



Techno-Economic Evaluation of Biomass Fired or Co-Fired Power Plant with Post Combustion Capture

Stanley Santos

*IEA Greenhouse Gas R&D Programme
Cheltenham, UK*

***Regional Workshop for
the Baltic Sea and Central & Eastern European Countries***

Vilnius, Lithuania

13th April 2011

Acknowledgement



- ***This presentation is the results of the work done by Foster Wheeler Italiana for IEA Greenhouse Gas R&D Programme***
- ***Would like to thank...***
 - Paolo Cotone
 - Franco Gasparini



Outline

- ***Motivation of this Study (Discussion Points)***
- ***Study Cases***
- ***Design Basis***
- ***Summary of Performance Results***
- ***Economic analysis***
- ***Concluding Remarks***

Discussion Point



- *How to consider the “Accounting” of CO₂ Captured from Biomass Fired Power Plant*
 - The discussion is now centred on how to consider the CO₂ emitted from biomass-fired power plants, if it is counted as “CO₂ neutral” and if stored, whether how this could be considered or accounted as a “negative” CO₂ emission.
 - Validation / Accounting methodology when CO₂ captured from Co-Fired Power Plant.
- *One of the questions/Issues addressed in this study:*
 - **“What should be the cost of CO₂ emissions avoided that would make CCS an attractive option to be incorporated into a biomass fired power plant assuming that the stored CO₂ from a biomass fired power plant could generate an additional revenue as CO₂ credit”**

Study Cases



- ***Case 1: Nominal 500 MWe (net) Coal co-fired with Biomass Supercritical PC Power Plant.***
- ***Case 2: : Nominal 500 MWe (net) Coal co-fired with Biomass Supercritical CFB Power Plant.***
- ***Case 3: : Nominal 250 MWe (net) Biomass (standalone) CFB Power Plant.***
- ***Case 4: : Nominal 75 MWe (net) Biomass (standalone) BFB Power Plant.***

- ***For all the four cases, power plants without and with CO₂ capture are evaluated***

Design Basis (Summary)



- ***Feedstocks:***
 - Eastern Australian Bituminous (LHV = XX MJ/kg; Coal S = 1.1% wt, dry ash free bases)
 - Biomass is a clean, virgin wood chips (LHV = 7.3 MJ/kg)
- ***Location of the Power Plant***
 - NE Coast of The Netherlands
- ***Reference Ambient Temperature: 9°C***
- ***Cooling Water Type:***
 - Once through sea water cooling
 - Cooling temperature: 12°C → 19°C

Design Basis (Summary)



- ***Emissions Limit;***

- Based on the requirement of the EC Large Combustion Directives.

- NO_x (as NO₂): $\leq 200 \text{ mg/Nm}^3$ (@ 6%_v O₂ – dry)
- SO_x (as SO₂): $\leq 200 \text{ mg/Nm}^3$ (@ 6%_v O₂ – dry)
- Particulates: $\leq 30 \text{ mg/Nm}^3$ (@ 6%_v O₂ – dry)

- ***CO₂ Characteristics at Battery Limits***

- Delivered Pressure: 110 Bar
- CO₂ Purity: $\geq 99\%$ ($\leq 10 \text{ ppm H}_2\text{O}$)

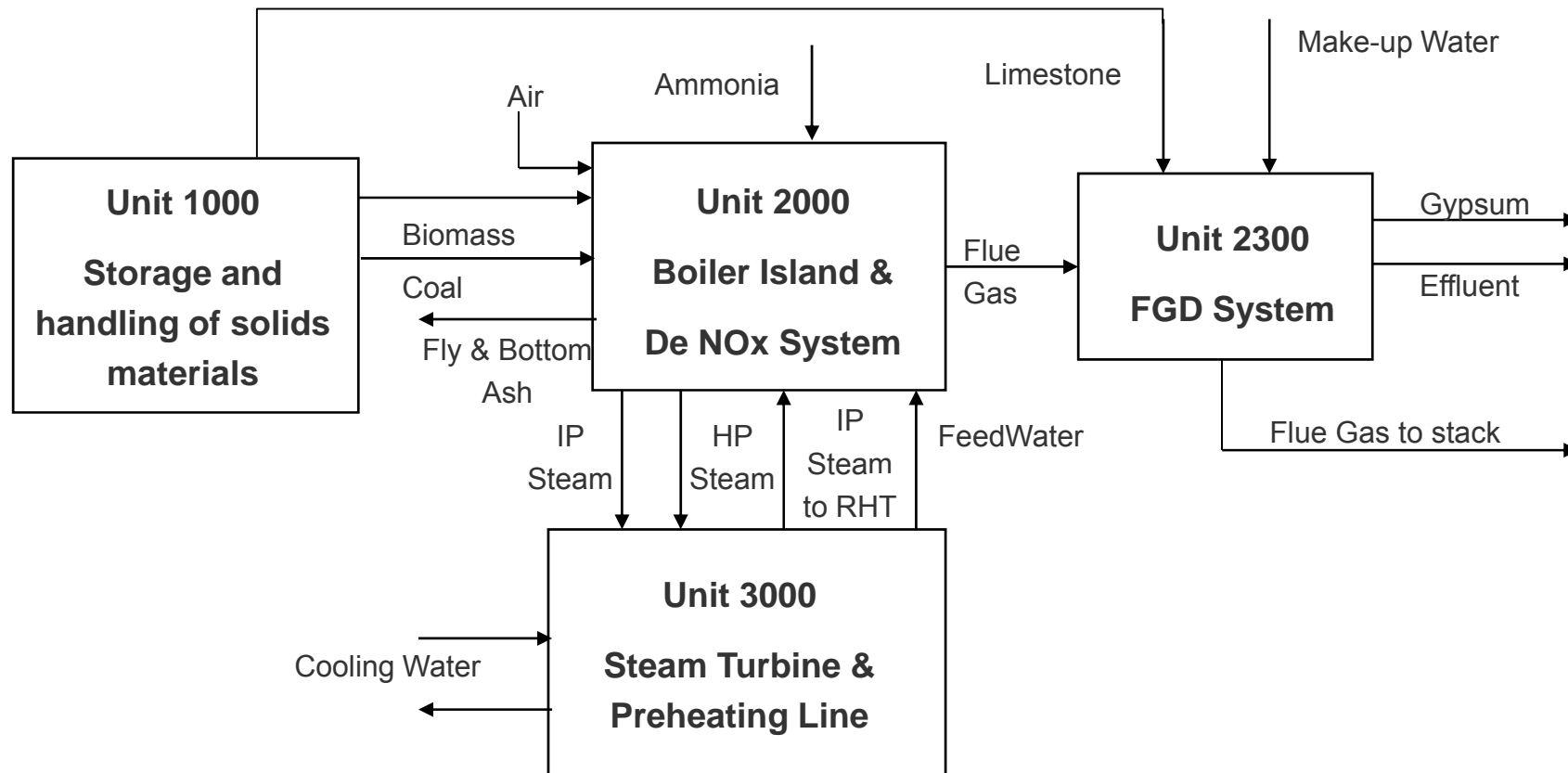
Summary – Cases



Case No.	Boiler Technology	Fuel Feedstock	Nominal Rating	CO ₂ Capture
1a	PC (supercritical)	Coal (90%) + Biomass (10%)*	500MWe (net)	No
1b	PC (supercritical)	Coal (90%) + Biomass (10%)*	500MWe (net)	Yes
2a	CFB (supercritical)	Coal (90%) + Biomass (10%)*	500MWe (net)	No
2b	CFB (supercritical)	Coal (90%) + Biomass (10%)*	500MWe (net)	Yes
3a	CFB (subcritical)	Biomass	250MWe (net)	No
3b	CFB (subcritical)	Biomass	250MWe (net)	Yes
4a	BFB (subcritical)	Biomass	75MWe (net)	No
4b	BFB (subcritical)	Biomass	75MWe (net)	Yes

* Based on thermal input (LHV value)

