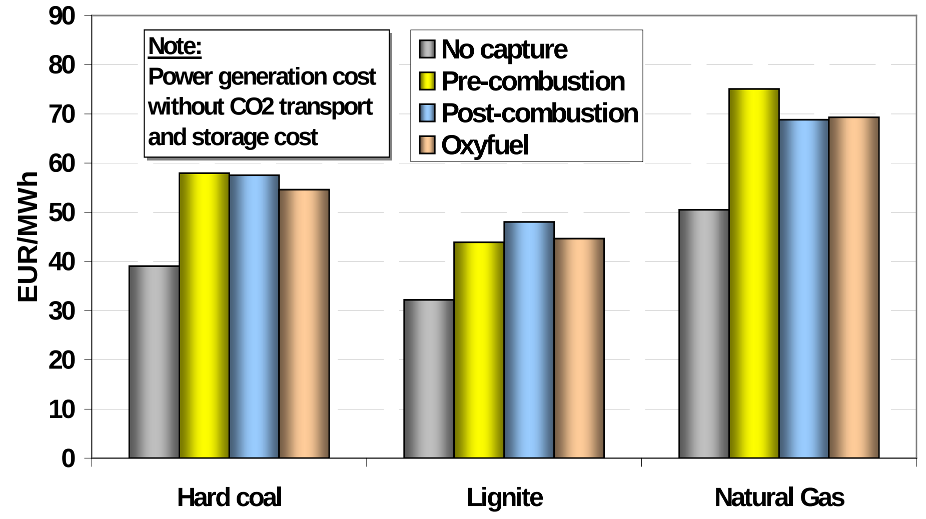
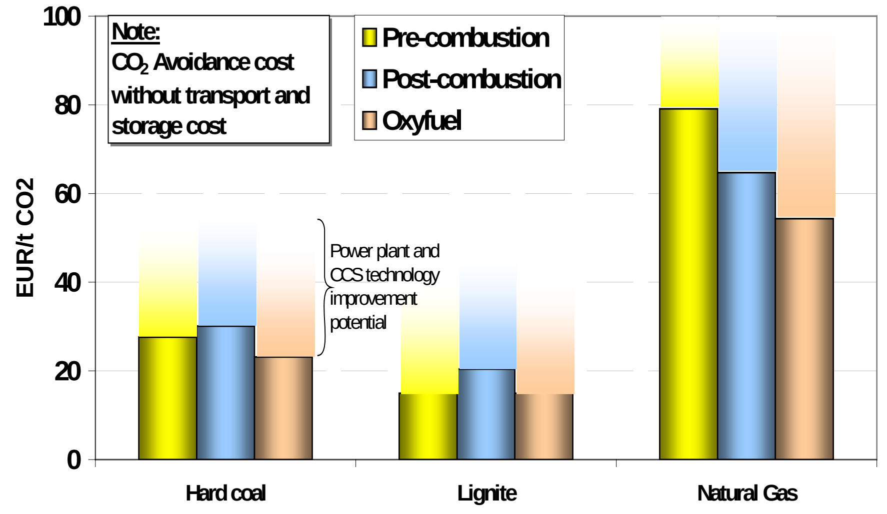
CCS in the European energy market 2/3

Estimated electricity generation cost from large coal, lignite and natural gas PPs in 2020, without and with CO_2 capture





Estimated CO_2 capture cost from large coal, lignite and natural gas PPs in 2020, without and with CO_2 capture

