Abbreviations and acronyms

ACC	Air-Cooled Condenser
AGR	Acid Gas Removal
ASU	Air Separation Unit
BOOS	Burner out of service
BOP	Balance of Plant
BREF	Reference Document on Best Available Techniques (IPPC)
CCGT	Combined Cycle Gas Turbine
CCPP	Combined Cycle Power Plant
CCS	Carbon dioxide Capture and Storage
CWS	Cooling Water Supply
DCS	Distributed Control System
ESP	Electrostatic precipitator
FF	Fabric Filter
FGD	Flue Gas Desulphurisation
GT	Gas Turbine
HHV	Higher Heating Value
HRSG	Heat Recovery Steam Generator
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPPC	Integrated Pollution Prevention and Control
LCP	Large Combustion Plant
LIMB	Limestone Injection Multistaged Burner
LHV	Lower Heating Value
MDEA	Methyl Di-Ethyl Amine
PC	Pulverised Combustion
PFBC	Pressurised Fluidised Bed Combustion
RDF	Refuse Derived Fuel
REF	Recovered Fuel
RH	Re-Heater
SCR	Selective Catalytic Reduction
S/C	Supercritical
SNRB	SOx-NOx-Rox Box
SRU	Sulphur Removal Unit
ST	Steam Temperature
USC	Ultra-supercritical
WFGD	Wet Flue Gas Desulphurisation
WWT	Waste Water Treatment
WCC	Water-Cooled Condenser

Annexes

7.1 - **Executive summary of IEA - Fossil Fuel-Fired Power Generation - Case studies of recently constructed coal and gas-fired plants,** *2007*

7.2 - **Expert opinion on Gas Combined Cycle (GCC) trends for electricity production, Jacques MAUNAND (EDF Chatou Research Centre),** *April 2008*

7.3 - **Report "Technical and economical data on depollution systems", Jean-Pierre RIVRON,** *March 2008*

7.4 - **Documents from the kick-off meeting -** *7 June 2007*

7.5 - **Documents from the 2nd meeting -** *1 October 2007*

7.6 - **Documents from the 3rd meeting -** *25 January 2008*

7.7 - **Documents from the 4th meeting -** *17 March 2008*

7.8 - **Documents from the 5th meeting -** *28 April 2008*

Annex 7.1

1.1 Executive summary of IEA - Fossil Fuel-Fired Power Generation - Case studies of recently constructed coal and gas-fired plants, 2007

Background

One of the ways of substantially reducing the emissions of CO_2 from fossil fired power generation is to maximise the efficiency of new plants being installed to meet future demand growth and for replacing inefficient capacity. This series of case studies was conducted to show what is achieved now in modern plants in different parts of the world. It arose from a request to the IEA in the Plan of Action regarding climate change that emerged from the G8 Summit communiqué in July 2005 to:

"... carry out a global study of recently constructed plants, building on the work of its Clean Coal Centre, to assess which are the most cost effective and have the highest efficiencies and lowest emissions, and to disseminate this information widely ...".

Recent coal-fired power plants of high efficiency use pulverised coal combustion (PCC) with supercritical (very high pressure and temperature) steam turbine cycles, and so most of the case studies are drawn from these. They were selected from different geographical areas, because local factors influence attainable efficiency. A review of current and future applications of coal-fuelled integrated gasification combined cycle plants (IGCC) is also included. Although these are small in number and not recently constructed (one is being constructed currently) so that there are greater cost and other uncertainties, the technology could form the foundation of many future power stations, with its very low conventional emissions and potential advantages for CO_2 capture. It should be noted that there is more uncertainty in IGCC cost and performance projections as the commercial ordering of coal-fuelled IGCC as a complete system for power generation by utilities has yet to occur. There is also a case study of a natural gas-fired combined cycle plant, included to facilitate comparisons.

Work method

Data gathering by questionnaire was followed up with plant visits by IEA CCC personnel. Information was also obtained from published sources. Some of the data, especially on costs, could not be supplied by all owners because of confidentiality considerations. Data gathering was carried out during 2006 and followed by analysis and report preparation. The final report does not include all the detailed information. The intention has been to identify and summarise important messages that emerge.

Case study plants

A list of the coal-fired plants, with boiler and turbine suppliers, some key features and the bases of the selections, is given in Table S1. The two plants in Europe are a cold sea water cooled plant fired on internationally-traded, bituminous coals (Nordjyllandsværket 3, Denmark) and an inland, lignite-fired unit in Germany (Niederaussem K). The case study plant in North America is the first modern supercritical unit and fires sub-bituminous coal. In Asia, three plants are included. In Japan, Isogo New Unit 1 has the highest steam conditions in the world among currently operating sliding pressure units and very low emissions. The first two units at Younghung Thermal Power Plant in the Republic of Korea illustrate the progression toward higher steam conditions ongoing in that country, and the first two units at Wangqu in China mark a development in firing low volatile coals in supercritical units. The subcritical plants in India, at Suratgarh, and South Africa, at Majuba, cover high ash coal burning in difficult locations, with Majuba illustrating the use of dry cooling. Experience will be relevant to future supercritical plants in these countries. The study findings are summarised below.

Nordjylland 3, Denmark

The 400 MWe Unit 3 at Nordjylland power station, owned by Vattenfall, is a sea water cooled ultra-supercritical unit fired on internationally-traded, bituminous coals. Opened in 1998, the plant is situated near the town of Aalborg, which it also supplies with heat. In power-only mode, net efficiency is 47%, on a fuel LHV basis* (44.9% on an HHV basis), so Nordjylland 3 is the most efficient coal-fired unit in the world. The high efficiency comes from use of a double reheat steam cycle at very high conditions (29 MPa/582°C/580°C/580°C) plus a low condenser pressure from the availability of cold sea water for cooling. The steam conditions took full advantage of newly available materials when the plant was designed but also necessitated the use of flue gas re-circulation and advanced water treatment as well as care in start-up to ensure integrity of boiler components.

Airborne emissions are very low. For NOx control, the tangentially fired boiler has low-NOx burners, overburner air and over-fire air as well as a selective catalytic reduction (SCR) unit. For dust removal there are electrostatic precipitators (ESPs,) and a limestone-gypsum flue gas desulphurisation (FGD) system achieves extremely low SO_2 residual levels. Virtually all solid by-products are utilised and calcium chloride liquor from the FGD waste stream will shortly be sold for road de-icing.

No economic information was available from the plant operators. According to DONG Energy (who now own ELSAM, the previous owners of the plant), the contracting strategy was owner design with multi-contract procurement. Information on the current cost of an 800 MWe ultra-supercritical plant from Siemens indicates that it would be around 1500 USD/kWso in 2006, excluding owner's costs or interest during construction.

**The calculation of fuel LHV used as the basis of the LHV efficiency throughout this publication includes subtraction of the latent heat of the water vapour formed from evaporation of the moisture originally present in the coal as well as that of the water vapour formed from combustion of the coal hydrogen.*

Table S1 • Main features of the eight coal-fired case study plants and bases for selection for study

Plant	Siting	Coal	MWe net	Boiler geometry	Main suppliers: boiler; turbine	Ultra-super-, Super- or sub-crit	Steam conditions MPa/°C/°C(/°C)	Why selected
Europe – Denmark: Nordjyllandsværket 3	coastal	international	384	tower	FLS miljo/BWE, Aalborg Industries, Volund Energy Systems; GEC Alsthom (now Alstom)	USC	29/582/580/580	Most efficient coal plant; double-reheat; very low emissions
Europe – Germany: Niederaussem K	inland	lignite	965	tower	EVT (today Alstom), Babcock and Steinmüller (today HPE); Siemens	USC	27/580/600	Lignite; top efficiency lignite plant; lignite drier demonstration
North America – Canada: Genesee 3	inland	sub-bituminous	450	2-pass	Babcock-Hitachi	S/C	25/570/570	Sub-bituminous coal; first sliding pressure S/C North America
Asia – Japan: Isogo New Unit 1	coastal	international	568	tower	IHI; Fuji Electric (Siemens)	USC	25/600/610	Very high steam parameters; very low emissions; activated coke regenerable FGD
Asia – Korea: Younghung	coastal	international	2x774	tower	Doosan Heavy Industries & Construction Co.	S/C	25/566/566	Most recent and largest coal-fired units in Korea
Asia – China: Wangqu 1, 2	inland	Chinese lean	2x600	2-pass	Doosan Babcock; Hitachi	S/C	24/566/566	Location; wall-firing of low-volatile coal with low NOx
Asia – India: Suratgarh 1-5	inland	~30% ash	5x227	2-pass	BHEL	Drum sub-crit	15/540/540	Location; high ash coal; drum boiler
Africa – South Africa: Majuba 1-6	inland	~30% ash	3x612 (dry) 3x669 (wet)	tower	Steinmüller; Alstom	once-through sub-crit	17/540/540	Location; dry versus wet cooling; high ash coal, once-through sub-critical boiler

USC: ultra-supercritical (steam temperatures of 580°C and above)
S/C: supercritical

This impressive unit was a result of initiatives by Danish utilities to move to much higher efficiency plants of high flexibility by working with major suppliers on designs that are practical and economic at high steam conditions. Danish engineers are continuing to look at innovative means to reach still better performance in future plants.

Niederaussem K, Germany

Niederaussem K, owned by RWE Power, is a 1000 MWe ultra-supercritical lignite-fired unit near Cologne. Net efficiency is 43.2%, on a fuel LHV basis (37% on an HHV basis). The unit is the most efficient lignite-fired plant in the world. Niederaussem K opened in 2002, and there are two further units based on the technology under construction at a neighbouring RWE power station site at Neurath.

In addition to the advanced steam conditions (27.5 MPa/580°C/600°C), there are other features that have been used for very high efficiency. Among these are a complex water circuit to exploit a unique heat recovery system downstream of the main economiser and a flue gas cooler for final heat recovery. The condenser pressure has also been made low by incorporating an unusually tall cooling tower. Although there were a few early difficulties with materials in parts of the boiler, these were solved by use of newer alloys.

NOx emissions from the boiler are low from the use of wall-mounted lignite-specific low-NOx burners and other fuel and air staging arrangements, so there is no downstream flue gas NOx control equipment. Electrostatic precipitators collect fly ash, and a wet FGD unit desulphurises the emerging flue gas.

The investment cost was around 1 175 USD/kWso in 2002, including interest during construction and owner's costs, and construction took 48 months.

The efficiency is very good for a plant firing 50-60% moisture content lignite fuel. A demonstration plant for pre-drying part of the lignite fuel feed using low grade heat is being installed to enable even higher efficiencies. The new units at Neurath will have slightly higher steam conditions and a simpler cycle, but include many of the features of Niederaussem K.

Genesee 3, Canada

Genesee 3, opened in March 2005, is the first sliding pressure coal-fired supercritical unit to be commissioned in North America. The 450 MWe unit, located 75 km from Edmonton, is jointly owned by EPCOR and TransAlta Energy Corporation. It operates on a sub-bituminous Albertan coal. Steam parameters (25 MPa/570C°/568°C) were chosen to maximise efficiency while minimising risk and net efficiency is over 41% on an LHV basis (40% on an HHV basis). The overall configuration consists of a two-pass supercritical boiler, a single reheat supercritical cycle with eight stages of feedwater heating, a spray-dry flue gas desulphurisation unit, and a bag filtration system.

Genesee 3 had to be suitable for flexible operation in a market-oriented environment without compromising on efficiency or environmental performance. The design SO_2 emissions are less than half the normal legislated level and emissions of NOx are much better than required through use of advanced low-NOx burners and over-fire air. The fabric filtration unit takes the concentration of particulates down to better than design.

The cost of Genesee phase 3 was approximately 1100 USD/kWso in 2005, excluding interest during construction or owners costs, and construction took 36 months. The power generating and emission control equipment was established through a single EPC contract.