Case 1a - Biomass Co-Fired SC PC Boiler Power Plant w/o CO₂ capture

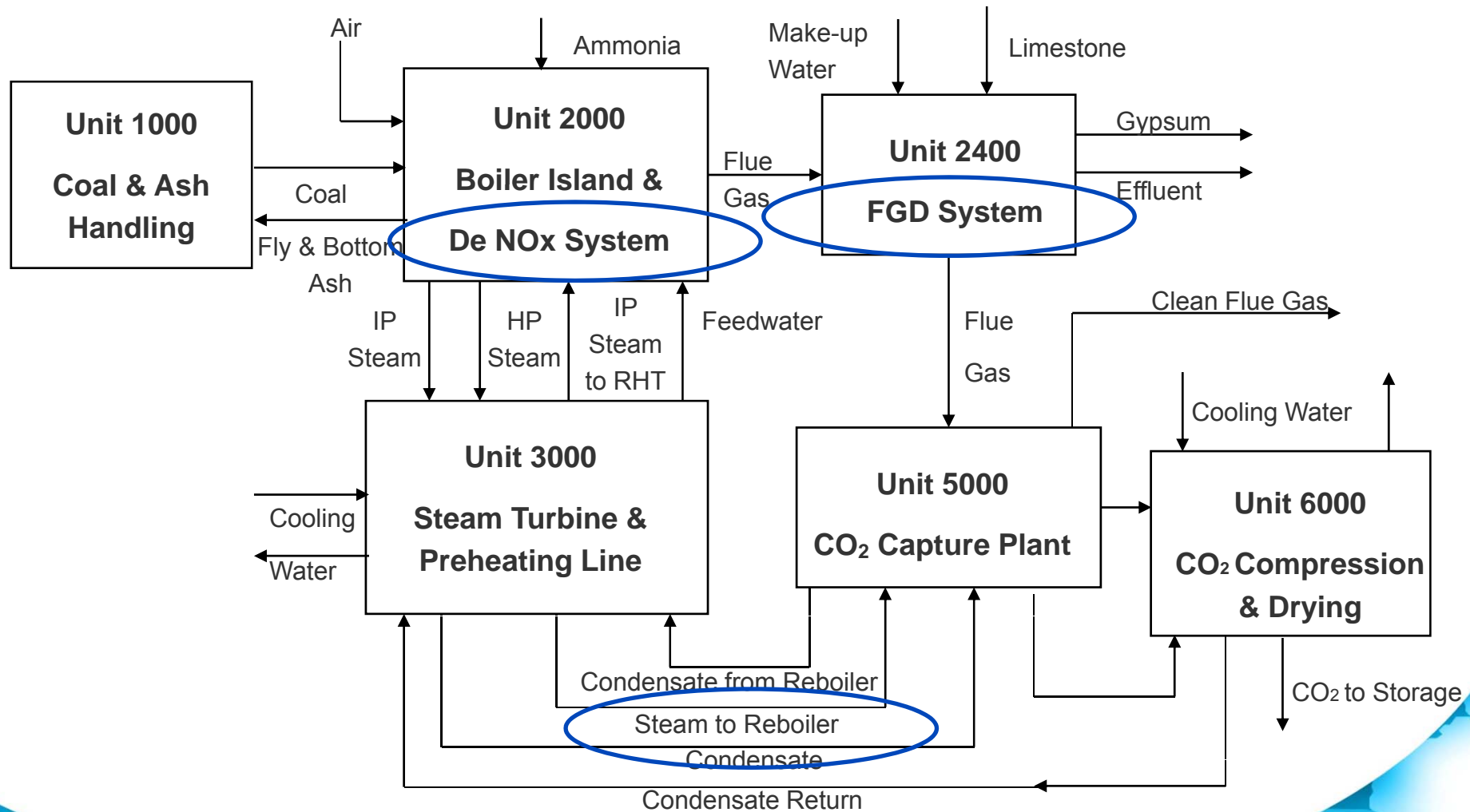


Case 1a (Power Plant Features)



- ***Power Plant Capacity***
 - Actual Net Power Output: 518.9 MWe
- ***Boiler is commercially available / proven***
- ***Boiler is co-fired with 10% Biomass (LHV basis); No pre-drying of biomass***
- ***Steam Conditions:***
 - 580°C HP (275 Bar) / 600°C RH (55 Bar)
 - Boiler Efficiency: ~93%
- ***SCR and FGD are installed to meet the emissions required.***

Case 1b - Biomass Co-Fired SC PC Boiler Power Plant with CO₂ capture

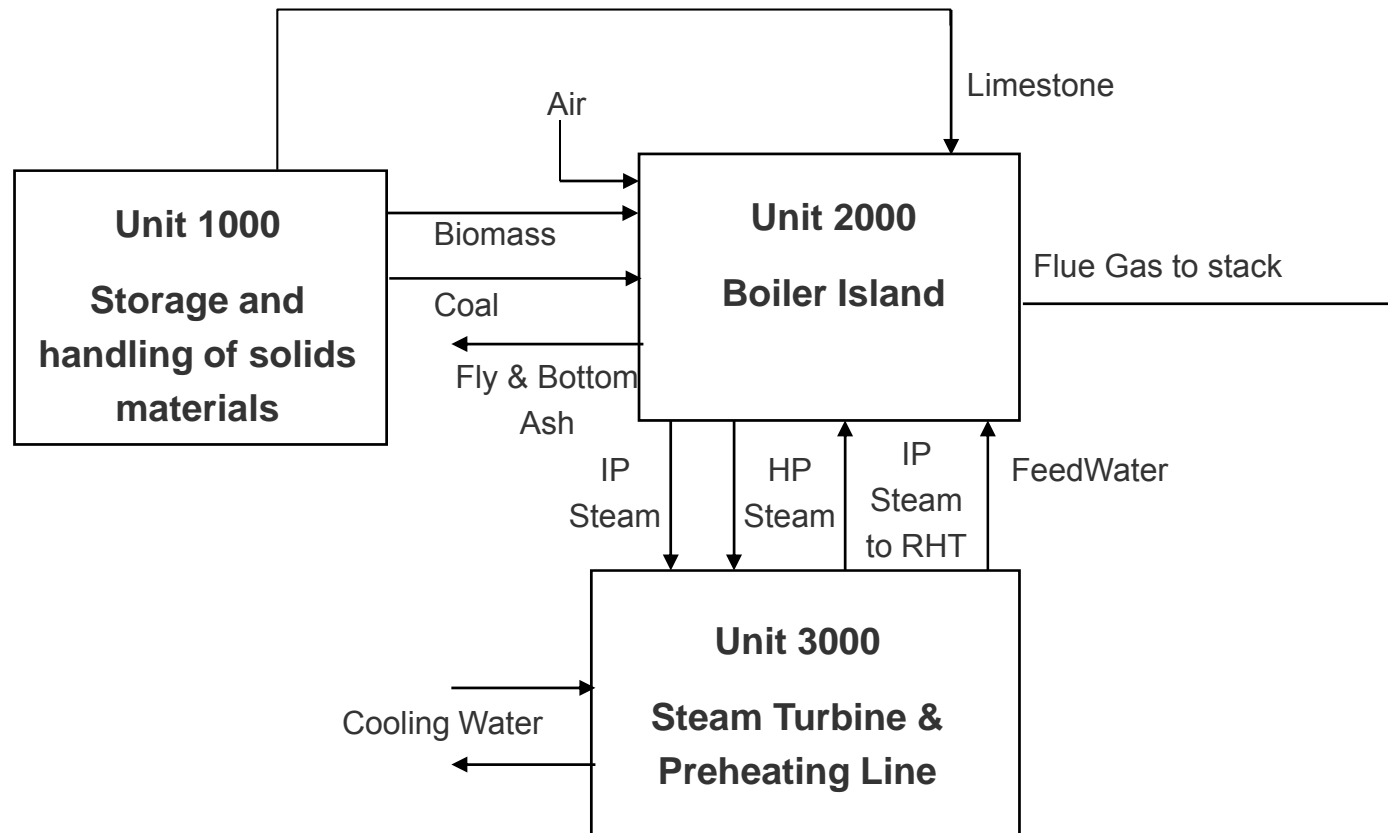


Case 1b (Power Plant Features)



- ***Boiler is the same size with Case 1a. Due to extraction of low pressure steam from the steam turbine for the reboiler of the CO₂ capture plant – actual output is reduced.***
- ***Actual Net Power Output: 399 MWe***
- ***SCR and FGD are installed to meet the 10 ppm and 20 ppm level for SO₂ and NO₂ respectively to reduce the MEA degradation.***
 - Deep removal of SO_x by the Limestone FGD should be demonstrated.
- ***Due to removal of CO₂ from the flue gas – NO_x level (mg/Nm³) should be expected higher (as compared to Case 1a)***
 - NO_x removal level at SCR outlet should be 15% lower.

