Agenda

Morning:

Time schedule	Session
9:30-10:00	Welcome of participants
10:00-10:10	Agenda of the meeting (Nathalie Thybaud)
10:10-12:30	Synthesis and validation of the collected data (Nathalie Thybaud and all participants)
12:30-14:00	Lunch

Agenda

Afternoon:

14:00-15:00	Presentation of the new contributions and discussion (all participants)
15:00-15:30	Structure of the report for presentation to WGSR of September 2008 (Nathalie Thybaud and all participants)
15:30-16:00	Conclusion and next steps (Nathalie Thybaud)

EGTEI

ENERGY SECTOR

Test for the Power Generation (LCP > 500 MWth)

Synthesis of collected data

Classification of technologies/techniques

- Ø Ia) Emerging technologies
- Ø Ib) Emerging abatement techniques
- Ø II) Emerging applications of existing abatement techniques
- Ø IIIa) Improvement of existing technologies
- Ø IIIb) Improvement of existing abatement techniques

Ia) Emerging technologies

Technology	Information	Pending information	Outside sub-group scope
Coal: Lignite predrying with low temperature heat			
Coal: IGCC	X		
Gas: Catalytic combustion			X
Biomass: IGCC			
Co-Combustion (Waste/Biomass)	X		
Oxycombustion		X? Air Liquide	
Coal: Underground gasification		X? BOT	
Coal: Low grade coal pre-processing		X? BOT	

Coal IGCC (Integrated gasification combined cycle)

IGCC is a combined cycle based on coal gasification and combustion of syngas in a gas turbine. The exhaust gases from the gas turbine are then fed into the steam cycle

Data from:

- Edipower (1)
- Study DFIU/IFARE – UBA Austria «Assessment of the air emissions impact of emerging technologies» - 2004 (2)
- IEA study «Fossil fuel-fired power generation» - 2007 (3)

Emerging technologies - Coal IGCC

Efficiency %	Environmental Impact				Investment M€/MW_{th}	Fixed operating costs M€/MW_{th}	Variable operating costs M€/MWh_{th}	Source of data
	NOx g/GJ fuel input (mg/kWh_{el})	SO2 g/GJ fuel input (mg/kWh_{el})	TSP g/GJ fuel input (mg/kWh_{el})	CO2 kg/GJ fuel input (g/kWh_{el})				
42.9 (LHV)	11.9 (100)	14.3 (120)	n.a.	92.1 (773)	Equipment only: 0.726	0.032 Personnel only	5.77 E-06	1 (information on Buggenum 585 MW_{th})
43 (LHV)	7.88 (66)	47.4 (397)	2.39 (20)	96.3 (806)	1 (1998)	n.a.	11.3 E-06 (only fuel)	1 (data from Elcogas Puertollano. 670 MW_{th})
	43	30	4.3		1.48 (2004)			2
40-43 (LHV)	50-75 mg/m^3	≈ 20 mg/m^3	<1 mg/m^3		+ 20% than PC			3

Emerging technologies - Coal IGCC

Conclusion

Ø Net efficiency: 43% (LHV)
Future developments (2010-2015): 50% efficiency (LHV)

Ø Low emissions. Mercury removal will be cheaper than for pulverised combustion

Ø Investment: 1-1.5 M€/MWth (demonstration plant)
Uncertainty in IGCC costs
+ 20% than pulverised combustion (IEA study)

Emerging technologies - Coal IGCC

Conclusion

- Challenges: reliability, availability and investment cost
- Development of IGCC with CO_2 capture and storage
  IGCC power plant with CO_2 removal needs an additional catalytic CO shift and a CO_2 absorption
- Commercially available (GE, Siemens) in 2020 (EDF expert)

Co-combustion

Biomass and waste may be co-combusted in regular combustion installations such as power plants.