The sliding pressure design used here allows economically competitive, flexible plants that will be suited to de-regulated environments elsewhere in North America. It has been a low-risk way of achieving high efficiency and environmental performance on sub-bituminous coals. After construction of a sister unit at a neighbouring TransAlta power generation site, later plants are likely to move to higher steam parameters, following the success of this and similar units currently being constructed in Canada and the USA.

Isogo New Unit 1, Japan

Isogo New Unit 1 is a sea water cooled, 600 MWe ultra-supercritical unit, owned by Electric Power Development Co. (J-POWER). It is located at Yokohama City, 25 km from Tokyo. The plant, opened in April 2002, burns Japanese and internationally-traded bituminous coals and some sub-bituminous coal. Very high steam conditions give a good efficiency of over 42% net, LHV basis (40.6%, HHV basis) at this rather warm sea water cooled site. Advanced steam parameters (25 MPa/600°C/610°C) were made possible by the availability of recently developed steels. The configuration includes a once-through wall-fired tower boiler fitted with combustion measures for low-NOx, a single reheat advanced supercritical steam turbine cycle, with eight stages of feedwater heating, an SCR, ESPs, and a dry FGD.

Isogo New Unit 1's environmental performance is very impressive. The plant easily meets extremely tight emissions levels on NOx, dust and oxides of sulphur. The flue gas desulphurisation system is a dry regenerable process which uses activated coke to capture the SO_2. It consumes less power and much less water than wet systems. J-POWER are marketing the technology under the name of ReACT as a multi-pollutant control system for oxides of sulphur, NOx and particulates, as well as heavy metals such as mercury. Virtually all solid by-products are utilised at Isogo.

The contracting strategy was to use owner design basic specification and the approximate capital cost was 1800 USD/kWso (2006), based on Isogo New Units 1 and 2 (latter not yet completed), including interest during construction and owner's costs. Construction time was 66 months.

Isogo New Unit 1 is a flagship PCC plant. It uses the highest steam parameters in the world for a modern sliding pressure system, and close to zero emissions of conventional pollutants have been achieved. The Isogo New Unit 2, construction of which commenced in October 2005, will have even higher steam conditions (25MPa/600°C/620°C) and use the ReACT system for multi-pollutant control.

Younghung Thermal Power Plant, Republic of Korea

Younghung Thermal Power Plant, owned by the Korean South-East Power Company (KOSEP), is the newest coal-fired plant in Korea. The first two units, opened in 2004, have supercritical steam parameters of 24.7 MPa/566°C/566°C. Younghung is located at Incheon, approximately 50 km from Seoul. The units are sea water cooled, rated each at 800 MWe, and fire internationally-traded bituminous coals. These are the largest coal-fired units to be built in Korea to date and have used higher steam conditions than previous plants in the country. A single reheat supercritical steam turbine system of conventional configuration with eleven stages of feedwater heating is used and design net efficiency is 43% on an LHV basis (41.9%, HHV basis). The aim is to establish twelve units on the site. Construction of Units 3 and 4 is in progress. These will be similar, but use higher steam temperatures of 593°C.

A combination of environmental control systems gives very good environmental performance. Low-NOx combustors and air staging in the boiler provide initial NOx minimisation, and an SCR unit removes much of the remaining NOx. Particulates are removed by ESPs, and 60% of the ash is utilised. A limestone/gypsum FGD system removes SO_2. By-product gypsum is sold to the construction industry.

The plant specific capital cost was 993 USD/kWso in 2003, but the basis is uncertain. Construction time was 64 months.

Thus, low emissions of conventional pollutants have been achieved in a cost-effective plant using conventional commercial systems. In Korea, plant designs are now moving toward higher conditions quite rapidly, and succeeding unit additions at Younghung will have progressively higher steam parameters.

Wangqu 1 and 2, China

Wangqu opened in 2006, and is owned by Shanxi Lujin Wangqu Power Generation Co. Ltd. It is at an inland location, 2 km from Lucheng City near Changzhi. The two new 600 MWe (nominal) units, completed in 2006, have a design net efficiency of over 41% on an LHV basis (40%, HHV basis). They represent a major step forward in being among the first wall-fired supercritical boilers to operate successfully using lean coals (10 to 20% V.M.) by employing advanced low NOx burners together with high velocity over-fire air. Due to pressure to send the best coals to steelmaking, China's power stations increasingly need to burn such coals.

Each unit has a two-pass supercritical boiler, a single reheat supercritical cycle with eight stages of feedwater heating, ESPs and a wet FGD. Steam parameters are 24.2 MPa/566°C/566°C, chosen to minimise risk, while giving good performance.

The combustion system has been developed to meet Chinese legislation on NOx emissions from new lean coal-fired plant even at low loads with good combustion efficiency. The SO_2 removal design efficiency at the plant is also good.

The contracting strategy used by the client was owner design specification with competitive bidding. The installation cost was approximately 580 USD/kWso in 2006. This figure is understood to exclude owner's costs and interest during construction. Construction time was 30 months.

These units are a good example of the way China is moving rapidly to improve the efficiency and emissions of its power plants by ordering high-performing international technology with licensing agreements to enable the country to use its own manufacturing capabilities for future plants. Two further identical 600 MWe units at the site will be air cooled, as Shanxi province has a water shortage problem.

Suratgarh, India

Suratgarh thermal power plant consists of five 250 MWe subcritical units commissioned between 1998 and 2003. It is owned by the Rajasthan State Electricity Board and is situated in the northern part of Rajasthan in the Ganganagar district on the edge of the Thar/Indian desert. A single reheat subcritical steam turbine system of conventional configuration with six stages of feedwater heating is used for each unit, and design efficiency is 37.1% on an LHV basis (35.1%, HHV basis). Steam parameters are 15.8 MPa/540°C/540°C. The units are water cooled, with mechanical draught cooling towers. Ambient conditions here result in a higher condenser pressure (10.5 kPa) than encountered in more temperate regions.

High efficiency ESPs are fitted for particulates control, and tangential firing and over-fire introduction of secondary air are used for NOx control. There is no SCR or FGD. Ash utilisation has grown steadily, and Suratgarh plans achieving 100% utilisation by 2010.

The units were designed to use indigenous coals of ash content 45% but the fuel used is now a blend, including some Chinese coal, to keep to around 30% in line with Government requirements to use maximum 34% ash coal. This is still high by world standards. Other challenges were associated with the desert environment giving difficult site ground conditions and water quality variations. Low rainfall necessitated construction of a reservoir for 21 days' operation. Air intakes are designed to avoid ingress of sand during sandstorms.

The plant specific capital cost was approximately 822 USD/kWso in 2002, but the basis of this was uncertain. Construction time for one unit was 39 months.

The thermal efficiency is inevitably penalised by the coal quality as well as the local conditions and the use of a subcritical cycle, but future, higher efficiency supercritical units will be able to build on the experience gained.

Majuba, South Africa

Majuba is another plant in an area of water shortage firing high ash coal, in this case of around 30% ash content and of slagging and fouling propensity. The plant is owned by Eskom and is situated near Amersfoort in Mpumalanga. The coal for the 4110 MWe power station is brought from collieries in the Witbank area of Mpumalanga. Majuba consists of six units of over 600 MWe. The first opened in April 1996 and the others followed at yearly intervals.

Each unit uses a subcritical once-through tower boiler of steam parameters 17.2 MPa/540°C/540°C and a single reheat subcritical steam turbine. Units 1-3 employ air cooling and units 4-6 have water cooling. Six stages of feedwater heating are used for both types. The design efficiencies of the dry-cooled and wet-cooled units are around 35% and 37% net on an LHV basis (33.8% and 35.7%, HHV basis), respectively.

Low-NOx burners give control of NOx. Staggered burner geometry is used to minimise slagging. There is no SCR or FGD. Fabric filtration systems remove particulates.

In the dry-cooled condensers, steam from the turbines is condensed inside tubing, across which air is blown. Condensing performance is very dependent on ambient temperature, so unit output and efficiency vary considerably with season. The wet cooled units have conventional condensers and natural draught cooling towers. Wet cooling was selected for these units for economic reasons.

The specific capital cost of Majuba was approximately 410 USD/kWso in 2001, including interest during construction and owner's costs. The plant is currently two-shifting and performing well, despite being intended for base load use.

Dry cooled units are less efficient than conventional systems and efficiency is also affected by the use of a subcritical cycle. Dry cooling would be considered for future plants, depending on water availability. Eskom is understood to be currently in the bidding stage for 3x660 MW supercritical power plants.

Natural gas-fired plant: Enfield, United Kingdom

The Enfield Energy Centre combined cycle plant in northeast London opened for commercial production in 2002 and is currently owned by E-ON. It is a 400 MWe system, based on a reheat gas turbine and reheat steam cycle. The design efficiency is 58% net on an LHV basis (52%, HHV basis). The combined cycle turbine is currently offered by the manufacturer with an efficiency of 58.5% (LHV).

Enfield employs Alstom's GT26B gas turbine, which has two combustion zones, with a high pressure expansion turbine between them and a low pressure turbine after the second combustor. The system was developed to give high efficiency without the need for the highest turbine inlet temperatures. The hot exhaust gases raise steam at three pressure levels for a subcritical reheat steam turbine, which is coupled to the same generator. The steam cycle here has an air cooled condenser.

The gas turbine uses a sequential annular combustion system and low-NOx burners to keep NOx production low without needing an SCR unit.

NGCC projects are lower in investment requirements than coal-fired projects in OECD locations. In this case, the total project cost was around USD350 million, or around 950 USD/kWso in 1999. The overnight cost will have been considerably lower. Gas turbine combined cycle projects have short construction times, and here it was 22 months. Enfield currently operates on a flexible, two-shift basis but efficiency is still high at 52% (LHV).

This plant highlights a continuing drive by manufacturers to move the technology on to higher future performance through innovation. High efficiency and lower capital requirements mean natural gas-fired combined cycles will continue to be specified for many power generation projects where natural gas is available.

IGCC technology review

Net efficiency for IGCC in existing plants is around 40-43% on an LHV basis (around 38-41%, HHV basis). Recent gas turbines would enable this to be bettered and future developments should take efficiencies beyond 50% on an LHV basis. Emissions are low, and mercury removal will be cheaper than for PCC. The specific investment cost of IGCC is about 20% higher than that of PCC. There is however more uncertainty in IGCC costs as there are no recently built coal-fuelled IGCC plants and the existing ones were constructed as demonstrations. Availabilities have also not yet reached the demonstrated level of operating PCC units. Suppliers have plans to bring the capital cost to within 10% of that of PCC. Note that, while there are competitive pressures, the capital costs being cited for many power projects have risen sharply recently because of increases in energy prices and their impacts on steel and concrete costs.

There are two demonstration plants in the EU. NUON's plant, at Buggenum in Holland, is a 250 MWe system, based on Shell gasification and a Siemens V94.2 gas turbine. It now operates as a commercial plant on imported coals with good availability and a net efficiency of 43% (LHV). The other is ELCOGAS's plant at Puertollano in Spain, a 300 MWe system based on the similar Prenflo gasifier and a Siemens V94.3 gas turbine. It uses a high ash coal/high sulphur petcoke mixed fuel and has a net efficiency of 42% (LHV). Both had initial problems in firing syngas and needed turbine combustor modifications. Both have highly integrated systems, which have proved to be rather inflexible. A 1200 MWe plant at another site is planned by NUON.