Case 2a - Biomass Co-Fired SC CFB Boiler Power Plant w/o CO₂ capture





Case 2a (Power Plant Features)

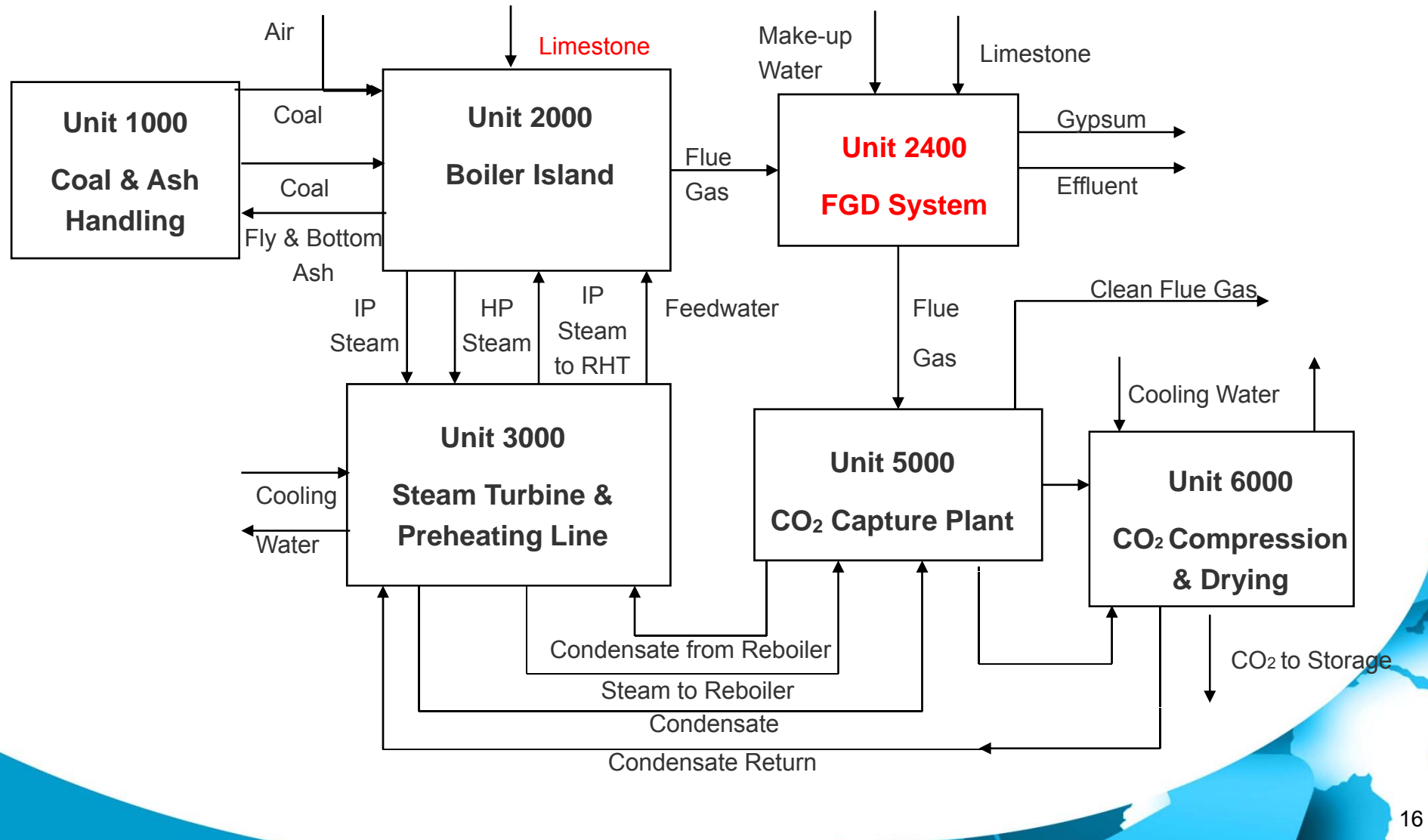
- ***Power Plant Capacity***
 - Actual Net Power Output: ~521 MWe
- ***Boiler is based on supercritical boiler technology which is commercially available / proven***
- ***Boiler is co-fired with 10% Biomass (LHV basis); No pre-drying of biomass***
- ***Steam Conditions:***
 - 580°C HP (275 Bar) / 600°C RH (60 Bar)
- ***Only limestone injection into the boiler is included. Ca/S ratio of 2.84 is used to achieve the minimum emissions required.***

Case 2a (Power Plant Features)



- ***No SCR is installed. Required NO_x emission is achieved by the CFB itself. Lower NO_x emission is expected due to lower combustion temperature in the CFB boiler.***
- ***Special Feature of the Power Plant:***
 - **A plastic heat exchanger is installed downstream of the ID fan to maximise the heat recovery thus achieving some efficiency gain. (Expected flue gas temperature at stack ~90°C)**

Case 2b - Biomass Co-Fired SC CFB Boiler Power Plant with CO₂ capture



Case 2b (Power Plant Features)



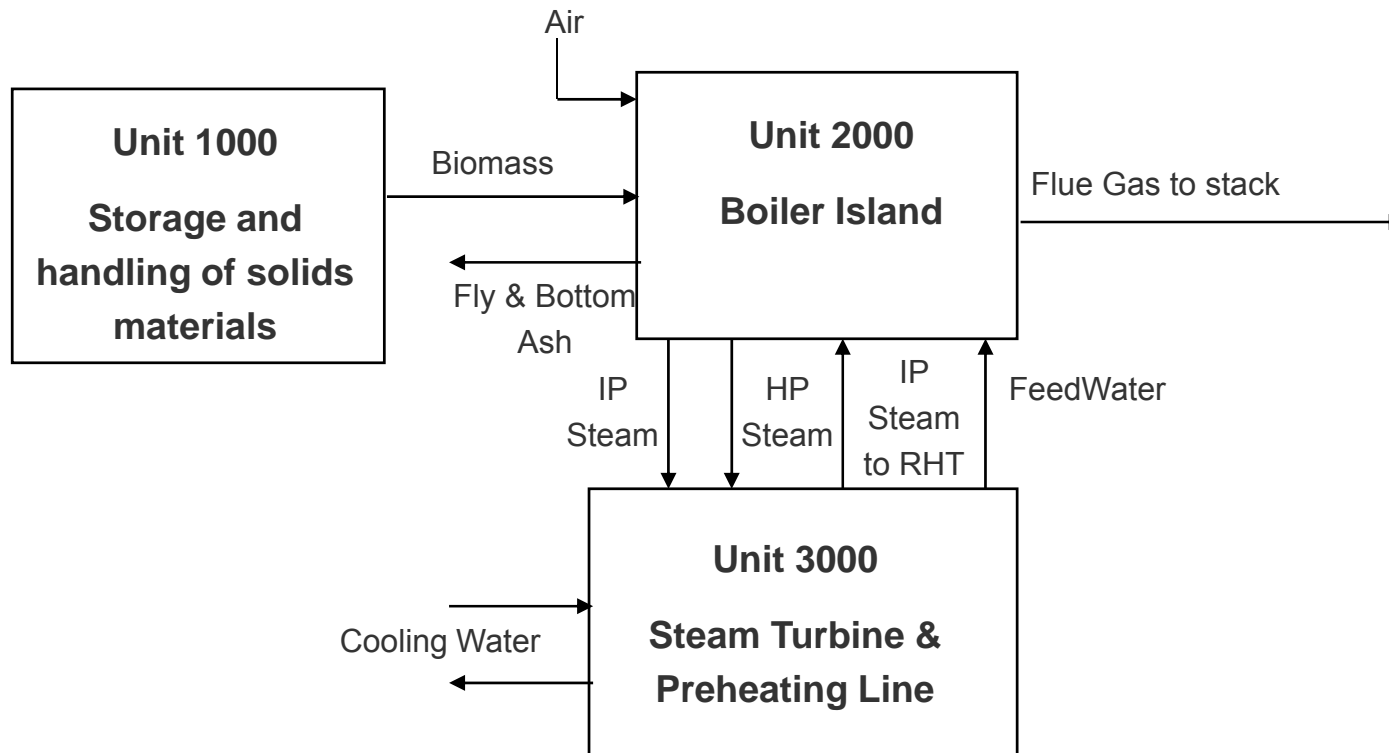
- ***Boiler is the same size with Case 2a. Due to extraction of low pressure steam from the steam turbine for the reboiler of the CO₂ capture plant – actual output is reduced.***
- ***Actual Net Power Output: ~390 MWe***
- ***To achieve the 10 ppm SO_x level, in addition to the limestone that is injected into the boiler with a Ca/S ratio of 1, an external FGD has been installed.***
- ***Unlike Case 2a, there will be no plastic heat exchanger installed downstream of the ID fan due to the installed FGD.***

Case 2b – Power Plant Features



- ***No SCR is installed. It is expected that NO_x level required will be met by the CFB Boiler itself.***
 - NO₂ in flue gas (15-20% of NO_x) is considered tolerable by the MEA without further abatement in the SCR system.
- ***N₂O at boiler outlet is expected to be low due to the higher operating temperature in the bed.***
 - N₂O is not expected to be removed by the MEA.
 - The possible formation of stable salts from N₂O should be investigated with the solvent suppliers.