Data from Edipower:

- Co-combustion (coal/waste) – experimental campaign in a power plant in Italy
- Co-combustion (coal/biomass) – feasibility study for implementation in a power plant in Italy
- *Co-combustion (oil/bio-oil) – 420 MWth*

Emerging technologies – Co-combustion

Description	Efficiency %	Environmental Impact				Investment M€/MW_{th}	Fixed operating costs M€/MW_{th}	Variable operating costs M€/MWh_{th}
		NOx g/GJ fuel input	SO2 g/GJ fuel input	TSP g/GJ fuel input	CO2 kg/GJ fuel input			
Co-combustion (coal/waste) 2x330 MWel. ESP + SCR + seawater pre-scrubber + limestone WFGD	35 (LHV)	88.3	123.6 (125.2 when 100% coal)	0.376* (0.959 when 100% coal)	99.5 (103 when 100% coal)	n.a.	n.a.	n.a.
Co-combustion (coal/wood pellets) 320 MWel. (800 MWth) 10% biomass co-firing ESP + SCR	36.5 (LHV)	72.9	113.3 (increase due to greater sulfur content in fuel mix)	12.76	100.5 (5% more than coal due to lower LHV)	0.15 (roughly estimated) 2007	n.a.	n.a.

*unexpected better TSP abatement compared to 100% coal is probably due to an increased efficiency of dust abatement by the scrubbers

Emerging technologies - Co-combustion

Conclusion

- The composition of the co-fired fuel have an impact which can be positive or negative on pollutant emissions
- Only data from feasibility studies

Missing information: costs data from implementation plants and information on the maximum co-firing ratio

Ia) Emerging technologies

Information outside the scope of LCP2030 sub-group

- Co-combustion (oil/bio-oil) – 420 MWth

- Catalytic combustion: pilot scale on a 1.5 MWel gas turbine. Plants for application on a 170 MWel gas turbine are being developed

Ib) Emerging abatement techniques

SO_2

Technique	Information	Pending information	Outside sub-group scope
Flowpac	X		
Limestone Injection Dry Scrubbing (LIDS)		X IFARE?	
Duct Sorbent Injection - Coolside			

Emerging abatement techniques – SO_2 - Flowpac

Flowpac (Alstom)

Wet FGD for desulphurization of flue gas using a bubbling technology instead of circulation pumps. Difficulties and power consumption are minimising by the suppression of recycle pumps, spray nozzles, headers, separate oxidation tanks and thickeners

Data from:

- Ø EDF via J-P RIVRON
- Ø Study DFIU/IFARE – UBA Austria «Assessment of the air emissions impact of emerging technologies» - 2004

Emerging abatement techniques – SO_2 - Flowpac

Implementation experience

- Karlshamn (SE), 1996, 3x340 MWe oil plant, 1 Flowpac (340MW), design for 3.5% sulfur content
- Elektrenai (LT), 2008, 4x150 MWe + 4x300MWe plant, fuel: natural gas, heavy oil, orimulsion, 3 Flowpac (3x150MW), design for 3.5% sulfur content
- Copenhagen, 2009, 1 Flowpac (150MW), design for 1.3% sulfur content
- No operational reference for unit > 340 MWe and coal unit. A prototype of 15 MW is in test in Sweden

Emerging abatement techniques – SO_2 - Flowpac

Performance

- The process has a compact design and allows to reach high desulphurisation rates (> 99%) with high sulphur content fuels (> 1.5%). SO_3 abatement efficiency: 60-70%

- High SO_2 and *particulate* removal efficiencies due to good gas/liquid contact

- The electrical consumption is lower in the Flowpac (1.3% of the power capacity in Karlshamm) than in the classical wet FGD (1.7/1.75%)

Emerging abatement techniques – SO_2 - Flowpac

Cost

- EDF: feasibility study on 2 coal units of 600 MWe in 2003
  Flowpac: 58 €/kWe (70 M€ for 2x600 MWe coal units)
  6% lower than classical wet desulphurisation (61 €/kWe (74 M€ for 2x600 MWe coal units))

- IFARE: 110 €/kW_{th} (2005), 90-110 €/kW_{th} (2010)

- According to Alstom, the yearly maintenance costs are lower for Flowpac (1.2% of the investment costs) than for the classical wet FGD (1.5%) due to a better accessibility

Emerging abatement techniques – SO_2 - Flowpac

Conclusion

- Ø High SO_2 efficiency
- Ø Low power consumption
- Ø Low capital cost due to elimination of spray pumps and associated equipment and compact design