IGCC plants currently operating in the USA are the Tampa Electric Polk project and the Wabash River coal gasification project, both constructed under the US DOE CCT Program. The 250 MWe Polk project uses a GE gasifier and GE 7FA gas turbine. The net efficiency was 35.4% on an HHV basis (36.7%, LHV basis) on coal feed. The 260 MWe Wabash River project uses ConocoPhillips E-Gas technology with a GE 7FA turbine and an existing steam turbine and has a net efficiency of over 38% on an HHV basis (40%, LHV basis). Both US plants are less integrated than the EU ones although some gas turbine air extraction has recently been incorporated at the Polk plant. The gas turbines performed well at both but there were some other difficulties. Both plants now operate commercially, although their availabilities are understood to be lower than the best in class operating supercritical PCC plants in the USA. A CCPI demonstration of the transport gasifier is to be constructed in Florida.

In Japan, the Clean Coal Power R&D Co., Ltd. (CCP) is constructing a 250 MWe IGCC demonstration project, due to start operation in 2007, at Iwaki City, based on the MHI air-blown entrained gasifier and an MHI gas turbine.

IGCC reference plant designs of 600 MWe have been developed by supplier groupings to encourage market uptake by driving down the cost and providing full single-point guarantees. Examples are those from GE-Bechtel and Siemens with ConocoPhillips. Some projects likely to use these include:

- Duke Energy, Edwardsport, Indiana – GE-Bechtel
- AEP, Meigs County, Ohio and Mason County, W. Virginia – GE-Bechtel
- Mesaba Energy Project, Minnesota – ConocoPhillips E-Gas (CCPI Demo)

With IGCC now available as a commercial package, more orders could follow as utilities see the cost decreasing and availability improving. It may still be necessary for subsidies or incentives to cover the higher cost compared with PCC.

IGCC fits well with CO_2 capture and storage and there are projects planned in several countries, including Canada, Australia, Germany, the UK, in addition to the US Government FutureGen and European Commission Hypogen initiatives and the GreenGen project in China. Inclusion of CO_2 capture and storage will reduce efficiency but the generation cost may be lower than for CO_2 capture on PCC.

Conclusions

Table S2 collects together the case studies with a summary of costs, emissions and efficiencies.

In the near future, leading edge supercritical pulverised coal technology in the EU and Japan will continue gradually to move to higher steam conditions, with in some cases simplification of cycles, in others, more complex systems. The current state-of-the-art for modern, sliding pressure-capable PCC boilers is 600°C main steam and 620°C reheat at the turbine. In other regions there will be a follow-up move through increasing conditions while keeping just behind the state-of-the-art in order to take advantage of the experience in the new plants, while minimising risk. Although even higher temperatures have been used in the past on early supercritical designs in the USA and elsewhere, these had availability difficulties and were not competitive. In due course, leading edge plant is likely to be built in all locations.

In some countries, such as India and China, subcritical plants will probably be built in addition to supercritical units for a while. Local manufacturing bases for current plant are now capable of supplying supercritical technology so there will be movement toward the most advanced steam conditions. Other countries, not yet using or building supercritical technology, will likely begin orders at some point within the next few years. The UK, Australia and South Africa are examples.

Advanced developments in natural gas-fired gas turbines will take the efficiencies of these systems to even higher levels, maintaining their strong presence for new power projects. Developments in gas turbines will benefit commercial offerings for turbines in coal IGCC. With IGCC now available as a commercial package, orders should follow, probably aided at first through market entry incentives.

At some point, it looks highly likely that fossil-fired plants will capture and store their CO_2 emissions. CO_2 capture will reduce efficiency markedly, so there will be a continuing need to use innovations such as those identified in these case studies. Future very high temperature PCC systems employing superalloys should enable power generation efficiencies with CO_2 capture to be comparable with those of current non-capture plants. High temperature hydrogen gas turbines and new CO_2 separation methods should give IGCC with CO_2 capture systems of similar performance, so both combustion-based and gasification-based platforms are likely to be important in the future.

The following main points have emerged from the case studies and subsequent analysis of results:

- New PCC projects use S/C or USC conditions as a matter of routine to achieve high efficiency;
- USC and S/C PCC systems are available for a wide range of coal types;
- Use of new materials has been important in achieving the high efficiency and reliability;
- Complex thermodynamic cycles have evolved to enhance efficiency further;
- Heat extraction to low temperatures has been demonstrated using non-metallic components in heat exchangers;
- Siting helps efficiency;
- Flexibility is no longer a problem in S/C or USC;
- A wide range of coal types can be burned in PCC systems;

Table S2* • *Costs, emissions and efficiencies of the case study plants and comments

Plant	**Capital cost,** USD/kWso	**Achieved emissions at 6% O_2, dry**	**MWe net**	**Steam conditions** MPa/°C/°C (/°C)	**Design efficiency, net** %, LHV and HHV bases	**Annual operating efficiency, net** %, LHV and HHV bases	**Factors affecting efficiency and other comments**
Europe – Denmark: Nordjyllandsværket 3	1500 (2006) for new 800 MWe excluding owners costs or IDC	NOx 146 mg/m^3 SO_2 13 mg/m^3 Dust 18 mg/m^3	384	29/582/580/580	47 LHV (no heat load) 44.9 HHV (no heat load)	47 LHV (not annual) 44.9 HHV (not annual)	High steam parameters Cold sea water cooling Double reheat Low auxiliary power Extremely low emissions No solid waste for disposal
Europe – Germany: Niederaussem K	1175 (2002) Total project cost	NOx 130 mg/m^3 SO_2 <200 mg/m^3 Dust <50 mg/m^3	965	27/580/600	43.2 LHV 37 HHV	43.2 LHV (base load) 37 HHV (base load)	Lignite fuel, 50-60% moisture content High steam parameters Large cooling tower for low condenser pressure Innovative heat recovery systems Low auxiliary power
North America – Canada: Genesee 3	1100 (2005) Overnight cost	NOx 170 mg/m^3 SO_2 295 mg/m^3 Dust 19 mg/m^3	450	25/570/570	41.4 LHV 40 HHV	41 LHV (base load) 39.6 HHV (base load)	Moderately high steam parameters Low auxiliary power First N American sliding pressure supercrit. Sub-bituminous coal
Asia – Japan: Isogo New Unit 1	1800 (2006) Total project cost incl New Unit 2 under construction	NOx 20 mg/m^3 SO_2 6 mg/m^3 Dust 1 mg/m^3	568	25/600/610	42 LHV 40.6 HHV	42 LHV (base load) 40.6 HHV (base load)	High steam parameters Moderately warm sea water cooling Low auxiliary power Low power demand FGD Extremely low emissions No solid waste for disposal

Table S2 • Costs, emissions and efficiencies of the case study plants and comments (continued)

Plant	Capital cost, USD/kWso	Achieved emissions at 6% O_2, dry	MWe net	Steam conditions MPa/°C/°C (/°C)	Design efficiency, net %, LHV and HHV bases	Annual operating efficiency, net %, LHV and HHV bases	Factors affecting efficiency and other comments
Asia – Korea: Younghung	993 (2003) Basis uncertain	NOx 83 mg/m^3 SO_2 80 mg/m^3 Dust 10 mg/m^3	2x774	25/566/566	43.3 LHV 41.9 HHV	41 LHV (capacity factor not known) 39.7 HHV (capacity factor not known)	Moderately high steam parameters Very low emissions Low auxiliary power
Asia – China: Wangqu 1, 2	580 (2006) Overnight cost	NOx 650 mg/m^3 SO_2 70 mg/m^3(des) Dust 50 mg/m^3	2x600	24/566/566	41.4 LHV 40 HHV	New plant - no operating history	Moderately high steam parameters Low auxiliary power Advanced low-NOx lean coal combustion system
Asia – India: Suratgarh 1-5	822 (2002) Basis uncertain	SO_2 unabated Dust 50 mg/m^3 (unit 5)	5x227	15/540/540	37.1 LHV 35.1 HHV	33.9 LHV (base load) 32.1 HHV (base load)	Subcritical cycle High ash coal
Africa – South Africa: Majuba 1-6	410 (2001) Total project cost	SO_2 unabated Dust 50 mg/m^3	3x612 (dry); 3x669 (wet)	17/540/540	35-37 LHV 33.8-35.7 HHV	34 LHV (two-shifting) 32.8 HHV (two-shifting)	Subcritical cycle High ash coal Dry cooling from water supply constraints
Europe – United Kingdom: Natural gas plant: Enfield	950 (1999) Total project cost	NOx 128 mg/m^3 SO_2 negligible Dust zero	373	Advanced GTCC	58 LHV 52 HHV	52 LHV (40% capacity factor) 47 HHV (40% capacity factor)	Combined cycle with reheat gas turbine Low auxiliary power Zero solid waste
IGCC general review	PCC+20%	NOx 50-75 mg/m^3 SO_2 ~20 mg/m^3 Dust <1 mg/m^3	300/ module	IGCC	40-43 LHV 38-41 HHV		Combined cycle Syngas-fired gas turbine Inert solid waste

- The operating efficiencies of the base-loaded plants generally lay close to design values;
- Efficiency and economics are unavoidably impaired by the use of dry cooling;
- Efficiency bases vary and scrutiny is needed to avoid misleading comparisons – e.g. basis of LHV;
- Virtually zero conventional emissions are possible now from PCC as well as IGCC;
- Tailoring plant design to the requirements of the coal feed can result in high performance and low environmental impact while saving in cost – e.g. by omitting SCR;
- Environmental performance is often better than design;
- Higher efficiency plants have lower CO_2 emissions;
- Combined heat and power systems have highest overall efficiencies;
- PCC specific capital costs after bringing to a common basis correlate broadly with steam parameters and with efficiency;
- Capital costs are rising for new projects (not just PCC) because of increased energy and raw material costs;
- PCC unit construction times vary considerably depending on site constraints;
- Manning levels in non-OECD plants appear in some modern plants to have become more in line with OECD practice;
- Ash sales depend strongly on local circumstances;
- The costs of ash disposal are highly location-specific and uncertain as they may represent a marginal cost or creation of a new disposal site;
- Delivered coal prices in non-OECD countries appear now to be broadly in line with coal prices in other parts of the world, in the range of 1.5-2.5 USD/GJ;
- Future PCC efficiencies of above 50%, LHV basis (approaching 50%, HHV), are envisaged within 10 years;
- IGCC could play a major role if the recent commercial offerings succeed;
- IGCC could also reach 50% efficiency, LHV basis (approaching 50%, HHV), within similar timeframe to PCC;
- Natural gas-fired CCs are more efficient and less expensive and quicker to construct than systems based on coal;
- Intrinsically high efficiency is vital as basis of future plants using CO_2 capture and storage.

Annex 7.2

Expert opinion on Gas Combined Cycle (GCC) trends for electricity production - Jacques MAUNAND (EDF Chatou Research Center) - April 2008

Projected future development for Gas Combined Cycle (GCC) technologies

GCC technology combines gas turbines and steam cycles. Combustion turbines can burn gas or oil; they can also burn biomass gas without difficulty in a proportion of up to 10%.

Efficiency

At present the average efficiency of 400 MWe GCC plants is about 58%. In 2008, GCC units with an efficiency of 59.4% were commercially available. An efficiency of 60% could be reached before 2010 (possibly General Electric 9H in operation in TEPCO or perhaps Alstom from the end of 2008).

An efficiency rate of 62% may be commercially available in 2015.

By 2023 commercial GCC will reach an efficiency of 65% using technologies which currently exist and are being developed: sequential combustion, cooling in closed circuit, fogging, etc.

As of 2035 GCC should be able to reach commercial efficiency of 70% by improving component efficiencies and using new materials, if research and development work is financed in a timely fashion.

A technology becomes commercially viable when the technology used is a proven solution.

According to Jacques Maunand, GCC efficiencies are likely to reach a ceiling of about 72% in around 2050.

Unit capacities

Increasing efficiency will follow on greater unit capacity; at present, GCC units (F technology) have a capacity of 430 MWe (in GCC configuration). Technologies of the H generation have a capacity of 530 MWe.

It can be projected that the GCC units will reach capacities of 600 to 700 MWe in the future.