Case 3a- Biomass Fired CFB Boiler Power Plant w/o CO₂ capture





Case 3a – Power Plant Features

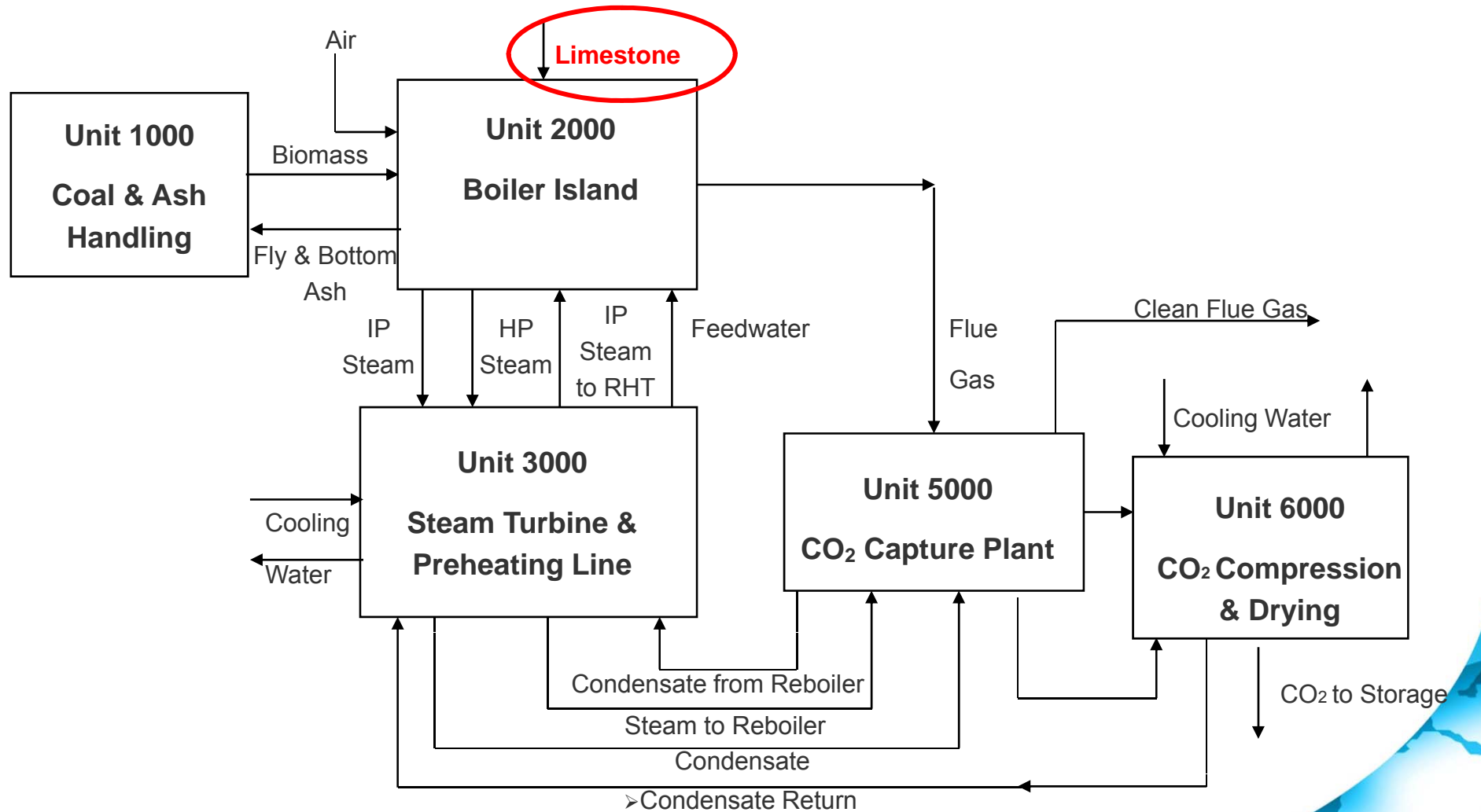
- ***Power Plant Capacity***
 - Actual Net Power Output: 273 MWe
- ***Boiler is a subcritical circulating fluidized bed unit which is commercially available / proven***
- ***Boiler is fired with 100% Biomass; no pre-drying of biomass is included.***
- ***Steam Conditions:***
 - 565°C HP (169 Bar) / 565°C RH (39 Bar)



Case 3a – Power Plant Features

- ***External FGD and limestone injection in the combustion chamber are not required to meet SO_x emission limits because of the low sulphur content in biomass.***
- ***NO_x is met by the CFB boiler. No SCR is necessary.***
- ***A Plastic Heat Exchanger is installed downstream of the ID Fan to maximise heat recovery.***

Case 3b - Biomass Fired CFB Boiler Power Plant with CO₂ capture





Case 3b – Power Plant Features

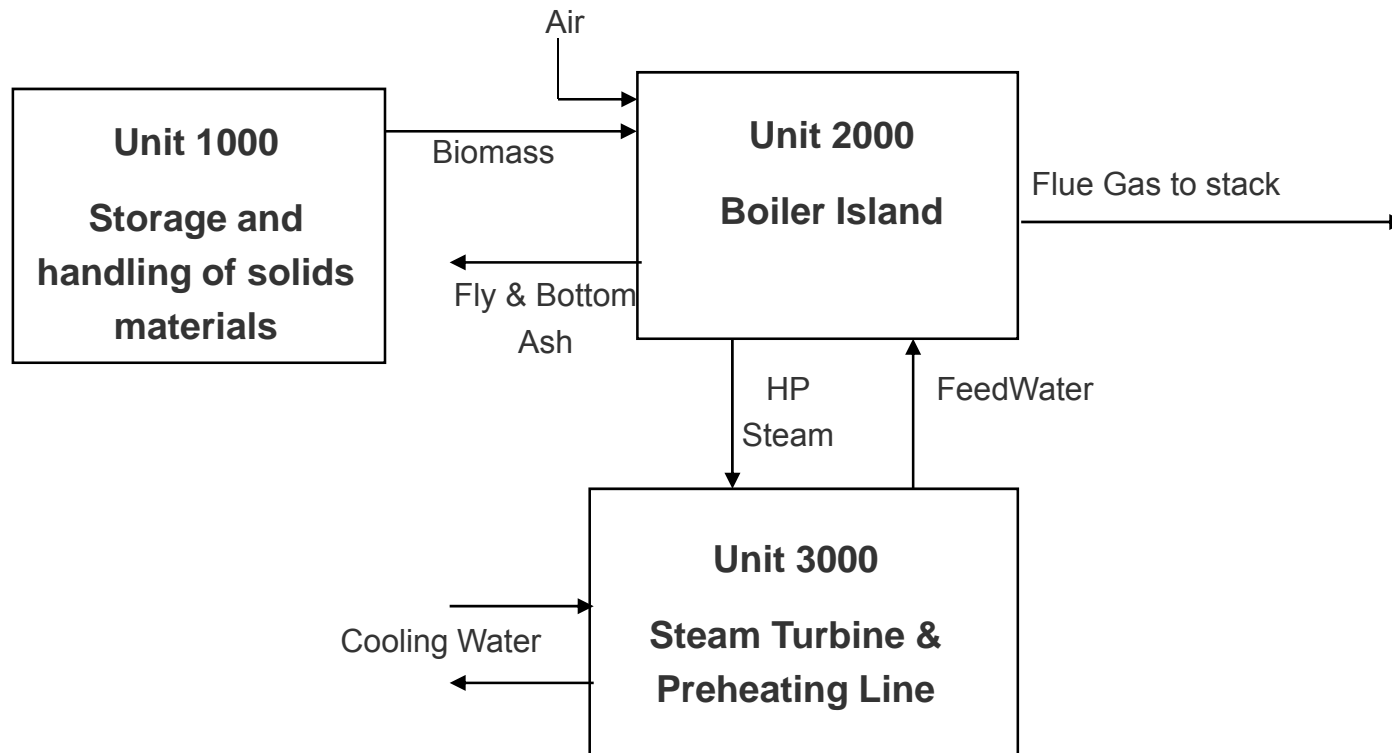
- ***Boiler is the same size with Case 3a. Due to extraction of low pressure steam from the steam turbine for the reboiler of the CO₂ capture plant – actual output is reduced.***
- ***Power Plant Capacity***
 - Actual Net Power Output: ~169 MWe
- ***No plastic heat exchanger installed downstream of the ID fan – due to the direct contact cooler of the CO₂ capture plant.***
- ***In order to achieve the 10 ppm SO_x level as required to reduce degradation of the MEA, limestone is injected into the boiler with Ca/S ratio of ~2.8. (This system requires demonstration.)***