Missing information: data on particulate removal efficiency, costs from implementation experience

Ib) Emerging abatement techniques

NO_x

Technique	Information	Pending information	Outside sub-group scope
Oxygen Enhanced Low-NOx Technology		X? Air Liquide	
Oxy-fuel combustion		X? Air Liquide	
Oscillating Combustion			
Dual-fuel combustion			

Ib) Emerging abatement techniques

SO_x-NO_x

Technique	Information	Pending information	Outside sub-group scope
CFB (flue-gas recirculating fluidized bed)			
US gas-phase oxidation process			
Limestone Injection Multistaged Burner (LIMB)			X
SOx-NOx-Rox-Box (SNRB)			X

Ib) Emerging abatement techniques

Information outside the scope of LCP2030 sub-group

- Ø SNRB: not considered as a priority (hazardous waste as by-product, rather low abatement efficiencies)

- Ø LIMB: not considered as a priority (problems of reliability, mediocre abatement efficiency)

Ib) Emerging abatement techniques

PM

Technique	Information	Pending information	Outside sub-group scope
Advanced PM1 Agglomeration ESP			X
Acoustics agglomeration			X
Fine particles collector	X		

PM1 not yet considered in RAINS/GAINS and lack of information from implementation experience

Ib) Emerging abatement techniques – PM – Fine particles collector

Technology name	Manufacturer	Technology description	Aim	Date of implement.
COHPAC+ TOXECON	Hamon-Research Cottrell (USA) under EPRI licendes	Combination of an existing or new electrostatic precipitator with a baghouse precipitator eventually with injection of additives sorbent	Reduce significantly mercury, sulphur dioxide and others toxics (dioxins…)	Tests in 2001 to 2004
INDIGO	Indigo technology LLC (USA)	Agglomerator located up-stream ESP to agglomerate fine particles with heavy particles to better capture them, with: -a fluidic mechanical agglomeration process -a bipolar electrostatic precipitator	Reduce by about a factor 10 the fine particles emissions	Test in 2004 in Australia

Missing information: costs from implementation experience

Ib) Emerging abatement techniques – CO_2 capture

Three types of CO_2 capture processes

- Ø post-combustion
- Ø oxy-combustion
- Ø pre-combustion

Emerging abatement techniques – CO2 capture

Post-combustion capture

Consist of separating the CO_2 from the flue gas of power plants, using a solvent for example. The solvent is then heated to release the CO_2 and regenerated

The solvents for CO_2 capture can be physical, chemical or intermediate. Chemical solvents, such as amines, are most likely to be used. The most advanced technology today

Other post-combustion capture solutions: absorption (chilled ammonia), adsorption, antisublimation, membranes

Source: IEA GHG “Capturing CO2”, May 2007

Emerging abatement techniques – CO_2 capture

Post-combustion capture and pollutant emissions

NO_2 and SO_X from the flue-gas react with the amine to form stable, non-regenerable salts and so cause a loss of the part of the amine

With amine, SO_X specification usually set as < 10 ppm(v) and NO_2 specification as < 20 ppm(v)

Limits for SO_x can be achieved by some FGD technologies

Experience from CASTOR pilot (post-combustion capture with amine): limestone gypsum flue gas desulphurization (FGD) plants can be designed to reduce SO_2 emissions down to 10 mg/Nm^3 with an increase of capital costs by up about 7% and 27% of operating costs

Limits for NO_x can usually be met by the use of low NOx burners and SCR

Source: IEA GHG “Capturing CO2”, May 2007

Emerging abatement techniques – CO_2 capture

Oxy-combustion capture

Consist of burning a fuel in oxygen and recycled flue gas. The gases produced by the oxy-combustion process are mainly water and CO_2, from which CO_2 can easily be removed at the end of the process

30 MW pilot plants under construction (Total, Vattenfal)

A large amount of oxygen is required for combustion, which is obtained by an air separation unit. A new and promising form of oxy-combustion: chemical looping

Source: IEA GHG “Capturing CO2”, May 2007

Emerging abatement techniques – CO_2 capture

Oxy-combustion capture and pollutant emissions

EU NO_x emission limits can be met with just the firing system of the boiler with staged combustion and low temperature at the furnace exit.