Gas combined cycle costs

Cost per kWh generated

For a GCC unit operated under baseload conditions with a lifetime of about 25 years, the costs are distributed as follows:

- investment: 12%
- operating costs (fuel excluded): 10%
- fuel costs: 78%

The cost of a kWh generated by GCC depends for 60-80% on the price of gas (under baseload conditions, for daytime operation with an interruption at night). This explains the need to increase efficiency, both at full and at intermediate capacity.

Investment

Investment currently stand at about 600 to 700 US dollars per kWe. Roughly, the investment is split 1/3 for the gas turbine and 2/3 for the steam cycle.

Operation costs

Roughly, 2/3 of operating costs come from the gas turbine and 1/3 from the steam cycle

Gas combined cycle operation mode

GCC units are operated under semi-baseload conditions: 5 000 hours per year. Expected lifetime is 25 years, or perhaps 20 years because given the possible high efficiency of new GCC turbines it will not be profitable to extend further the lifetimes of older GCC units.

GCC turbines are generally designed for 100 000 to 120 000 hours of operation.

Lowering NO_x emissions on GCC

It can be projected that by 2012 the four GCC manufacturers (General Electric, Siemens, Alstom, and Mitsubishi) will be able to lower NO_x emissions below 15 ppm (30 mg/Nm^3) without SCR selective catalytic reduction). Regulations will probably follow technical development.

NO_x emissions of 5 to 10 ppm will be reached by 2020, in parallel with the increase in efficiency.

It is technically possible to use SCR to reduce NO_x emissions but in Europe this solution is not considered realistic for GCC. The improvement of gas turbine performance both in terms of efficiency and of NO_x emissions renders SCR irrelevant. SCR technology has several disadvantages: efficiency reduced by a small percentage, excessive costs for only slightly lower NO_x emissions, NH_3 leakage to the atmosphere, lower $DeNO_x$ efficiency during daytime operations. In the USA, there is a tendency to use SCR technology. Some US states already require NO_x emissions below 5 ppm which makes SCR necessary.

Combustion turbine in simple cycle

Combustion turbines in simple cycle are used under peak conditions (fewer than 500 hours per year). These turbines can burn gas, as well as oil which can be stocked. The efficiency of these turbines is at present only 38 to 40%. In the United States a combustion turbine with an efficiency of 44% has been in operation for just two years. In the future efficiency should increase as for CCG turbines, but will remain 15 to 20% lower with a ceiling estimated at 50% by around 2050.

Technical trends for combustion turbines

Jacques Maunand thinks that lower NO_x emissions will be achieved by conventional technologies: Dry low NO_x, poor pre-mixing combustion or simply water injection.

Alstom is studying burnt gas recirculation: this interesting technology also enriches flue gas in CO_2 and thereby facilitates post-combustion capture of CO_2 for storage.

Jacques Maunand is sceptical about the development of catalytic combustion which theoretically should permit NO_x emissions of just a few ppm (5 mg/Nm^3 possible) but this solution will be very costly.

Regarding efficiency, Jacques Maunand considers that improvements will be obtained by improving component performance and by increasing temperatures with new materials. Jacques Maunand is not very confidant about using ceramics in the combustion chamber.

General comments

GCC technology is a mature technology which can be improved in the next 30 years; these improvements are expected to economise gas reserves (estimated at 60 years). The share of GCC in world power production should continue to rise slightly. The co-existence of GCC (for semi-baseload use) and coal-fired plants (for baseload use) will continue for the next 30 years.

Investment for various technologies

GCC: 600 to 700 dollars/kWe

Pulverised coal: 1 500 dollars/kWe (1 800 to 1 900 with CO_2 capture)

IGCC: 2 200 dollars/kWe

Jacques Maunand explains that GCC turbine prices have risen by 30% everywhere, and the industry is experiencing manufacturing delays. Manufacturers' resources are producing at their maximum capacity. GCC investment prices have been very stable over the past ten years. Jacques Maunand thinks that GCC prices will fall by 15% in the next 18 years because this is chiefly a temporary problem: some orders may be cancelled, lowering the pressure on prices.

IGCC

The IGCC technology consists in gasifying coal and using the gas produced ($CO+H_2$) in a Gas Combined Cycle unit. The gas mixture can also be reformed to extract CO_2 in order to use only hydrogen in combined cycle operation.

Prototype IGCC technologies exist and will be commercially available around 2020 (GE, Siemens).

In North America there is a push towards the development of IGCC technologies at present because it is the only technology available to exploit the enormous fields of bituminous oil sands in Canada.

Europe seems more interested in pulverised coal technology with high efficiency and CO_2 capture. Great Britain appears to be set to pursue this technology that Alstom is strongly developing. Alstom says it will be ready with a commercial offer for CO_2 capture in 2012. CO_2 capture will probably be commercially operational in 2020 if a regulatory framework can be implemented.

German electricity suppliers are hesitating between the two technologies: IGGC or pulverised coal+CO_2 capture.

Fuel cells

Jacques Maunand is not fully confidant as regards the commercial development of fuel cells for two reasons:

- the lifetime of fuel cells is limited to a few thousand hours;
- a technology which has not produced results after 30 or 40 years of work is a technology which seems have fundamentally insoluble problems

Annex 7.3

Report "Technical and economical data on depollution systems", Jean-Pierre RIVRON, *March 2008*

This report includes:

- interviews and data collected from EDF experts
- an analysis of VGB data given by Dr KRUEGER (VGB).

Summary

1) Rising plant costs
2) Abatement technique costs: FGD, SCR and precipitators
3) EDF experts' comments
4) Emerging technologies for fine particle collection: COHPAC and INDIGO systems
5) Estimation of DENOx and DESOx costs for a 300 MWe hard-coal unit according to VGB Powertech documents: size effect analysis
6) Reference plant RPP NRW (VGB) at a hard-coal-fired 600 MWe plant: increasing costs with net efficiency
7) Dust emission reduction by installation of SO_3 injection (Le Havre 4)
8) EDF comments on FLOWPAC desulphurisation
9) Cost comparisons between electrostatic precipitators and fabric filters

1) RISING PLANT COSTS

Precautions to take when talking about plant costs

It is always difficult to talk about and to compare costs, because a lot of parameters impact plant costs; following are some parameters which have to be taken into account:

-New plant or existing plant

Investments are not the same for a new plant and for an existing plant: for instance, a lack of space in an existing plant can completely change the investment for FGD or SCR.

Similar abatement techniques will not perform in the same way downstream of old and new boilers, because of flue gas imbalances, cold points etc.

-Different kinds of costs

It is necessary to distinguish between the various kinds of costs to be sure to compare them correctly: equipment costs, foundations and connection costs, engineering costs, capital costs etc.

Generally a manufacturer lists costs exclusive of site costs (foundations, connection, site engineering). Problems with ground work can increase the cost of an abatement technique by 30% (especially when retrofitting).

-Performance and costs

Costs are obviously dependant on the concentration of pollutants and the performance of the abatement technique: FGD costs are not the same with a coal sulphur content of 3% or 1.2%, and if the desulphurisation rate is 95% or 99%.

-Size effect

The specific cost of abatement technique is not the same for a unit of 1 000 MWe and a unit of 100 MWe.

-Series effect

Generally, if several abatement techniques systems are ordered at the same time, there is a reduction in price.

Cost trends

Between 2003 and 2007 boiler costs (and abatement technique system costs) were multiplied by a factor of 1.5 to 2. There are two main reasons for this increase.

-Increasing steel costs

For example, the cost of steel rose by 54% between 2000 and 2007 (+58% during year 2007). The price of steel is correlated with ferrous scrap prices and energy prices.

In recent years the lowest price was in January 2002 (price index 80). The price index in January 2008 was 160; steel price had doubled.

Considering that a large part of the cost of a plant is dependant on steel prices, this shows how difficult it is to compare abatement technique prices at different periods.

Another example of rising costs is the price of catalyst for SCR which has risen by at least 20% in the last two years.

-Market tension

The small number of abatement technique manufacturers and the approaching regulatory deadline for application of the LCP Directive (2015) contribute to increase market pressure on prices for abatement techniques and also for new plant prices.

This market tension, together with the rising cost of steel, explains the global increase in plant and abatement technique costs.

This market tension is felt in different ways. Classical pricing formulas are no longer in effect; there is no reduction in price for the purchase of several units in series. The market is saturated up to 2014 and even beyond because new countries in the European Union have been granted an extended timetable for application of EU regulations. The time required to build a plant is now very long. Manufacturers are at present free to choose the tenders for which they wish to compete.

Conclusion

Cost comparisons are only meaningful when set in actual contexts. The figures given in the following tables must be taken as estimated costs.

2) SOME ABATEMENT TECHNIQUE COSTS

FGD

Unit capacity MWe	Unit efficiency %	Unit capacity MWth	Fuel	Abatement technique	Investment M euro	Estimation year	Specific cost* euro/kWe	Specific cost* euro/kWth	Existing unit or new unit	Sources Comments
1000	41.3	2421	coal	FGD	66	2006	66	27	new	VGB
800		1937			57.2		72	30		
600		1453			47.3		79	33		
400		968.5			35.8		90	37		
300		726			30.3		101	42		
200		484			22		110	45		
100		242			13.8		130	57		
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		2007/ 2008	110			EDF

Est. = estimation
*engineering included

SCR

Unit capacity MWe	Unit efficiency %	Unit capacity MWth	Fuel	Abatement technique	Investment M euro	Estimation year	Specific cost euro/kWe	Specific cost euro/kWth	Existing unit or new unit	Sources Comments
1000	41.3	2421	coal	SCR	58.5	2006		24	new	VGB
800		1937			47			24		
600		1453			35.5			24		
400		968.5			24.1			25		
300		726			18.3			25		
200		484			12.6			26		
100		242			6.8			28		
600	36	1667	oil	SCR	44	2007	73	26	existing	EDF Porcheville

DUST CAPTURE

Unit capacity MWe	Unit efficiency %	Unit capacity MWth	Fuel	Abatement technique	Investment M euro	Estimation year	Specific cost euro/kWe	Specific cost euro/kWth	Existing unit or new unit	Sources Comments
600	36	1667	oil	ESP	16	2007	27	10	existing	EDF Porcheville
600	42	1429	coal	ESP	28	2004	47	20	new	EDF Est.

3) EDF EXPERTS' COMMENTS

EDF comments (Christine Lecuyer, EDF engineering Paris La Défense, meeting on 26 February 2008)

-Oil-fired units

For an existing 600 MWe oil-fired unit (Porcheville for instance), the costs of abatement techniques were estimated in 2007 as follows:

SCR: 40 M euros (44 with engineering costs)

ESP: 15 M euros (16 with engineering)

Units 2, 3, 4 at the Porcheville oil plant are already equipped with cyclones which limit dust emissions to below 50 mg/Nm^3

These oil units used in peak conditions are operated 400 or 500 hours per year. It means that the abatement technique costs are often excessively high for a small gain in pollution emissions.

Generally bag filters are not used on oil units because of clogging problems.

ESPs are generally used on oil units, even if clogging may occur sometimes.

The BOOS technique has been used with success at Porcheville to lower NO_x emissions. This technique consists of no longer using the higher burners of the boiler.

On this kind of oil unit, the SO_2 emissions are lowered by lowering sulphur content in the oil (0.5 or 0.3%). FGD, even Flowpac, is not economically acceptable.

-Coal-fired units

All the French coal-fired units which will be operated after 2015 are completely equipped with abatement techniques (FGD, SCR, and ESP).

All FGD manufacturers are improving their FGD technology.

For some EDF experts, the best performing wet FGD technology in the future could be the Double-Contact-Flow Scrubber (DCFS) developed by Mitsubishi, with a double-contact fountain which achieves a desulphurisation rate above 99%. With this FGD, SO_2 emissions can be below 30 mg/Nm^3.