Case 3b – Power Plant Features

- ***NO_x emissions limit is met by the CFB. NO₂ in the flue gas is considered tolerable by the MEA, thus there will be no SCR installed.***
- ***N₂O at the boiler outlet is expected to be low due to the slightly higher temperature in the bed. N₂O is not expected to be removed by MEA. However the possibility of formation of stable salts from N₂O should be investigated with the MEA suppliers.***

Case 4a - Biomass Fired BFB Boiler Power Plant w/o CO₂ capture





Case 4a – Power Plant Features

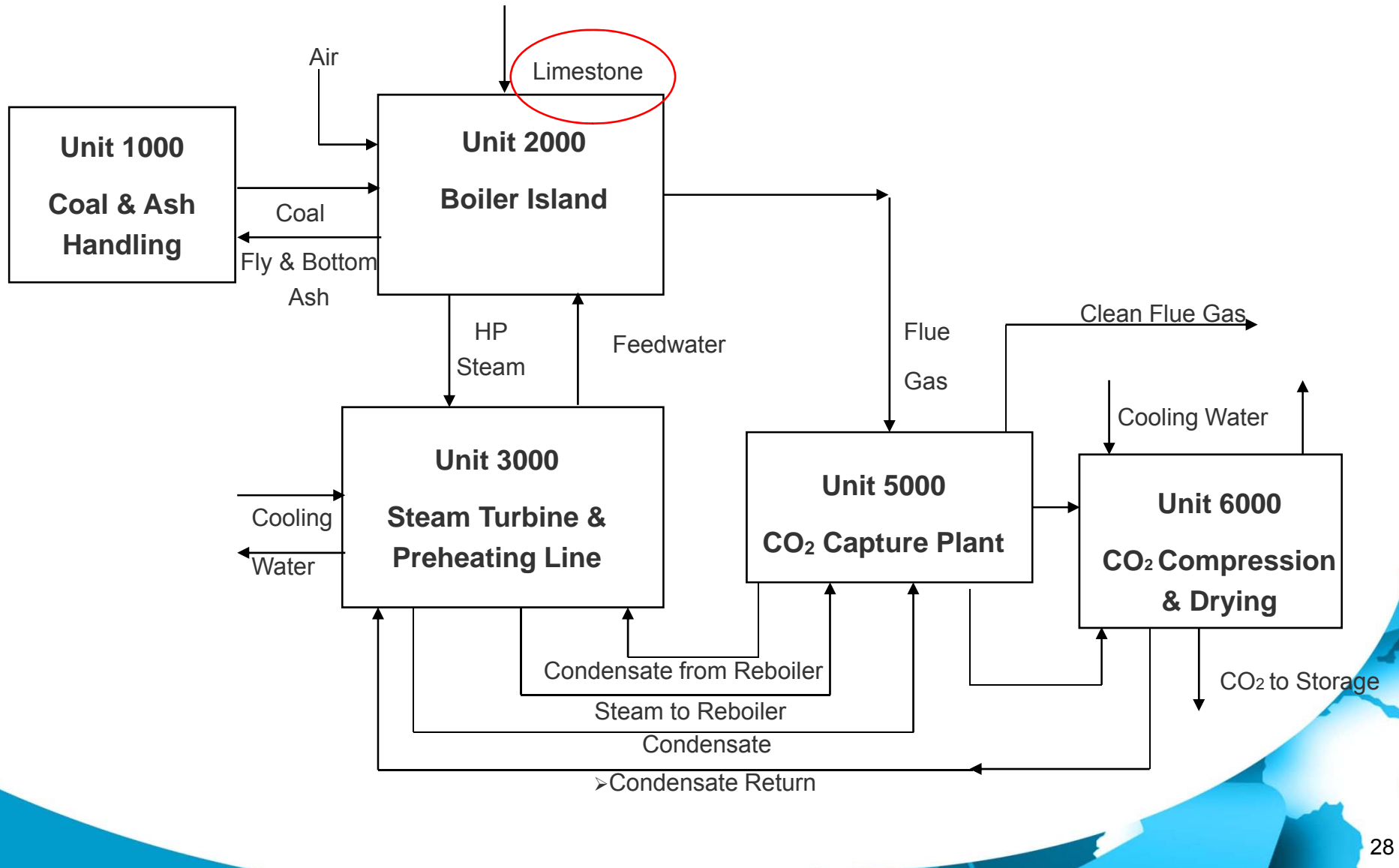
- ***Power Plant Capacity***
 - Actual Net Power Output: 75.8 MWe
- ***Boiler is a subcritical bubbling fluidized bed unit which is commercially available / proven***
- ***Boiler is fired with 100% Biomass; no pre-drying of biomass is included.***
- ***Steam Conditions:***
 - 540°C HP (115 Bar) / No Steam Reheat



Case 4a – Power Plant Features

- ***External FGD and limestone injection in the combustion chamber are not required to meet SO_x emission limits because of the low sulphur content in biomass.***
- ***NO_x is met by the BFB boiler. No SCR is necessary.***
- ***No Plastic Heat Exchanger is installed downstream of the ID Fan due to performance increase does not justify the investment cost.***

Case 4b - Biomass Fired BFB Boiler Power Plant with CO₂ capture





Case 4b – Power Plant Features

- ***Boiler is the same size with Case 4a. Due to extraction of low pressure steam from the steam turbine for the reboiler of the CO₂ capture plant – actual output is reduced.***
- ***Power Plant Capacity***
 - Actual Net Power Output: ~49 Mwe
- ***In order to achieve the 10 ppm SO_x level as required to reduce degradation of the MEA, limestone is injected into the boiler with Ca/S ratio of ~2.8. No external FGD is required.***
- ***NO_x emissions limit is met by the BFB. The NO₂ level is considered tolerable to the MEA.***
- ***N₂O is considered low – but would require the evaluation of MEA solvent supplier with regard to formation of stable salt.***

Performance of the Power Plants - Summary



Case	Plant Type	Nominal Size	SCR	FGD	CO ₂ Capture	Net Efficiency	Net output
1a	SC PF boiler	500 MWe	Yes	Yes	0	44.8%	518.9 MWe
1b	SC PF boiler	500 MWe	Yes	Yes	90%	34.5%	398.9 MWe
2a	SC CFB boiler	500 MWe	No	No	0	45.1%	521.4 MWe
2b	SC CFB boiler	500 MWe	No	Yes	90%	38.8%	390.5 MWe
3a	CFB boiler	250 MWe	No	No	0	41.7%	273.0 MWe
3b	CFB boiler	250 MWe	No	No	90%	25.8%	168.9 MWe
4a	BFB boiler	75 MWe	No	No	0	36.0%	75.8 MWe
4b	BFB boiler	75 MWe	No	No	90%	23.2%	48.9 MWe

Economic Assessment



- ***Basic Assumptions & Assessment Criteria***

- ✓ **Availability:** *90% (w/o capture) 88% (w/ capture)*
- ✓ **Cost of coal:** *2.90 €/GJ*
- ✓ **Cost of biomass:** *8.39 €/GJ*
- ✓ **Plant cost:** *in Euro (May 2009)(1 € = 1.35 US \$)*
- ✓ **Discount Rate:** *10% (Annual Basis)*
- ✓ **Plant life:** *25 years*
- ✓ **CO₂ transport cost:** *Not considered*

Economic Analysis (cont'd)