SCR and FGD units may not be needed

Source: IEA GHG “Capturing CO2”, May 2007

Emerging abatement techniques – CO_2 capture

Pre-combustion capture

Conversion (gasification or partial oxidation) of a fuel into a synthetic gas (carbon monoxide and hydrogen) which is then reacted with steam in a shift reactor to convert CO into CO_2

The process produces highly concentrated CO_2 that is readily removable by physical absorbents. H_2 can then be burned in a gas turbine

For the moment, none of the existing coal-fired IGCC plants includes shift conversion with CO_2 capture

Emerging abatement techniques – CO_2 capture

Performances and costs of the power plants with CO_2 capture

	Net Power	Efficiency (LHV)	CO_2 capture	Capital cost	Electricity cost
	MW	%	%	€/kW	€c/kWh
Post combustion capture					
Pulverised coal	761.0	35.5	85	1645	5.39
CFB	614.4	35.5	85	1552	5.34
PCFB	688.4	32.5	85	1788	5.55
Oxycombustion					
Pulverised coal	741.3	37.5	93	1882	5.46
Pre-combustion capture					
Future Energy gasifier	665.2	34.7	85.8	1706	5.41
Shell gasifier	628.8	34.5	85.2	1917	5.94
Foster Wheeler gasifier	686.6	34.1	82.9	1795	5.64

Load factor: 85%
Annual discount rate: 10%
Plant operating life: 25 years
Reference coal price: 1€/GJ
2005: 1€ = 1.3 US$ (1.17 US$ by December)

Source: CO_2 capture in low rank coal power plants (IEA GHG 2006/2)

Emerging abatement techniques – CO_2 capture

Indicative characteristics of power plants with CCS

Fuel & Technology	Year	Effic.	Effic. loss	Capture effic.	Invest. Cost	Capture cost	Electr. Cost	Electr. Cost no CCS
		%	%	%	$/kW	$/t	$/MWh	$/MWh
Coal steam cycle, CA	2010	31	12	85	1850	33	68	38
Coal steam cycle, CA	2020	36	8	85	1720	29	61	38
Coal steam cycle, CA	2030	42	8	95	1675	25	57	38
IGCC, selexol, PA	2010	38	8	85	2100	39	67	38
IGCC, selexol, PA	2020	40	6	85	1635	26	57	38
NGCC, CA	2010	47	9	85	800	54	57	38
NGCC, oxyfuel	2020	51	8	85	800	49	54	38
Black liquor, IGCC	2020	25	3	85	1620	15	34	24
Biomass IGCC	2025	33	7	85	3000	32	100	75

Note: 10% discount rate, 30-year lifetime, overnight investment costs, coal price: $1.5/GJ, NG: $3/GJ, CO_2 produced at 100 bar, transport and storage not included, CA: chemical absorption, PA: physical absorption, IGCC data for 2010 refer to highly_integrated plant (Shell gasifier) while 2020 data refer to US E-gas gasifier with high-efficiency gas turbines

Source: IEA Energy Technology Essentials, Dec. 2006

Emerging abatement techniques – CO_2 capture

Conclusion

- Due to efficiency drop with CO_2 capture, increase of efficiency of power plants is necessary
- CO_2 capture and storage in power plants is being demonstrated in a few small-scale pilot plants. Large-scale demonstration plants with carbon capture and storage (CCS) are planned by around 2015 with the objective of developing CCS until 2020
- No available cost data on large scale CO_2 capture implementation. Only assessment of costs from case studies
- There is no consensus on which option (post, pre or oxy-combustion) will cost least in the future

II) Emerging applications of existing abatement techniques

PM – SO_3 injection

SO_3 injection to lower particles emissions in case of combustion of high resistivity coal ashes

Implementation experience: EDF Le Havre 4, 600 MWe coal unit (1580 MWth), 2004

Dust abatement: average 50% efficiency, with possibility of 75 to 85%. Dust abated factor: 6.2 g/GJ fuel input

Electricity consumption: 0.013 kWh/GJ fuel input

SO_3 equipment investment (engineering included): 700 €/MWth (1.1 M€)