EDF comments on dust capture (Veronique Arrondel, Michel Hamlil, EDF Research Centre Chatou, meeting on 22 February 2008)

The experts recommend a book entitled *"Les polluants et les techniques d'épuration des fumées"* published in 1998 by the RECORD Association (including the French Environment Ministry, ADEME, EDF, GDF, Solvay, French cement manufacturers, French car manufacturers and others). This book explains the different abatement techniques used for waste incineration, but the content is also applicable to large combustion plants.

At the same time, in 1998, the RECORD association also created a cost database, but this proprietary database has not been published. It would be interesting to obtain this cost data as a 1998 baseline reference, by writing to Nicolas Caraman (EDF Chatou) who is the RECORD correspondent for EDF.

All precipitator manufacturers are striving to improve the two main systems used for large combustion plants: electrostatic precipitators and filter bag precipitators. For instance, Alstom has developed a High Frequency Transformer Rectifier which consumes less electrical energy and has lower counter-emissions. There are no revolutionary new techniques for capturing dust.

EDF recommends the following two innovative dust-capture systems for fine particles but these techniques are not really suitable when wet FGDs are used because wet FGD also captures fine particles. These advanced technologies appear to be used in USA and Australia to capture fines particles when there is no wet FGD:

-COHPAC process,

-INDIGO process.

4) EMERGING TECHNOLOGIES FOR FINE PARTICLE COLLECTION

COHPAC fine particle collector technology

-Description

COHPAC is an EPRI-licensed technology which is centred around combination of an existing or new electrostatic precipitator with a baghouse precipitator.

The baghouse precipitator is placed in a separate casing downstream of the ESP (known as COHPAC I) or within the existing ESP casing by replacing one or more fields of collecting plates with baghouse modules (COHPAC II).

The technology is based on the fact that a baghouse collects higher levels of particulates and finer particulates than an ESP of equivalent size; the baghouse acts as a "polishing device". By using dry additives, COHPAC in combination with TOXECON offers the ability to significantly reduce mercury, sulphur dioxide and others toxic emissions (dioxins) that an ESP alone could not economically collect.

TOXECON is an EPRI-licensed technology involving the introduction of a sorbent between a primary particulate collector such as either an ESP or a mechanical collector. The dry sorbent additives can be activated carbon, sodium or calcium compounds.

-References

Hamon Research-Cottrell (HRC) website:

"Effective use of both COHPAC and TOXECON technologies as the technologies of the future for particulate and mercury control on coal-fired boilers" (by Richard Miller...).

HRC has installed over 1 700 MW of COHPAC technology on both coal-fired and waste–to-energy combustors.

Full scale demonstration of TOXECON is currently underway at Alabama Power, E.C. Gaston Steam Plant (USA). This long-term demonstration project funded by DOE is the second phase in a programme begun in 2001. HRC is a co-contributor in this program designed to demonstrate the ability to control mercury emissions utilising both COHPAC and TOXECON technologies. Testing began in 2004.

-Performance

-High collection efficiencies (>99, 9%)

-Low capital cost (much lower than competing systems to achieve comparable particulate control levels)

-Manufacturer

Hamon Research-Cottrell (HRC) is the only experienced licensed supplier of EPRI's COHPAC and TOXECON particulate and mercury reduction technologies on both coal-fired and waste-to-energy fired boilers.
Hamon Research-Cottrell - Robert A. Mastropietro
Hamon Corporate Plaza - 58 East Main Street - P.O. Box 1500 - Somerville, NJ 08876 USA
Tel: 908 333 2077 - Fax: 908 333 2154 - robert.mastropietro@hamonusa.com

-Comments (Veronique Arrondel , Michel Hamlil EDF)
These technologies have been developed in the United States to capture toxic emissions (mercury and dioxins).
These technologies are perhaps less relevant to Europe.
Nonetheless, the combination of ESP and baghouse is interesting because this combination appears to perform better for extracting fine particles at a lower investment cost. The advantages of this technology in conjunction with FGD remain to be demonstrated.

INDIGO fine particles agglomerator

-Description of the Indigo technology
The Indigo Agglomerator utilises a combination of two patented processes that cause fines particles to attach to large particles which are easily captured by an electrostatic precipitator.

- Fluidic Agglomeration Process (FAP), a physical process that occurs without the need for electrical energisation.
- Bipolar Electrostatic Agglomeration Process (BEAP) which uses two key processes to reduce fine particle emissions: a bi-polar charger used to charge in an alternating way half of the dust with a positive charge and half negatively, and an especially designed size selective mixing system.

The agglomerator is located in front of an electrostatic precipitator (up-stream ESP).

-Indigo technology references
Tests at full load were carried out at Mississippi Power's Watson Plant starting in January 2004 with an Indigo agglomerator trial installation on unit 4 (a 250 MW wall-fired pulverised coal boiler with two air-heaters connected to two separate electrostatic precipitators).Tests have been also implemented at the Tarong Power Station (4x350 MWe coal units; Babcock Hitachi boilers), 180 km west of Brisbane, Australia.

-Fine particles health context
Fine particles, in particular PM2.5, are a recognised heath hazard. Electrostatic precipitators are poor collectors of fine particles, particularly between 0.5 and 2 micrometers. Electrostatic precipitator collection efficiency, normally around 99.9% for larger particles, is generally less than 90% in this particle size range and can fall below 50% under worst case conditions.

-Indigo Agglomerator performance
The Indigo Agglomerator provides a significant reduction in fine particle emissions by attaching fine particles to large particles which are easily collected in the electrostatic precipitator.

Particle size	10 micrometers	0.1 micrometer	$PM_{2.5}$
Agglomerator reduction	60% about a factor 2	90% about a factor 10	80%

Tests at the Tarong power station show that the capture of arsenic in ash is significantly increased. Tests at the Watson power station show that mercury emissions are divided by a factor of 4.
Recent regulations in the US require mercury emission controls on coal-fired power stations. Mercury is considered a major health hazard because it concentrates in the food chain. The Indigo Agglomerator enhances mercury collection by increasing the interaction between mercury and the adsorbent, either injected activated carbon or using LOI from the combustion process.

-Manufacturer
Indigo Technologies LLC - Robert (Bob) Crynack, Ph.D. - President
8980 Perry Highway, Suite 205 - Pittsburgh, PA 15237 USA - Tel. +1 412 358 0171 - bob@indigotechnologies-us.com

-Comments (Veronique Arrondel, Michel Hamlil EDF)
It seems that the agglomerator is only used in plants not equipped with wet FGD. In Europe, this kind of technology might be less useful than in the US or Australia for two reasons:
-generally the types of coal burnt in Europe do not contain mercury (except perhaps for some local coal types, especially in Central Europe),
-at the end of 2015, almost all the LCPs in the European Union will be equipped with wet FGD which efficiently captures fine particles.

-Reference
ICESP X – Australia 2006 Paper 6A2

5) ESTIMATION OF DENO$_x$ AND DESO$_x$ COSTS FOR A 300 MWe HARD COAL UNIT ACCORDING TO VGB POWERTECH DOCUMENTS

Date of the estimation: 2006

-Power unit characteristics
LCP capacity: 300 MWe / 726.4 MWth
Efficiency (net caloric value): 41.3%
Net caloric value of coal: 25000 kJ/kg
Effective full load operation hours per year: 6000 h
Electrical production per year: 1.8 TWh
Coal consumption: 104.6 t/h
Primary energy input per year: 15690 TJ
Flue gas emission per coal Kg: 10 m^3/kg
Flue gas flow: 1 046 005 m^3/h
Specific energy consumption: 0.9%
Internal costs of electricity: 0.03 euro/kWh
NO_2 concentration at DENOx inlet: 700 mg/m^3
NO_2 concentration at DENOx outlet: 200 mg/m^3
S content of coal: 1%

-**Comparison of data for the emerging technologies sub-group**

	DENO$_x$ (SCR)	DESO$_x$ (wet FGD)
Abatement efficiency (%)	71.5	88
Abated emission factor (g/GJ fuel input)	185	641
Electrical consumption (kWh/GJ)	0.19	1
CO_2 impact (from energy consumption) (t CO_2/GJ fuel input)	0.00016	0.0009
Equipment lifetime (years)	30	30
Specific abatement technique invest (euro/kWth)	25.2	41
Fixed operating costs (M euro/y/MWth)	0.0014	0.0023
Variable operating costs (M euro/y/MWth)	NH_3 0.0011 NH_4OH 0.0022	0.0014

-Relationship between FGD costs and unit capacity
Efficiency 41.3%

Electrical capacity of the unit MWe	Thermal capacity of the unit MWth	Investment M euro	Investment +10% for additional investor costs: engineering, foundation, connections… M euro	FGD specific cost M euro/MWe	FGD specific cost M euro/MWth
1 000	2 421	60	66	0.066	0.027
800	1 937	52	57.2	0.072	0.030
600	1 453	43	47.3	0.079	0.033
400	9 68.5	32.5	35.8	0.090	0.037
300	726	27.5	30.3	0.101	0.042
200	484	20	22	0.110	0.045
100	242	12.5	13.8	0.138	0.057

-Relationship between SCR costs and unit capacity
Efficiency 41.3%

Electrical capacity of the unit MWe	Thermal capacity of the unit MWth	Investment M euro	SCR specific cost M euro/MWe	SCR specific cost M euro/MWth
1 000	2 421	58.5	0.059	0.024
800	1 937	47	0.059	0.024
600	1 453	35.5	0.059	0.024
400	968.5	24.1	0.060	0.025
300	726	18.3	0.061	0.025
200	484	12.6	0.063	0.026
100	242	6.8	0.068	0.028

-Size effect

Electrical capacity MWe	Thermal capacity MWth	SCR investment M euro	FGD investment M euro	SCR specific cost M euro/MWth	FGD specific cost M euro/MWth	SCR size effect	FGD size effect
1 000	2 421	58.5	66	0.024	0.027	0.86	0.47
800	1 937	47	57.2	0.024	0.030	0.86	0.53
600	1 453	35.5	47.3	0.024	0.033	0.86	0.58
400	968.5	24.1	35.8	0.025	0.037	0.89	0.65
300	726	18.3	30.3	0.025	0.042	0.89	0.74
200	484	12.6	22	0.026	0.045	0.93	0.79
100	242	6.8	13.8	0.028	0.057	1	1

6) REFERENCE POWER PLANT RPP NRW

This document is composed using cost figures drawn from the VGB document "Concept study Reference Power Plant North Rhine-Westphalia (RPP NRW)" (February 2004).

-Brief overview

The concept of the "Reference Power Plant North Rhine-Westphalia" (RPP NRW) is based on a hard-coal-fired 600MW plant with optimised plant technology and efficiency of 45.9%. Efficiency of over 48% could be achieved with certain technical measures, but that would require site and economic boundary conditions different from what can currently be assumed. With efficiency of 45.9%, the NRW reference power plant is clearly above the average for hard coal power plants currently in operation in Germany (average efficiency is around 38%). Thus this concept can make a considerable contribution to attaining targets for the reduction of CO_2.

This NRW Reference Power Plant study was produced with the aim of developing a concept for a sustainable hard-coal-fired power plant that takes these challenges into account.

A number of innovative proposals have been included in the plant design.

The building of the RPP NRW will involve a total order volume of around 480 million euros.

- Results for the reference case

The RPP NRW in the reference case is clearly superior economically to the other hard coal technologies, the 700°C plant and the IGGC plant. The RPP NRW also proved to have the advantage over a combined cycle plant operating on natural gas. Only modern lignite power plant proved to be more cost-effective.