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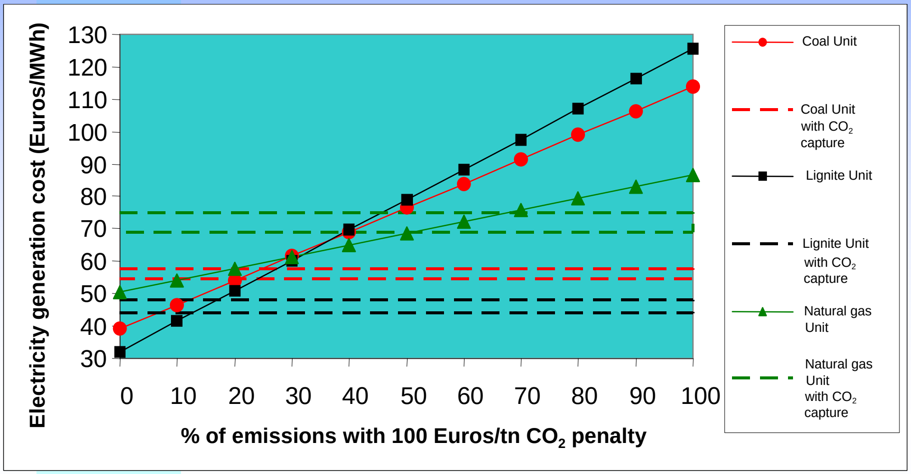
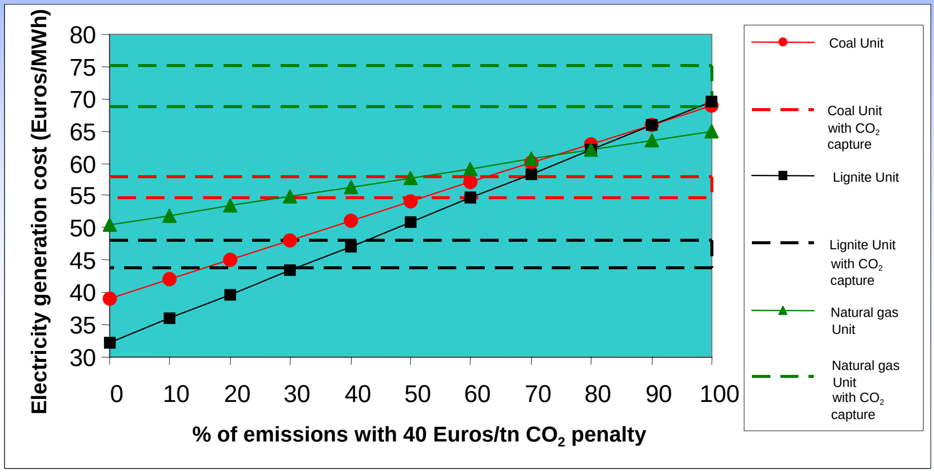
CCS in the European energy market 3/3

Electricity generation costs of large PPs with and without CO_2 capture/with CO_2 penalty in 2020





At the left of the point of intersection of the cost curves without and with CO_2 capture, investment in CCS technologies becomes economically viable

	Break-even point where CCS technologies become viable (% emmissions)		
CO_2 pentalty (Euros/tn)	Coal	Lignite	Natural gas
100	23.5	14.2	56.9
40	58.8	35.6	>100

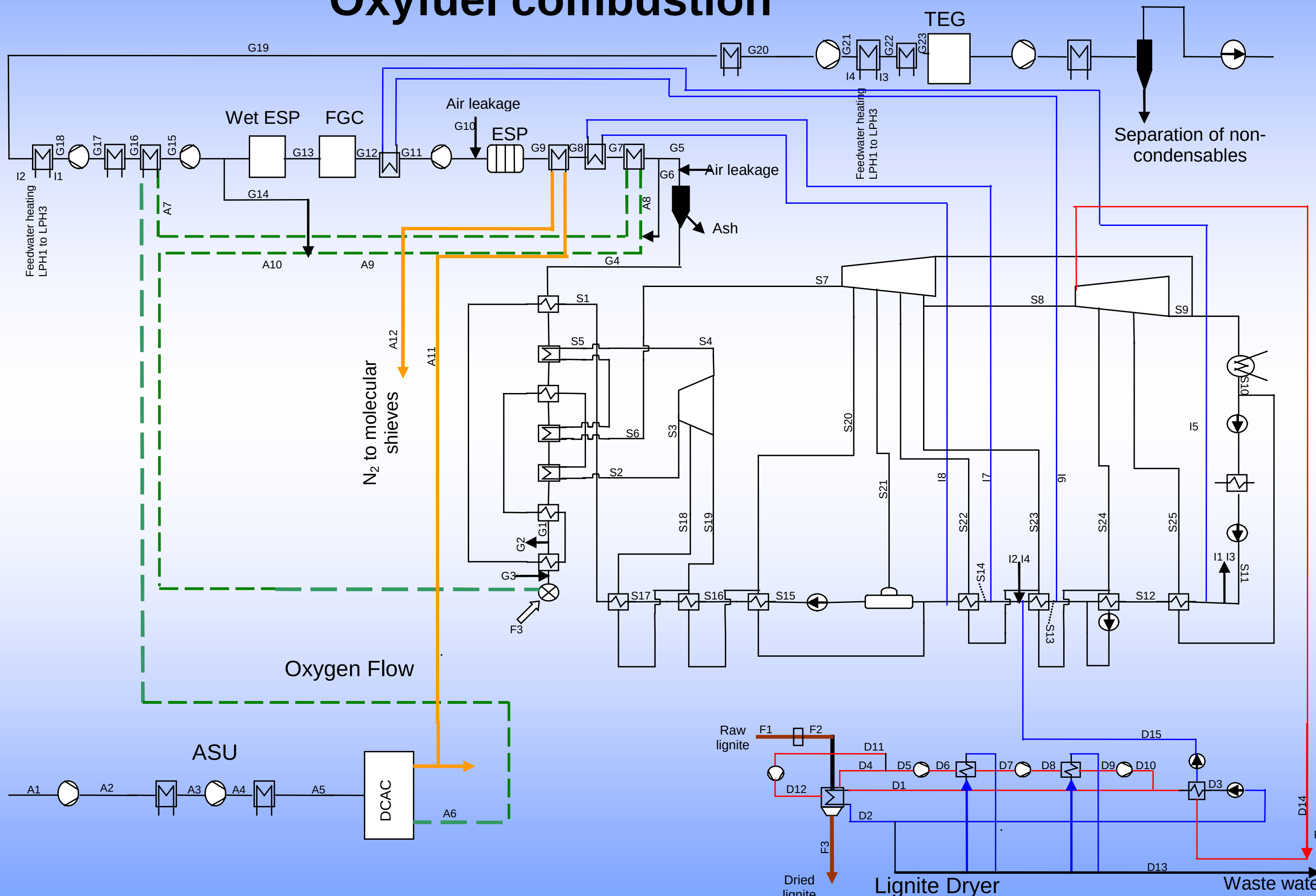
CO_2 Capture Retrofit in Greek Power Plants