Fixed operating cost: 0.0012 €/GJ (not significant)

Variable operating cost: 0.001 €/GJ (not significant)

IIIa) Improvement of existing technologies

Technology	Information	Pending information	Outside sub-group scope
Coal: Pulverised Coal (PC)	X		
Coal: Circulating Fluidised bed combustion (CFBC)	X		
Coal: Pressurised fluidised bed combustion (PFBC)	X		
Oil: Combined cycle combustion (repowering)			
Gas: Gas turbines			
Gas: Gas fired boilers and heaters			
Gas: Combined cycle	X		
Gas: Co-generation (CHP)			
Pressurized Pulverized Coal Combustion (PPCC)			

IIIa) Improvement of existing technologies

Data from:

- Edipower (Combined cycle)
- Study DFIU/IFARE – UBA Austria «Assessment of the air emissions impact of emerging technologies» - 2004 (PFBC)
- IEA study «Fossil fuel-fired power generation» - 2007
  1) Pulverised coal firing (subcritical to ultra-supercritical)
  2) Natural gas plant
  3) IGCC

A lot of performance and costs data of recent power plants

IIIb) Improvement of existing abatement techniques

SO_2

Technique	Information	Pending information	Outside sub-group scope
Low sulphur fuels or fuels with basic ash	X		
Adsorbents in fluidised bed combution			
Wet lime/limestone scrubbers	X		
Jet bubbling reactor	X		
Spray dry scrubbers			
Furnace sorbent injection			
Duct sorbent injection (dry FGD)			
Magnesium oxide process			

Improvement of existing abatement techniques – SO_2

FGD

FGD cost and performance

Relation between plant sizes and FGD costs

Data from:

- VGB documents (2006)
- EDF
- Edipower

Improvement of existing abatement techniques – SO_2 - FGD

FGD performance (from VGB Powertech)

Coal-fired power plant: 300 MWe, 41.3% efficiency

SO_2 abatement efficiency: 88%

SO_2 abated factor: 641 g/GJ fuel input

Electricity consumption: 1 kWh/GJ fuel input

CO_2-e impact: 0.0009 tCO_2/GJ fuel input

Improvement of existing abatement techniques – SO_2 - FGD

Costs of different FGD systems for a 600 MWe power plant

Unit capacity MWe	Unit efficiency %	Unit capacity MWth	Fuel	Depollution system	Depollution Investment costs M€	Est. year	Specific cost* €/kWe	Specific cost* €/kWth	Existing unit or New unit	Sources comment
600		1453			47,3		79	33		VGB
600	42	1429	coal	Classic FGD	37	2003	62	26	new	EDF Est.
600	42	1429	coal	Flowpac	35	2003	58	24	new	EDF Est.
>600?				FGD		Mid 2006	88			EDF Rybnik
>600				FGD		2007/ 2008	110			EDF

Est=estimation
*engineering included

Improvement of existing abatement techniques – SO_2

Wet lime/limestone scrubber and jet bubbling reactor

Description	SO2		TSP		Elect. Cons.	CO2-e impact	Invest.	Var. operat. costs	Data source
	Abat. Eff. %	Abated factor g/GJ fuel input	Abat. Eff. %	Abated factor g/GJ fuel input	kWh/ GJ fuel input	tCO2/GJ fuel input	M€/MWth	M€/MW hth	
Single WFGD 2x160MWe Oil 3% S	95.8	56.3	n.a.		1.37	10.04 E-04	0.043	3.37 E-07	Edipower Retrofit project under construction
1 WFGD + 2 ESP in parallel 2x300MWe Lignite 2.39% S	96.2	184	50%	13.8	4.03	8.066 E-03	0.0315		Edipower Project under execution Ref. year: 2005
Single FGD 2x160MWe Oil 3% S	95.8	56.3	> 90%		1.508	11.05 E-04	0.043	3.37 E-07	Edipower Tender

IIIb) Improvement of existing abatement techniques

NO_x

Technique	Information	Pending information	Outside sub-group scope
Air staging (burners out of service (BOOS))	X		
Air staging (overfire air (OFA))			
Flue-gas recirculation			
Air-staged low NOx burner			
Flue-gas recirculation low NOX burner			
Selective catalytic reduction (SCR) for conventional boilers	X		
SCR for gas combined cycle plants	X		
Selective non-catalytic reduction (SNCR)			
Hybrid SCR and SNCR for conventional boilers			