Price basis 2003	Fixed cost ct/kWh	Variable cost ct/kWh	Cost of electricity ct/kWh
RPP NRW Reference case	1.9	1.45	3.35
CCPP gas Combined cycle	1	2.5	3.5
MLP Modern Lignite Plant	2.3	1	3.3
700°C Plant	2.5	1.3	3.8
IGCC	2.8	1.3	4.1

Cost of generating power
No CO_2 cost impact
Gas price: 122 ct/kWh
Price of hard coal: 48 euros/t
Lignite price: 31 euros/t

-The volume of investments in the reference power plant

Aspect	Unit	Amount
Price of the plant	Euro/kW (gross)	798
Installed gross capacity	MW	600
Order volume	Million euros	478.8
Period of use	Years	35
Owner's own contribution (5% of the order volume)	Million euros	23.9
Flat rate for imponderables (3% of the order volume)	Million euros	14.4
Total sum of investment	Million euros	517.1
Specific sum of investment	Euros/kW	798x1.08=861.8

-Basic data for determining operating costs of the reference power plant

Cost category	Unit	Amount
Installed gross power	MW	600
Specific plant price	Euros/kW (gross)	798
Absolute plant price	Million euros	478.8
Aux. station power requirement	% of gross installed power	7.4
Aux. station power requirement	MW	44.4
Maintenance	%/y	1.5
Operating personnel	Persons	70
Payroll costs for each employee	Euros/y	70000
Fuel price	Euros/t	41
Fuel price	Euros/t hard coal units (tce)	48
Consumables and operating supplies	Euros/MWh	1

-Quality of coal

		Guarantee design coal	Fuel band
Lower heating value	MJ/Kg	25	21 to 29
Water	%	7.5	7 to 18
Ash	%	14	5 to 22
Volatile matter (daf)	%	30	23 to 47
Nitrogen	%	1.5	<2
Sulphur	%	0.6	<1.5
Chlorine	%	<0.01	<0.3

- Project duration: 36 months + two months trial operation

-Thermodynamic design: overview summarising the findings

1 - Utilisation of hot mill air or flue gas waste heat by transferring the heat to the HP feed water heating line
2 - Use of an external desuperheater to increase final feed water temperature up to 320°C
3 - Reduction of pressure drop in the extraction lines for HP feed water heaters
4 - Reduction in terminal temperature differences for HP feed water heaters
5 - Consideration of use of an additional LP feed water heater (9th feed water heater)
6 - Thermo compression in the area of the area of the LP feed water heaters
7 - Concepts for reheat temperature control (control within boiler or spray or by allowing reheat temperature to slide)
8 - Consideration of use of an HP feed water heater bypass for mobilisation of short-term peak output
9 - Study of a feed water pump drive concept (turbine drive vs. electric drives with various designs)
10 - Optimisation of the cold end (LP turbine exhaust cross-section and size of cooling tower)

-Power plant concept

Gross capacity	600 MW
Type of boiler	Tower-type boiler with vertical tubes and steam coil air heater
Heat recovery	Utilisation of mill air heat recuperation
Flue gas discharge	Discharge via cooling tower
Turbine model	H30-40/M30-63/N30-2x16m^2
Main steam parameters	285 bar/600°C/620°C
Condenser pressure	45 mbar
Generator	Water/hydrogen cooling
Feed water heating stages	8 feed water heaters + external desuperheater
Feed water final temperature	303.4°C
Feed water pump concept	3x50% electric motor-driven feed water pumps, variable-speed drive with planetary gearing

-Operating concept

The following major boundary conditions have been specified for the operating concept:
-Service life: 200 000 operating hours
-Baseload for the first 15 years at 7 500 h/year, then intermediate load at 5 500 full load operating hours per year
-2 860 starts over the entire period of usage.

-Preferred variant

A total power plant price of 798 euros/kW (gross) was offered for the preferred variant (45.9% of net efficiency) (861.8 euros/kW taking into account +8% for owner contribution and imponderables).

	Preferred variant
Gross installed capacity	600 MW
Net installed capacity	555.5 MW
Net efficiency	45.9%
Main steam parameters	285bar/600°C/620°C
Feed water end temperature	303.4°C
Price of the plant	478.5 M euros
Boiler type	Benson tower boiler with vertical tubes
Utilisation of waste heat	Use of mill air heat
Flue gas cleaning	SCR-$DENO_X$. Electrostatic precipitator. Flue gas desulphurisation using limestone
Flue gas discharge	Discharge via cooling tower
Steam turbine	Three-casing steam turbine with simple intermediate heating and low-pressure stages made of titanium alloy
Generator stages	Cooled by water/hydrogen
Economiser stages	Eight economisers+external desuperheater
Feed water pump concept	3x50% electric motor-driven feed water pumps . variable-speed drive with planetary gearing
Condenser pressure	45 mbar. wet closed-circuit coming via natural-draft cooling tower
Price of the plant	478.5 M euros
Specific plant price	798 euros/kWgross

-Increasing cost in relation to net efficiency.

Net efficiency	Total power plant price
Preferred Variant 45.9%	798 euro/kW
45.9 to 46.1%	798 euro/kW + Appr. 20 euro/kW per % pt
46.1 to 46.2%	798 euro/kW + Appr. 25 euro/kW per % pt
46.2 to 46.5%	798 euro/kW + Appr. 30 euro/kW per % pt
46.5 to 47.3%	798 euro/kW + Appr. 35 euro/kW per % pt

Efficiency	Calculation	Specific power price	Total specific power price x1.08	600 MWe plant total price
45.9%		798 euro/kW	861.8 euro/kW	517 M euros
46.1%	+20 euro/kWx0.2%= +4 euro/kW	802 euro/kW	866.2 euro/kW	520 M euros
46.2%	+25 euro/kWx0.1%= +2.5 euro/kW	804.7 euro/kW	868.9 euro/kW	521 M euros
46.5%	+30 euro/kWx0.3%= + 9 euro/kW	903.7 euro/kW	878.6 euro/kW	527 M euros
47.3%	+ 35 euro/kWx0.8%= + 28 euro/kW	931.7 euro/ kW	908.8 euro/kW	545.3 M euros

-Innovations

The greatest improvement in efficiency is achieved by raising the steam parameters to the high steam conditions at boiler outlet (292.5bar/600°C/620°C). A further improvement in plant efficiency has been achieved by optimising the economiser section and raising the feed water temperature. These temperature and pressure increases make it necessary to use new materials for the walls and new super heater materials.

The efficiency of the boiler is improved to 95% by keeping to the very low excess air coefficients of 1.15 and exhaust gas temperatures of 115°C. The distance to the dew point temperature for flue gas ducts and the electrostatic precipitator is achieved by specified coal with a guaranteed sulphur content of only 0.6%.

-Flue gas cleaning

Flue gas cleaning consists of plant components for denitrification, dust collection and desulphurisation.

Emission limits: SO_x and NO_x < 200 mg/Nm^3

Dust<30 mg/Nm^3 (<20 mg/Nm^3 with German requirements)

SCR

Ammonia (NH_3) liquefied under pressure is used as the reducing agent. It is taken from the liquid ammonia tank, dry, at 6% by volume O_2.

The maximum NH_3 slip at the end of the life of the catalyst (24 000 hours of operation) is 2 vpm. The design of the reactor for an NH_3 slip of only 2 ppm is required in order to limit the ammonia content of the fly ash to a maximum of 100 mg/kg, even if the ash content of the coal is very low.

The reactor is not fitted with a bypass.

So-called "acoustic horns" are used in addition to the steam operated soot-blowers for cleaning the catalysts.

Dedusting: Electrostatic precipitator

The use of a fabric filter has been ruled out because of higher pressure losses and higher maintenance costs.

FGD

The absorber is optimised in 3 areas:

-The absorber diameter was selected so that the maximum velocity of the flue gas is around 4 m/s.

-Nozzle levels were optimised with the help of a numerical simulation program.

-A frequency controlled drive is used for one recirculating pump.

The required availability for FGD is >98%.

-Cooling water systems

The cooling water systems essentially consist of the natural-draft cooling tower.

7) DUST EMISSION REDUCTION BY INSTALLATION OF SO_3 INJECTION UPSTREAM OF PRECIPITATOR EDF Le Havre 4 coal power station (600 MWe)

-Reference document
EDF document "Installation de conditionnement des fumées par injection de SO_3 en amont du dépoussiéreur de la tranche 4 du Havre" (Mathieu, INSA)

-Dust problem characteristics at Le Havre 4
Le Havre 4 is a coal-fired power unit commissioned in 1983. Generally dust emission was 30 or 40 mg/m^3, always below the regulatory limit of 50 mg/m^3. From 2000 onwards combustion of imported coal has produced ashes with high resistivity (>10^{11} ohm.cm, 2x10^{11} with some low sulphur content coals from South Africa) which prevents good dust capture in the electrostatic precipitator. With this kind of coal dust emissions could reach 110 mg/m^3 or even theoretically 200 mg/m^3, forcing a halt due to the flue gas desulphurisation operational limit.

-SO_3 injection upstream of precipitator
The SO_3 injection system includes:
-liquid sulphur storage and pumping
-a combustion chamber to oxidise sulphur to SO_2
-a catalytic converter to transform SO_2 to SO_3
-injection nozzles to inject SO_3 in the flue gas upstream of the precipitator.
The SO_3 system was implemented at the Le Havre 4 unit in 2005. With this system, dust emissions are below the required limit of 50 mg/m^3 whatever the kind of coal used.

-Data contribution for the emerging technologies Sub-Group

Short description: SO_3 injection to lower particle emissions in case of combustion of high resistivity coal ashes (Le Havre 4 600MWe/1580 MWth coal-fired unit in 2006)

Dust abatement efficiency: average 50% 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): 0.0007 M euro/MWth (1.1 M euro)
Fixed operating costs: not significant: 0.0012 euro/GJ
Variable operating cost: not really significant; 0.001 euro/GJ

-Some figures

References:
Le Havre 4 in 2004
2 563 GWh (gross)
5 737 operation hours
4 202 full capacity equivalent operational hours
279 tonnes dust emissions
68 mg/m^3 yearly average dust emission
918 899 tonnes of coal
24 405 kJ/kg heating value
22 426 TJ primary fuel input/ year 2004

Dust abated emission factor
50% average abatement due to SO_3 injection
139 500 kg/year
139 500 000/22 426 000 = 6.2 g/GJ fuel input

SO_3 system electrical consumption: 50 kW
50kW x 5 737 hours = 286 850 kWh
286 850/22 426 000 = 0.013 kWh/GJ

Fixed costs
Maintenance: 2.5% investment (estimation)
1.1M euro x 0.025 = 27 500 euros/year
27 500/22 426 000GJ = 0. 0012 euro/GJ

Variable costs (sulphur cost)
5 100 euros/1 000 full equivalent capacity operational hours
21 400 euros for 4 202 full capacity equivalent hours (2004)
21 400/22 426 000GJ = 0.001 euro/GJ

8) ALSTOM'S TURBULENT BED DESULPHURISATION SCRUBBER FLOWPAC

- Description

The Flowpac process is a wet desulphurisation process developed by ALSTOM. It is a turbulent bubble bed reactor. The flue gas is injected into a slurry through numerous submerged pipes while limestone slurry is fed into the turbulent bubbled bed reactor and air for oxidation is blown into the slurry. The absorber type is a good example of a simplified FGD process. It eliminates the need for recycle pumps, spray nozzles and headers, separate oxidation tanks and thickeners, thereby minimising difficulties as well as power consumption.

- Performance

The process has a compact design and attains high desulphurisation rates (>99%) with high sulphur content fuels (>1.5%).
Power consumption is lower using Flowpac (1.3% of the power capacity in Karlshamm) than with the classical wet FGD (1.7/1.75%).
According to Alstom, yearly maintenance costs are lower for Flowpac (1.2% of investment costs) than for the classical wet FGD (1.5%) due to a better accessibility.