Estimated CAPEX



	Total Investment cost Million of Euro	Specific Cost Euro/kW
Case # 1 a	657.21	1267
Case # 1 b	824.32	2066
Case # 2 a	707.28	1357
Case # 2 b	918.37	2352
Case # 3 a	370.30	1356
Case # 3 b	519.73	3077
Case # 4 a	185.42	2446
Case # 4 b	256.39	5243

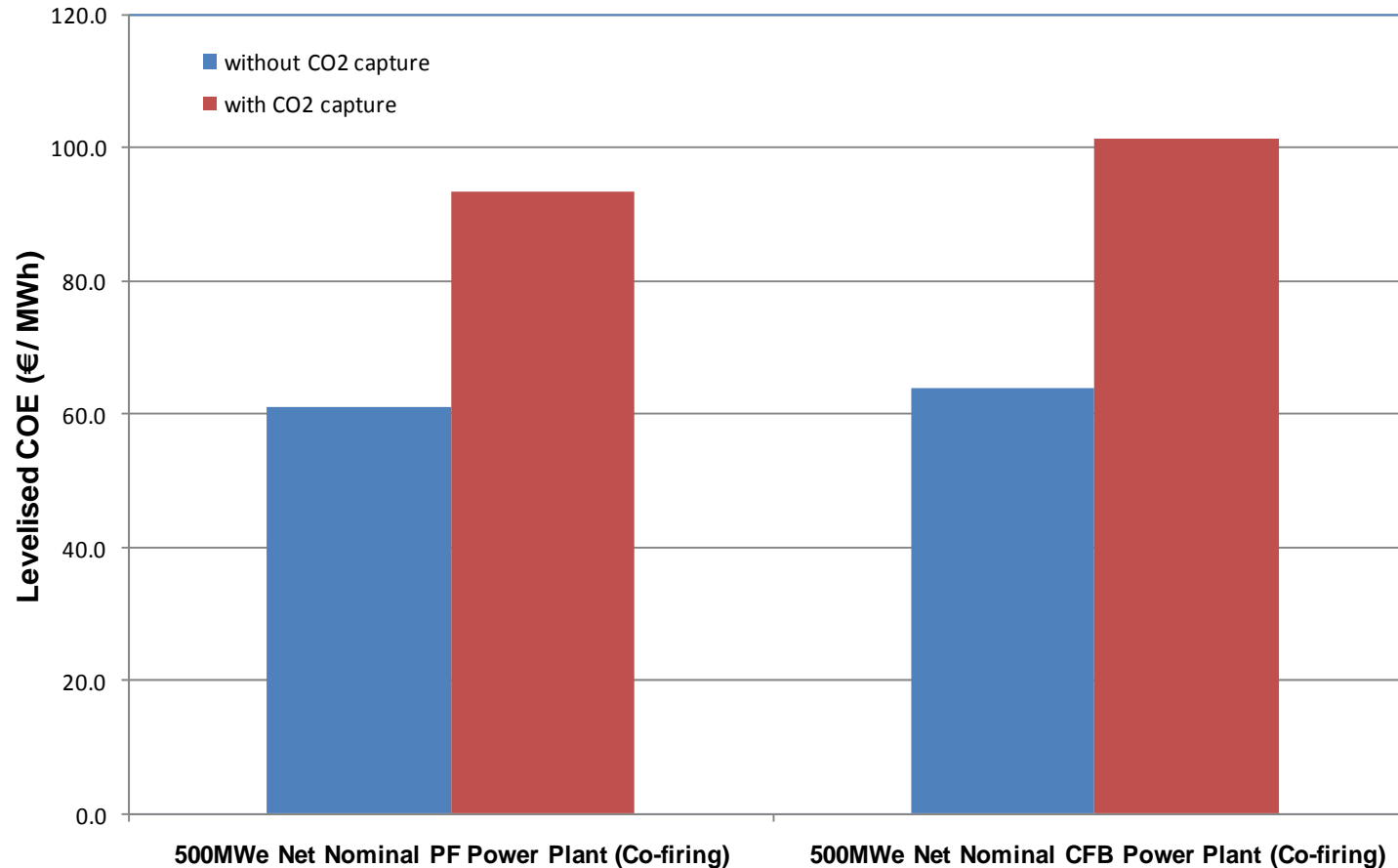
Scenarios Considered



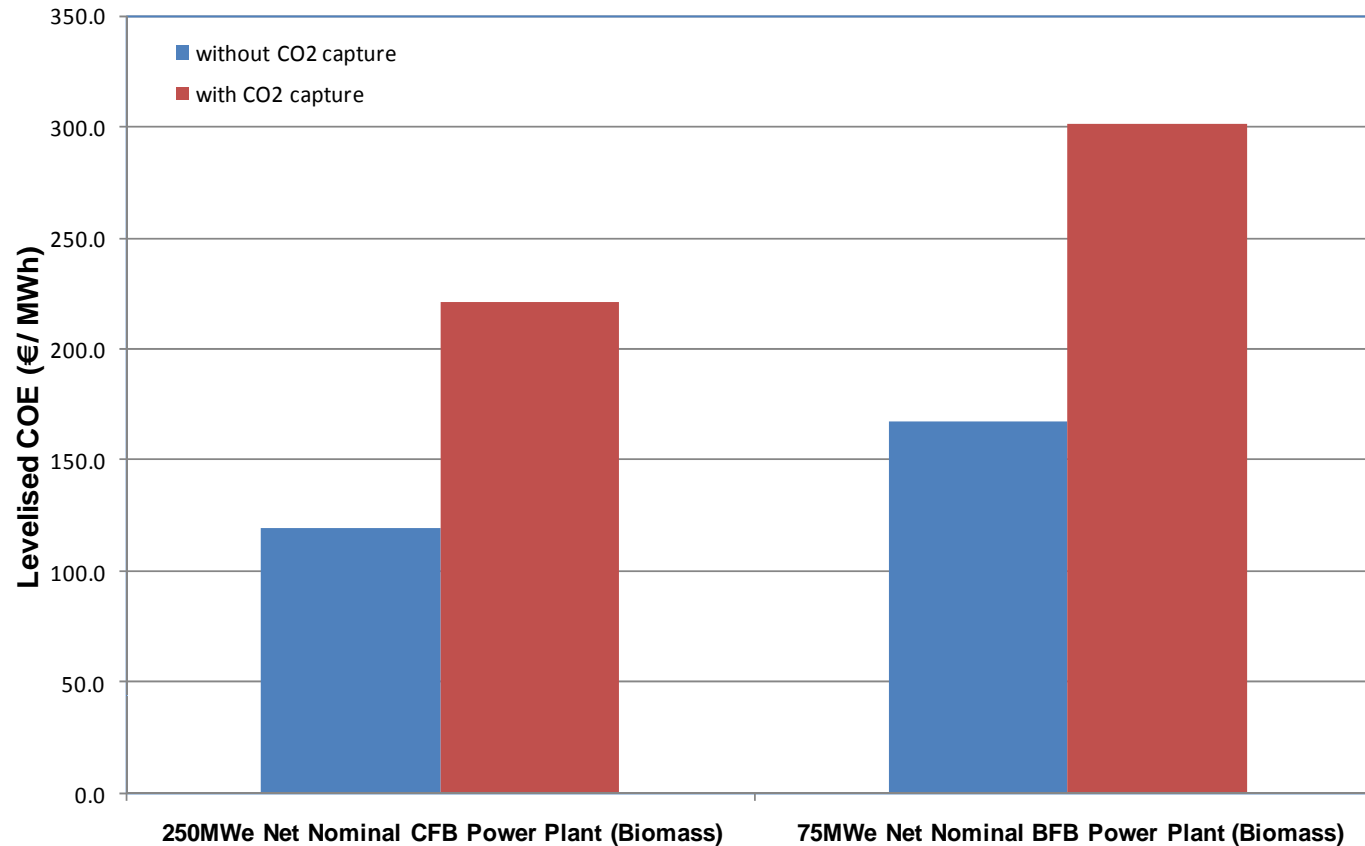
4 scenarios considered for the economical analysis:

- *Scenario 1: the calculation of the cost of electricity does not include the revenues from the green certificates nor from the ETS mechanism.*
- *Scenario 2: the calculation of the cost of electricity only includes the revenues from the green certificates (50 €/MW).*
- *Scenario 3: the calculation of the cost of electricity only includes the revenues from the ETS mechanism (14€/t CO₂).*
- *Scenario 4: the calculation of the cost of electricity includes both the revenues from the green certificates and from the ETS mechanism.*