Improvement of existing abatement techniques – NO_x - SCR

SCR for conventional boiler

SCR costs and performance

Relation between plant sizes and SCR costs

Data from:

- VGB documents (2006)
- EDF
- Edipower

Improvement of existing abatement techniques – NO_x - SCR

SCR performance (from VGB Powertech)

Coal-fired power plant: 300 MWe, 41.3% efficiency

NO_x abatement efficiency: 71.5%

NO_x abated factor: 185 g/GJ fuel input

Electricity consumption: 0.19 kWh/GJ fuel input

CO_2-e impact: 0.00016 tCO_2/GJ fuel input

Improvement of existing abatement techniques – NOx - SCR

SCR for conventional boiler and for gas combined cycle

Description	NOx		SO2		Elect. Cons.	CO2-e impact	Invest.	Var. operat. costs	Data source
	Abat. Eff. %	Abated factor g/GJ fuel input	Abat. Eff. %	Abated factor g/GJ fuel input	kWh/ GJ fuel input	tCO2/GJ fuel input	M€/MWth	M€/MW hth	
2x160 MWe Retrofit with Hi-dust SCR Oil 3% S	89	28.1	0.5-1 SO2 to SO3		0.25	1.846 E-04	0.0238	3.36 E-07	Edipower Retrofit project under construction
CCPP 2xGT 250 MWe Natural gas fuel	50	16.4			0.121	4.44 E-04	0.0044	2.04 E-08	Edipower Tender

Improvement of existing abatement techniques – NOx

Air staging (burners out of service – BOOS)

Power plant: 4x160 MWe retrofitted with BOOS, oil 1% S

NO_x abatement efficiency: 55%

NO_x abated factor: 140 g/GJ fuel input

Investment: 120 €/MWth (estimate)

Since 6 years in operation

IIIb) Improvement of existing abatement techniques

PM

Technique	Information	Pending information	Outside sub-group scope
Electrostatic precipitators (ESP)	X		
Fabric filters (baghouses)	X		
Centrifugal precipitation (cyclones)			

Improvement of existing abatement techniques – PM

ESP and fabric filters

Cost and performance

Cost comparisons between electrostatic precipitators and fabric filters (2006)

Data from:

- Edipower
- EDF (Rod Hansen and Robbie Van Rensburg communication on 6x600 MW units at DUVHA power station (South Africa))

Improvement of existing abatement techniques – PM

ESP and fabric filters

Description	TSP		Elect. Cons.	CO2-e impact	Invest.	Data source
	Abat. Eff. %	Emission factor g/GJ fuel input	kWh/GJ fuel input	tCO2/GJ fuel input	M€/MWth	
4x160 MWe ESP (3 fields) on each unit Oil 1% S	85	6.47	0.132	9.7 E-05	0.0133	Edipower Retrofit project In operation since 2003
2x300 MWe 2 ESP (3 fields) in parallel on each unit + 1 WFGD Lignite 2.39% S	99.9 (design)	27.6	0.31	6.2 E-04	0.0082	Edipower Project under execution Ref. year: 2005
2x320 MWe Fabric filters Coal max 1% S	99.9 (design)	4.34	0.46	4.46 E-04	0.0062	Edipower Tender

Other data (for information)

- Impact of efficiency improvement of power plants
- Fuel switch from about 1% to about 0,1% Sulfur content (and to less than 1% ash content) for coal
- Increasing of cost in relation with net efficiency from study "Concept study Reference Power Plant North Rhine-Westphalia (RPP NRW)" – VGB - February 2004
- Increasing of costs between 2000 and 2007

State of progress

Pending contribution from:

- Ø Air Liquide (oxy-burner, oxycombustion) – May 2008
- Ø Interview of EDF expert on combined cycle – May 2008
- Ø Interview of EDF expert on coal power plant
- Ø Czech Republic (Andrea Krizova)?
- Ø BOT (Jacek Gadowski)?

Thank you for your attention