- In order to demonstrate the potential of CO_2 capture technologies for lignite applications, the simulation of a “typical” new 330 MWel Greek PP was performed, including the retrofit options of amine scrubbing and Oxyfuel fuel firing. The PP has a supercritical boiler, a three pressure stage steam turbine and 8 regenerative feed water preheaters.

		Conventional PP	OxyFuel	Amine
Fuel Thermal Input	MWth	**830.0**		
Thermal Consumption for Solvent Regeneration	MWth	**-**	**-**	**256.5**
ASU Consumption	MW_{el}	**-**	**58.1**	**-**
CO_2 Compression Consumption	MW_{el}	**-**	**22.4**	**20.5**
Cooling Pumps Consumption	MW_{el}	**-**	**1.5**	**0.7**
Power Consumption from Amine Scrubbing Unit	MW_{el}	**-**	**-**	**8.7**
Net Power Output	MW_{el}	**293.7**	**211.0**	**200.5**
Efficiency	%	**35.74**	**25.42**	**24.16**

Green-field Power Plants with CO_2 capture

Oxyfuel combustion



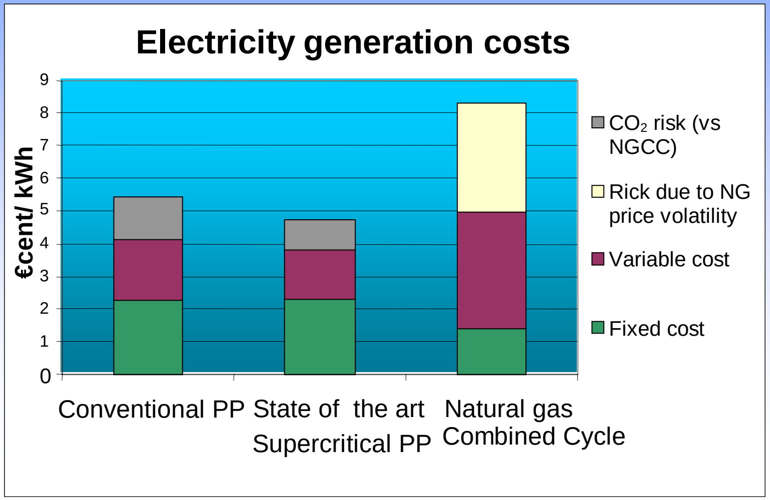
New 360 MWel Lignite PP with Oxyfuel combustion (typical Greek lignite)