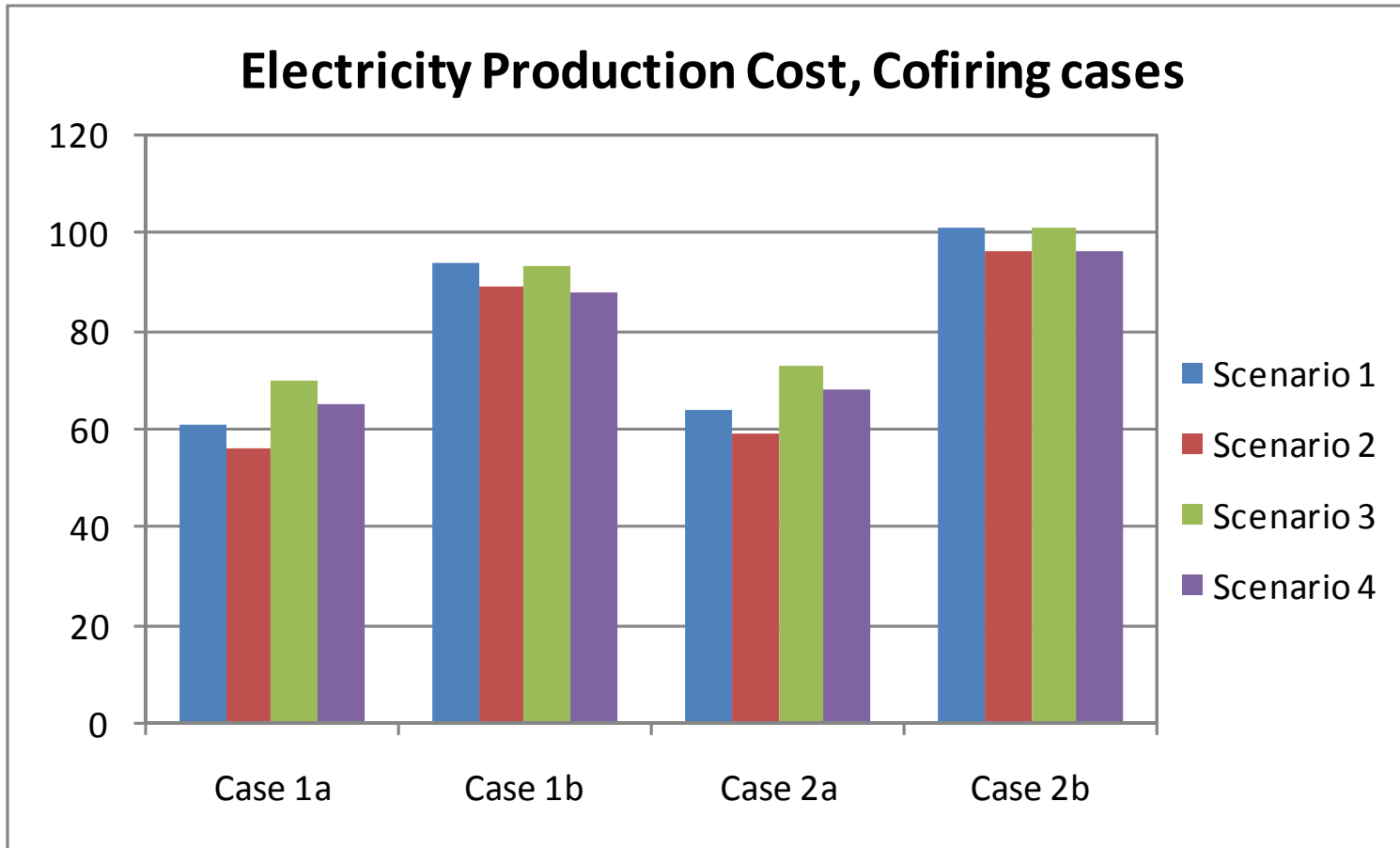
For Scenario 01 – No Consideration of ETS or Green Certificate Incentives (Case 1 and 2)



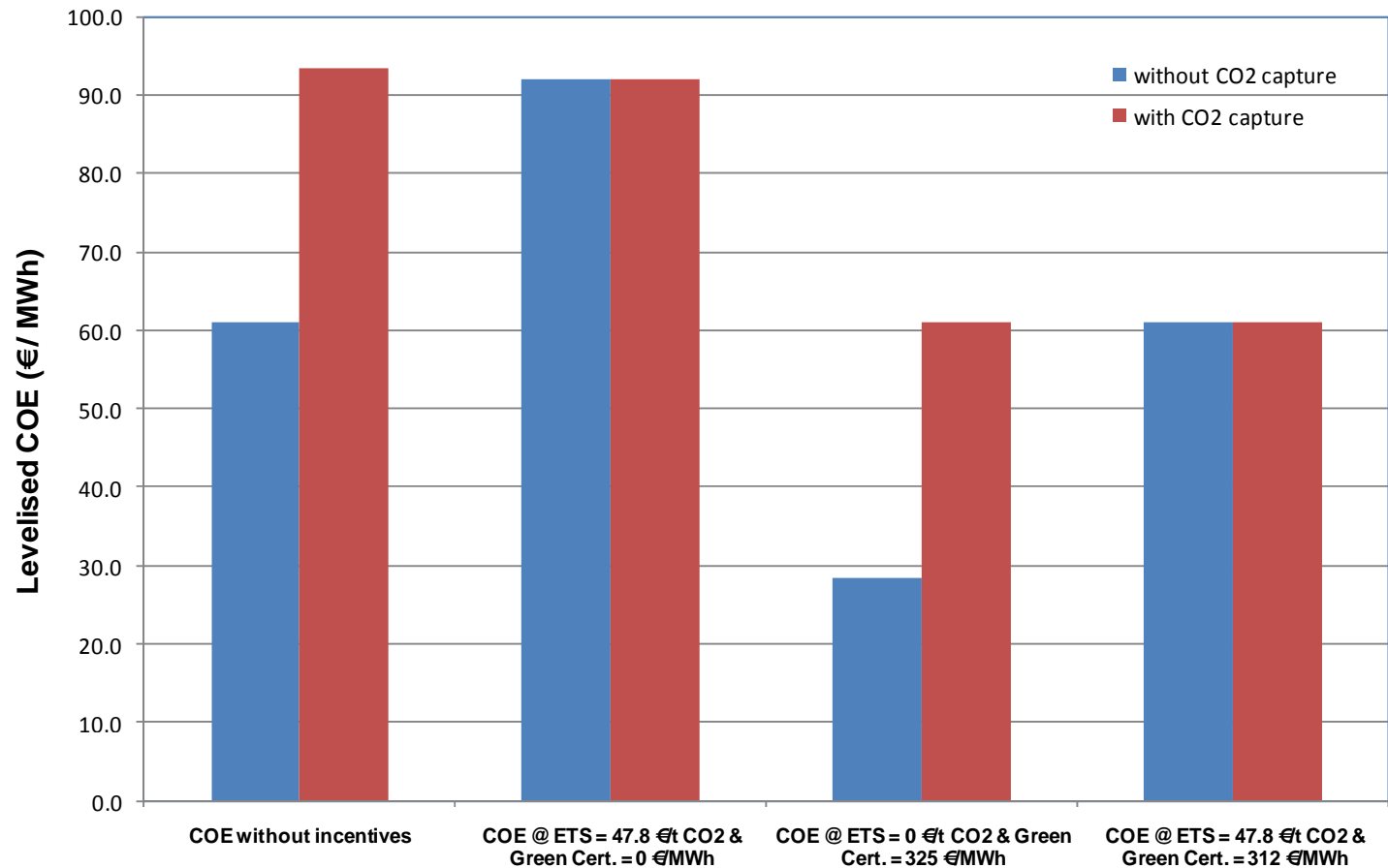
For Scenario 01 – No Consideration of ETS or Green Certificate Incentives (Case 3 and 4)