- **References**

Few Flowpac absorbers have been built in the world. The prototype was built in 1996 on unit 3 of the Karlshamm power station in Sweden (3x340 MWe oil plant). The gas flow is 1 080 000 Nm^3/h, and the design oil sulphur content is 3.5%.
Three other Flowpac units (3x150 MWe) were built recently at Lietuvos Elektrine Power Plant (Lithuania) for start-up in 2008 (according to Alstom references). The gas flow is 1 800 000 Nm^3/h and the design sulphur content is 3.5%.
Lietuvos plant: 4x150MWe+4x300MWe=1800MWe: 5 FGD units have been implemented in Lietuvos: boilers 1+2 (2x150 MWe); boilers 5A+5B (300 MWe); boilers 6A+6B (300 MWe); boilers 7A+7B (300 MWe); boiler 8A (300 MWe); fuel: natural gas, heavy oil (sulphur content up to 3.5%),Orimulsion (sulphur content up to 3%).
Another Flowpac unit will be started in 2009 at the Amagervaerket plant in Copenhagen (owner/operator Energi E2) (150 MW; 540 000 Nm^3/h; 1.3% sulphur content).
There is no reference for capacity >340 MWe and no operational reference for coal units. A prototype of 15MW is being tested in Sweden. For a unit of 600 MWe, Alstom proposes 2x300 Flowpac in parallel, without references.
From the expert point of view, this kind of process is advisable for oil units <340 MWe until more experience has been acquired.

- Costs

The investment for desulphurisation of two coal units of 600 MWe were estimated in 2003:
Flowpac: 58 euros/kWe (70 M euros for 2x600 MWe coal units), 6% lower than the classical wet desulphurisation: 61 euros/kWe (74 M euros for 2x600 MWe coal units).

- Sources:

EDF: "Procédé de désulfuration humide innovant Flowpac: état des connaissances" (C. Derousseau, I. Gasquet)
Alstom website documentation
IPPC draft reference document on Best Available Techniques for LCP

9) COST COMPARISONS BETWEEN ELECTROSTATIC PRECIPITATORS AND FABRIC FILTERS (2006 prices)

At the Duvha power station, ESKOM operates 6 x 600 MWe coal units. The first 600 MWe unit went on-line in 1980. Units 1 to 3 were initially fitted with American Air Filter (AAF) ESPs. AAF ESP's were problematic mainly due to poor collector plate and discharge wire rapper design, which resulted in stack emissions <800 mg/m^3. In 1993, the ESPs were upgraded and pulse jet fabric filters (PJFFP) retrofitted into the existing casing. Since the installation of the PJFFP particulate emissions have fallen from >800mg/m^3 to below 30 mg/m^3.
The PJFFP was installed with polyacrylonitrile (PAN) bags and early bag failures occurred after 3 000 operating hours. Initial bag tests showed severe chemical degradation and distorted flow distribution which resulted in disintegration of the fibre. Total failure of the plant resulted in full rebagging which had to be done between 12 500 and 15 000 operating hours.
It was decided to change from polyacrylonitrile low temperature bags to polyphenylene sulphide polyamide (PPSPI) high temperature bags. This has resulted in an increased bag life of 32 000 hours.

	Number of Bag failures (for 3x600 MW)
PAN bags	1 500 per year (average)
PPSPI bags	300 per year (average)

-Operating costs per unit per annum

	PPSPI Bags	PAN Bags
Total re-bag cost	3 158 729 Rands 309 376 Euros	5 217 211 Rands 510 990 Euros
Total Maintenance cost	415 454 Rands 40 691 Euros	1 228 854 Rands 120 358 Euros
Total power consumption	3 019 887 Rands 295 777 Euros	3 351 015 Rands 328 209 Euros
Total cost	6 594 071 Rands 645 844 Euros	9 797 081 Rands 959 557 Euros

1 Euro =10.21 Rands (March 2008)

-Operating costs for ESPs with SO_3 flue gas conditioning per unit per annum

Units 4 to 6 have originally installed Lurgui design ESPs. These ESPs have subsequently been retrofitted with sulphur trioxide flue gas conditioning. The following comparison can be made:

	Maintenance cost	Power consumption cost	Total
PPSPI bags	415 454 Rands	3 019 887 Rands	3 435 341 Rands 336 468 Euros
PAN bags	1 228 854 Rands	3 351 015 Rands	4 579 869 Rands 448 567 Euros
ESP's with SO_3 conditioning	476 200 Rands	2 550 960 Rands	3 027 160 Rands 296 490 Euros

Marginal cost of production at Duvha: 42 rands / MWh (4.1 euros/MWh)

-Reference

ICESP X –Australia 2006

Rod Hansen and Robbie Van Rensburg, communication "Cost comparisons between electrostatic precipitators and pulse jet fabric filters and inherent challenges of both technologies at Eskom's 6x600 MW units at DUVHA power station (South Africa)".

-Theory of SO_3 flue gas conditioning

The concept of artificially modifying fly ash resistivity is not new. For almost eighty years it has been recognized that by varying the quantity of SO_3 in the flue gas, the performance of an electrostatic precipitator can, in many instances, be improved.

Precipitator performance depends upon the physical and chemical properties of the flue gas and particulate treated. In a power plant, the type of coal burned, the furnace design, and the overall operation of the boiler govern these properties. The composition, temperature and pressure of the gas govern the basic particle charging capability of the precipitator while particle size, particle concentration, and electrical resistivity of the ash affect both the charging and collecting capability of the precipitator.

The chemical composition of the fly ash varies widely. Major constituents of most fly ashes are silica, alumina and iron oxides, and, to a lesser extent sodium and calcium. Silica and alumina are present in the ash primarily in the form of silicates, which contribute to the typical glassy appearance of the particles. The specific quantities of these constituents are also major contributors to fly ash resistivity.

Fly ash resistivity depends upon a number of factors, including not only the chemical composition, but the flue gas temperature, the moisture content, and the SO_3 content in the flue gas. At typical air heater gas outlet temperatures, (250° - 350°F), surface conduction over the fly ash particles predominates and is heavily dependent on the moisture and SO_3 levels. At higher temperatures, volume conduction through the particles predominates.

Sulphur occurs in coal as organic and inorganic compounds. When coal is burned, more than 95% of the sulphur becomes SO_2. A small fraction is converted to gaseous SO_3. When the flue gas temperature drops below approximately 600°F, SO_3 begins to react with water vapor to produce sulphuric acid vapor. The reaction is essentially complete when the temperature drops to about 300° - 350°F, where precipitators normally operate. Thus, in a strict sense conditioning results from sulphuric acid vapor, rather than SO_3, being absorbed onto the surface of the fly ash particles.

Some fly ashes do not readily absorb the sulphuric acid vapor, generated naturally from sulphur in coal or from SO_3 Flue Gas Conditioning, which would be expected to be of sufficient quantity for fly ash resistivity modification. The primary reason for this occurrence is the silica, alumina and iron.

When the sum of these three constituents is high, the surface characteristics of the ash become more glass-like and less absorbent. This is analogous to trying to moisten glass or Teflon - it does not occur to an appreciable extent. In these instances, the addition of ammonia (NH_3) has proven to be beneficial.

-Sulphur Trioxide as a Conditioning Agent

When coals with high sulphur contents are burned, there is generally enough SO_3 formed to bring the fly ash resistivity into a range that results in good precipitator operation. However, when switching to a coal with low sulphur content an insufficient amount of naturally occurring SO_3 is present for resistivity modification, and precipitator performance deteriorates. Thus, the purpose of the SO_3 injection is to simply supplement the SO_3 which is formed naturally to modify the resistivity to that which produces optimum precipitator performance.

Over the years, many SO_3 containing chemicals and processes-including sulphuric acid, oleum, liquid SO_3 and catalytic conversion from SO_2 have been tried. However, the sulphur-based, catalytic conversion process, due to safety, simplicity and cost considerations, is the predominant system in use today."

Annex 7.4

Documents from the kick-off meeting – 7 June 2007

7.4.1 Meeting report

Participation

15 people participated in the kick-off meeting of the EGTEI sub-groups on emerging technologies in large combustion plants and power generation. The following persons were present: Mr Gwénaël GUYONVARCH (ADEME), Mrs Nathalie THYBAUD (ADEME), Mr Eric VESINE (ADEME), Mr Jean-Guy BARTAIRE (Co-chairman of EGTEI, EDF), Mrs Carole ORY (EDF), Mr Jean-Pierre RIVRON (expert in LCP), Mrs Nadine ALLEMAND (CITEPA), Mr Dave HARRIDGE (ENTEC, representative of DEFRA), Mr Mats LINDGREN (Swedish EPA), Mr Peter MEULEPAS (Ministry of the Flemish Region, Environmental Administration), Mr Michael HIETE (IFARE), Mr Pierre KERDONCUFF (IFARE), Mr Jacek GADOWSKI (BOT Gornictwo i Energetyka SA), Mr Andrzej JAGUSIEWICZ (Clean Air for Europe - KlinEr), Mr Pier Lorenzo Dell'Orco (EDIPOWER s.p.a.).

Ms Katja KRAUS (German Federal Environmental Agency), Ms Andrea KRIZOVA (Czech Hydrometeorological Institute), Ms Kristina SAARINEN (Finnish Environment Institute), Mr Hartmut KRUGER (VGB PowerTech e.V.) and Mr Richard HOTCHKISS (RWE nPower) were excused.

Context

The kick-off meeting was hosted by ADEME and chaired by G. GUYONVARCH. After a brief presentation of ADEME, G. GUYONVARCH presented the aim of the meeting. Taking a proposal prepared by N. THYBAUD as a starting point, the objective was to structure the work to be carried out and to identify the main contributions that the experts could make in both sub-groups (up to 2020 and 2020 to 2050).

N. ALLEMAND reminded that taking emerging technologies into account will lower the emissions of the MTFR scenario and hence will reduce the gap still present between the effect level obtained with the MTFR scenario and the no emissions effect level. JG BARTAIRE reminded that IIASA expects both information on the evolution of existing technique performance and information on new technologies. JG Bartaire stated that the work is also useful for the future revision of the LCP BREF.

N. THYBAUD proposed a structure for the work plan and the types of data to be collected. She proposed to distinguish between two groups: i) emerging techniques and technologies, and improvement of existing abatement techniques up to 2020, which is the time horizon considered by the Thematic Strategy for the new NEC and by a potential revision of the Gothenburg Protocol and ii) emerging techniques and technologies with a longer term perspective (2020 to 2050).

Experience from experts

M. HIETE presented the project on emerging technologies carried out by IFARE and UBA Vienna with a participation of ITA and CITEPA, for the EC in 2003/2004. The project was very ambitious with a very short lead time. The study covered all industrial sectors (excluding transport and agriculture). A list of promising candidate technologies was set up for all sectors, but the data collection was not satisfying as experts were not willing/unable to make projections. For IFARE, data collection must be simpler for the LCP sector, as it is rather well defined. The energy production system is already partially described in PRIMES, whose data are used as exogenous data in RAINS/GAINS. According to the participating experts, PRIMES is not sufficiently transparent and the work of the EGTEI group on emerging technologies will also help to improve the situation. The added value of EGTEI is the participation of industry on this item.

A. JAGUSIEWICZ presented the situation of the electricity market in Poland and EU environmental challenges to be faced by Poland. The energy consumption in Poland increased continuously during the last years and is expected to increase further in the coming years. New plants have to be built to face the increasing demand. Existing Polish plants are often old and do not meet the LCP Emission Limits Values scheduled to come into force in 2016. The accession treaty demands lower emission ceilings than the Gothenburg Protocol. The technological choices for new plants depend on environmental constraints. As example, a new plant in operation in 2009 will meet the performances of BAT for SO_2, NOx and PM. Poland does not agree with PRIMES results whereby only 6% of electricity generation in Poland will be coal-based in 2020, because coal will remain the main energy source in Poland. To meet the legal requirements, Poland must go towards emerging technologies, BAT and CCS.