CCS in the Greek energy market 1/3

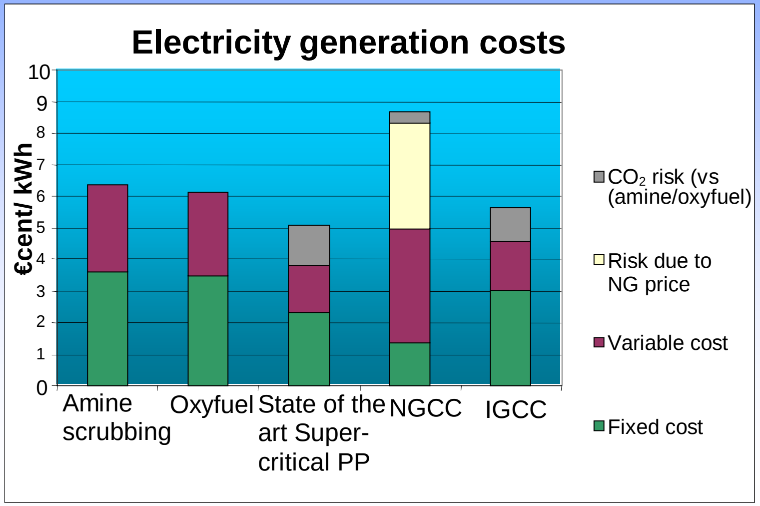
- The electricity generation cost has been assessed for the following technologies:
  - Conventional lignite PP
  - Conventional lignite PP with CO_2 capture with amine scrubbing
  - Conventional lignite PP with CO_2 capture with oxyfuel combustion
  - State of the art super-critical lignite PP (CCT)
  - Natural gas Combined Cycle (NGCC)
  - Lignite Integrated Gasification Combined Cycle (IGCC)
- The general and case-specific assumptions for the calculations are the following:
  - Discount factor: 8%, Inflation: 3%
  - Lignite cost: 1.8 €/ GJ, κόστος φυσικού αερίου: 5.5 €/GJ
  - Depreciation for Solid fuel units: 25 years, for NG and IGCC units: 15 years
  - O&M costs: 3% of capital costs per annually, variable cost 0.01 €/kWh for a lignite unit and 0.005 €/kWh for a natural gas unit.
  - 7500 h of operation per year at full load
  - CO_2 market cost: 18 €/tn

		Conv. lignite PP	Conventional lignite PP with amine scrubbing	Conventional lignite oxyfuel PP	State of the art super-critical lignite PP	NGCC.	IGCC
Net power output	MWel	294	201	211	300	380	766
Efficiency	%	35.7	24.2	25.4	44.0	56.5	43.0
Capital cost	€/kW	1100	1900	1570	1150	600	1370
Specific CO_2 emissions	kg/kWh	1.075	0.17	0.34	0.865	0.37	0.76

CCS in the Greek energy market 2/3



Electricity generation costs for current technologies



Electricity generation costs for future technologies

- Fixed cost includes depreciation and O&M costs, variable cost includes fuel.
- The units have been grouped in two categories: current technologies and technologies that will be commercially available in the future. The difference in specific emissions from the reference unit for each category multiplied by the CO_2 cost is an estimation of the price risk due to the emitted CO_2.

CCS in the Greek energy market 3/3

- The NGCC unit has the lowest fixed cost, due to the low capital cost, while on the other hand, the high capital and O&M costs for the units with CO_2 capture and the IGCC unit contribute significantly to the kWh cost.
- The lignite units, due to the low fuel price, demonstrate lower variable costs with respect to natural gas units.
- The low efficiency of units with CO_2 capture increases significantly variable costs.
- The increased volatility of NG price, due to its dependency to oil price (up to 40% of total costs) contributes in an increased uncertainty concerning the electricity generation cost from NGCC units, in contrast to the domesticlocal lignite market.
- The conventional lignite, the state of the art super-critical lignite and the IGCC units have the lowest kWh cost, while the NGCC unit has the highest generation cost, due to the high fuel price and the market volatility.
- The application of CCS technologies increases considerably capital costs and reduces efficiency and, as a consequence, increases electricity generation costs. Nevertheless, taking into account the CO_2 price, they can remain competitive.

Συμπεράσματα

- CCS technologies can contribute in the reduction of CO_2 emissions from the electricity generation sector.
- Nevertheless, the efficiency penalty and increased capital costs associated to the implementation of CCS technologies increase the kWh costs.
- In addition, the purchase of CO_2 credits from the through the CO_2, market is expected to increase electricity generation costs.
- From the assessment of different technological options for the Greek electricity sector, it is concluded that lignite units can be competitive to natural gas units, the latter presenting a greater market risk due to fuel price volatility.