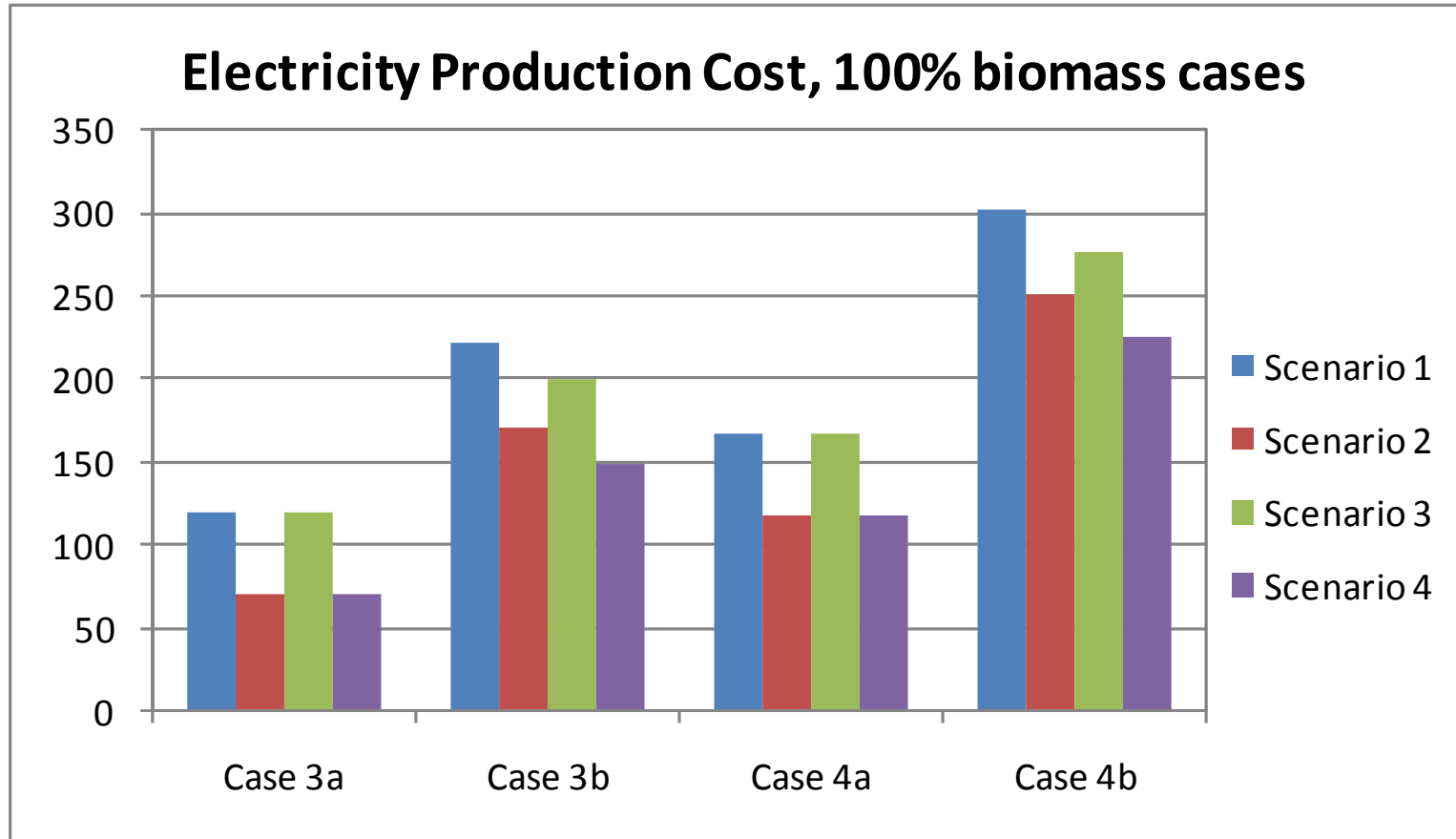
Economic summary



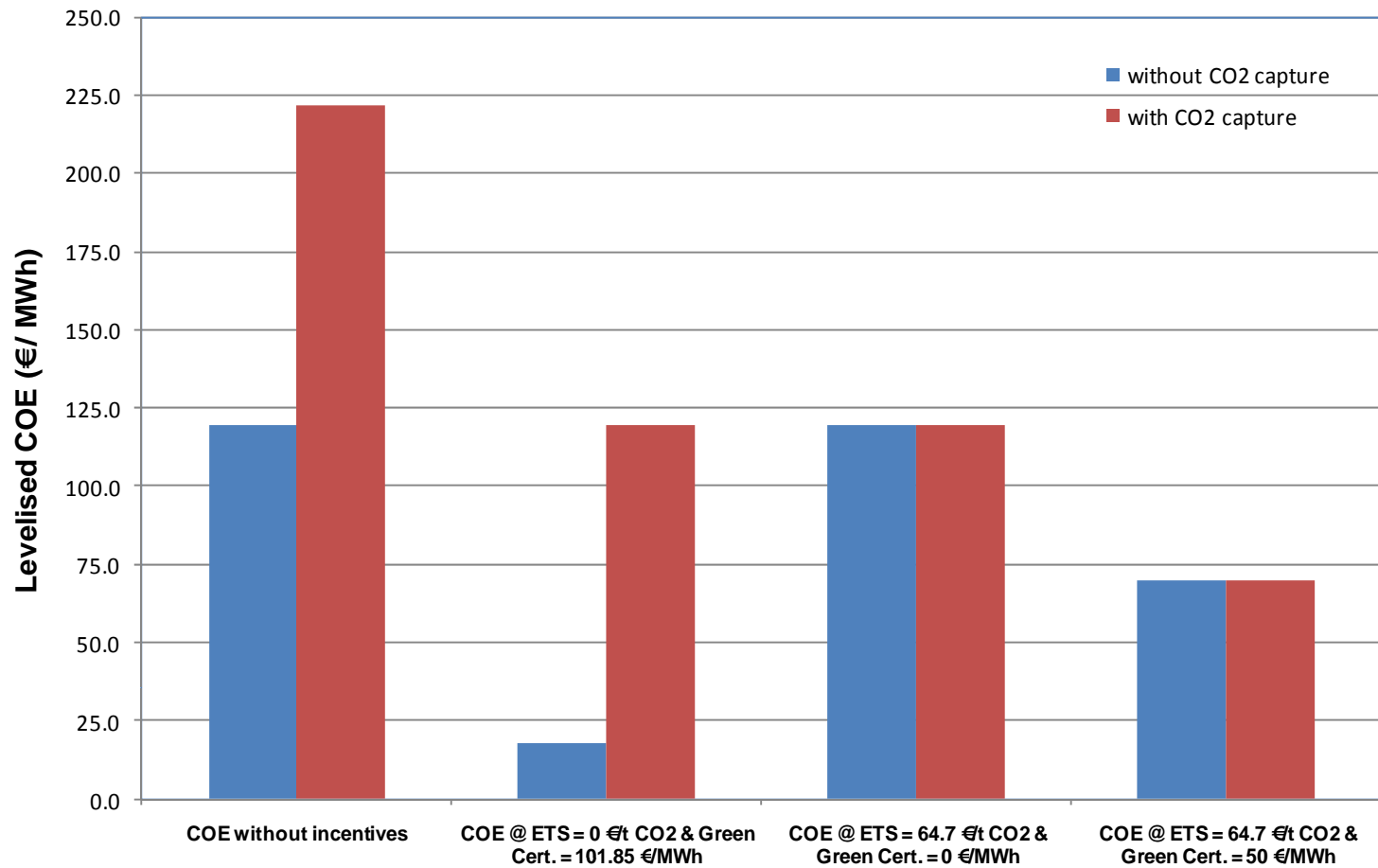
Cost of ETS to Incentivise Biomass CCS (Case 1a and Case 1b)



Economic summary



Cost of ETS to Incentivise Biomass CCS (Case 3a and Case 3b)



Concluding Remarks



- ***There is potential for the use of biomass fired power plant with CO₂ capture to be economically viable.***
 - The economic viability of capturing CO₂ from biomass fired or co-fired power plant could be dependent on the price of carbon / carbon tax that would incentivise the CO₂ negative emissions.
- ***The study only evaluated the use of virgin wood as biomass feedstock – which is considered more expensive than indigeneous low quality and more difficult burning biomass fuel. This should provide lower biomass fuel cost.***
- ***The capture of CO₂ from a biomass fired power plant using MEA Solvent, the following should be noted:***
 - it should be expected that the need to treat larger volume of flue gas and a deeper removal of the SO₂ and NO_x in the flue gas would contribute to the reduction of the performance of the plant and increase in cost (CAPEX and OPEX).
- ***This study only evaluated standard MEA solvent – therefore there are room for improvement in terms of cost and efficiency by using advance solvent.***



Thank you

Email: stanley.santos@ieaghg.org

Website: <http://www.ieaghg.org>