JP RIVRON completed the questionnaire sent by ADEME to prepare the meeting. The power generation system in France is untypical because fossil fuel plants are used to satisfy the peak demand, whereas they are used for the base load in most countries. Therefore, they contribute to only 5% of the total electricity production in France. 13 fossil fuel plants will be closed by 2015 according to the National reduction scheme. All remaining 12 plants still operational in 2015 will be equipped with SCR and FGD. In fact the abatement techniques are well known but investments for plants working less than 1000 h per year are economically unviable.

Discussions

Future technological choices depend on environmental policies and GHG reduction policies and especially CO_2 market. The security of power supply is also of major importance, which is not guaranteed when a country depends on a single imported energy source.

The initial proposal was to have two sub-groups working on different time horizons as described above. However, discussions have led to the decision to merge the two sub-groups and to consider an intermediate time horizon of 2030. It has been recognised that collecting information for the longer term horizon would be very difficult. The future energy production system will be probably very different from what can be imagined now. The BREF can be used to establish a first list of emerging technologies. CCS will be included.

The proposed definitions were largely commented. It was agreed to keep a certain degree of flexibility in the definition of emerging technologies. However, only techniques/technologies not yet in a commercialisation phase should be considered as emerging.

The group will focus both on combustion based technologies for power generation, on emerging applications of existing abatement techniques and on existing abatement techniques and the evolution of their performance over time. This is a request of IIASA for improving the modelisation, in which the efficiency of abatement techniques is presently kept constant over time.

The power of a combustion plant is defined at the unit level (not at the stack level).

The penetration rates (defined in RAINS as application rates) and the applicability rates will have to be clearly defined. The definition could be a little bit different from the RAINS definition in which the rates are defined for an activity level (e.g. consumption of different types of fuels in a given sub-sector).

It is not the job of the EGTEI group to decide what technologies/techniques will be integrated but a proposal will be made to TFIAM for future possible integration changes in RAINS/GAINS.

To facilitate the work of data collection, ADEME will prepare a proposal of sheets to be completed by experts and will provide definition of the terms used.

Some parameters in the list proposed by ADEME will be difficult to obtain; mainly those related to investments or operational costs for emerging technologies/techniques. Contacting manufacturers should be envisaged in order to get better information.

Conclusions

The group will focus on LCP up to 2030 by considering the different types of combustion based energy production technologies and abatement techniques according to the following definitions:

- New technologies and abatement techniques (R&D)
- Improvement:

New applications of existing abatement techniques, technical improvements of existing technologies and abatement techniques.

Clear definitions are necessary; however, a certain flexibility must remain. Pollutants to be addressed are SO_2, NO_x, PM and CO_2.

A list of potential technologies/techniques has to be established. Experts are invited to express which technologies/techniques should be prioritized by the group.. The list should be at minimum 10 items long (fluidised bed, IGCC, pressurised bed…)

By the 22nd of June ADEME prepares a document with definitions, a first list with technologies/techniques, and information about the type of data to be collected. Comments are expected soon, so that ADEME can send a consolidated document with a list of technologies/techniques by July 6th. Detailed contributions about the technologies are expected from experts until the end of August. Experts will be able to complete the form based on a common understanding.

The report of the kick off meeting will be sent at the same time for comments expected by the end of June, for a consolidated report by the 6th of July.

ADEME will merge all contributions for the second meeting of the group scheduled on 1st of October, just before the EGTEI meeting on 2nd of October. The second meeting will take place in Angers.

The EGTEI website will be updated for including this new group.

The timing for the work is still as proposed: 3rd meeting in December, 4th meeting in February 2008 for final delivery of a report on April 2008.

7.4.2 Aim of the sub-group LCP2020 (Nathalie THYBAUD - ADEME)

Expert sub-Groups on Emerging Technologies

EGTEI

ENERGY SECTOR

Test for the Power Generation
(LCP > 500 MWth)

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

Convention on Long-Range Transboundary Air Pollution

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

EGTEI is commissioned by UNECE to:

- Initiate some work on emerging technologies to reduce air emissions
- Assess what could be done technically and economically to reduce air emissions from LCP up to 2020/2030

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

Two sub-groups with two different time scales

- LCP 2020 Group
  Up to 2020
- Power Generation (PG) 2050 Group
  2020-2050

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

Aim of the sub-groups

Provide technical and economical information on emerging technologies and on evolution of abatement technologies for the coming years

Provide information for modelling work

Focus on:

- Environmental performance of technologies
- Energy consumption and CO_2 impact
- Applicability for new or existing plants
- Cost and rate of penetration

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

LCP 2020 Group: description and limits

Proposal of emerging technologies classification:

- Identified technology not available (R&D evolution)
- Technology available but with economical barriers
- Technology technically and commercially available but with possible technical improvements

Emerging technologies concern both primary and secondary measures

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

LCP 2020 Group: description and limits

Make a distinction between:

- Existing plants still operational in 2020
- New plants without capture ready built within the coming years and still operational in 2020
- New plants with capture ready built within the coming years and still operational in 2020

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

LCP 2020 Group: description and limits

Focus on PM, SO_x, NO_x and CO_2

Estimate the CO_2 emissions due to abatement technologies

Have a more global view on a technology taking into account the whole process

Focus on LCPs > 500 MWth and load factor taken into consideration

Need for judgement from industrial and national administration experts

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

LCP 2020 Group: Organisation

Kick-off meeting in ADEME Paris, June 7th, 2007

2nd meeting: end of September 2007

3rd meeting: December 2007

- Draft report (January 2008)

4th meeting: February 2008

- Final report (April 2008)

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

Questionnaire

Do you know reference documents useful for sub-groups?

- Emerging Techniques Chapters in LCP BREF
- Document of EU-project "Assessment of the air emissions impact of emerging technologies"
- Energy Efficiency in power plants – KEMA Power Generation & Sustainables
- Energies for the New Millenium (RAG & STEAG)
- CO_2 capture Ready Recommendations of European Power Plant Suppliers Association (EPPSA)
- …

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

Questionnaire

Do you know reference Internet sites useful for sub-group?

Do you work (project, study, …) or do you know some work on emerging technologies for LCP?

- Document of EU-project "Assessment of the air emissions impact of emerging technologies"

Do you have other type of data on emerging technologies?

Would you recommend to contact other experts?

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

LCP 2020 Group: Type of contribution

Pollutant	Abatement techniques (primary or secondary measures)	Abatement efficiency (%)	Energy consumption and other utilities	CO_2 impact	Maturity (*)	Penetration rate	Possible use on New or existing plant?		Retrofit factor for existing plant	Costs		
							New	Existing		Investment (for new and existing plants)	Fixed O&M	Variable O&M
NOx												
SOx												
…												

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

Definition of costs

The **investment cost** includes the retrofit factor

The **fixed operating costs** cover the costs of maintenance and administrative overhead

The **variable operating costs** related to the actual operation of the plant take into account:

- additional labor demand
- increased energy demand for operating the device (e.g., for the fans and pumps)
- sorbent material demand (e.g., limestone)
- byproducts / waste disposal

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

Conclusion

Identify emerging abatement techniques to reduce air emissions

Assess at 2020 horizon:

- abatement efficiency
- energy consumption and CO_2 impact (GAINS model)
- penetration rate

Focus more precisely as possible on cost assessment for modelling work

Kick-off meeting – LCP 2020 Group - Paris – June 7th, 2007

7.4.3 Aim of the sub-group PG2050 (Nathalie THYBAUD - ADEME)

Expert sub-Groups on Emerging Technologies

EGTEI

ENERGY SECTOR

Test for the Power Generation (LCP > 500 MWth)

Kick-off meeting – PG 2050 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

PG 2050 Group: description and limits

Proposal of emerging technologies classification:

- Technology not available in 2020 (R&D evolution)
- Technology available in 2020 but with economical barriers
- Technology technically and commercially available in 2020 but with possible technical improvements

Kick-off meeting – PG 2050 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

PG 2050 Group: description and limits

Emerging technologies concerned:

- Primary and secondary measures
- CO_2 capture (post-combustion, oxycombustion, pre-combustion)

Make a distinction between:

- Existing plants (before 2020) without capture ready and still operational between 2020-2050
- Existing plants (before 2020) with capture ready and still operational between 2020-2050
- New plants built from 2020

Kick-off meeting – PG 2050 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

PG 2050 Group: description and limits

Focus on PM, SO_x, NO_x and CO_2 emissions

Have a more global view on a technology taking into account the whole process

Focus on LCPs > 500 MWth and load factor taken into consideration

Need for judgement from industrial, national administration and research experts

Kick-off meeting – PG 2050 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

PG 2050 Group: Organisation

Kick-off meeting in ADEME Paris, June 7th, 2007

2nd meeting: end of September 2007

3rd meeting: December 2007

- Draft report (January 2008)

4th meeting: February 2008

- Final report (April 2008)

Kick-off meeting – PG 2050 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

Questionnaire

Do you know reference documents useful for sub-group?

- Document of EU-project "Assessment of the air emissions impact of emerging technologies"
- Strategic Deployment Document (ETP ZEP)
- IPCC Special Report on Carbon Dioxide Capture and Storage
- CO_2 capture Ready Recommendations of European Power Plant Suppliers Association (EPPSA)
- …

Kick-off meeting – PG 2050 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

Questionnaire

Do you know reference Internet sites useful for sub-group?

- IPCC Special Report on carbon dioxide capture and storage
  http://www.ipcc.ch/activity/srccs/index.htm
- IEA: web resources on CO_2 capture and storage
  http://www.co2captureandstorage.info
- European Technology Platform on Zero Emission Fossil Fuel Power Plants (ETP ZEP)
  http://www.zero-emissionplatform.eu/website/
- Club CO2
  http://www.clubco2.net
- …

Kick-off meeting – PG 2050 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

Example of France: Club CO_2

Key element in the organisation of French research in the field of CO_2 capture and storage

A response to the need to more effectively federate national efforts

Missions of Club CO_2

- Identify the broad orientations and the major challenges to be targeted by scientific and technical programmes
  - ✓ Proposal of R&D programme on CCS (2005)
- Recommend to decision-makers of research funding bodies that inter-disciplinary efforts should be initiated and expanded
- …

Kick-off meeting – PG 2050 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

PG 2050 Group: Type of contribution

Pollutant and CO_2	Abatement techniques or techniques of power generation with CO2 capture	Abatement efficiency (%)	Energy consumption	CO_2 impact	Maturity (*)	Horizon of deployment (2020, 2030, …)	Penetration rate	New or existing plant		Retrofit factor	Costs		
								New	Existing		Investment	Fixed O&M	Variable O&M
NOx													
SOx													
…													

Kick-off meeting – PG 2050 Group - Paris – June 7th, 2007

Expert sub-Groups on Emerging Technologies

Conclusion

Identify emerging abatement techniques to reduce air emissions and CO_2 emissions

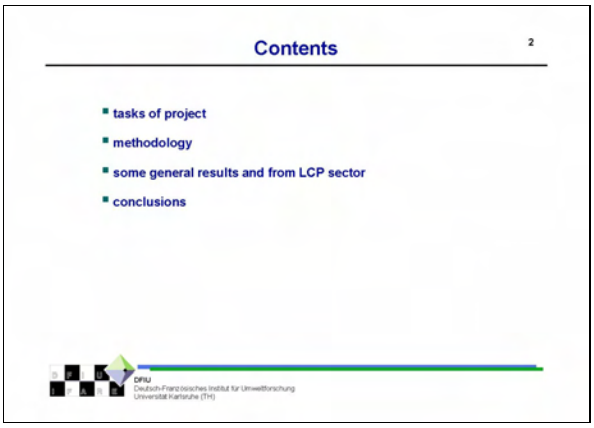
Assess at 2030 and 2050 horizons:

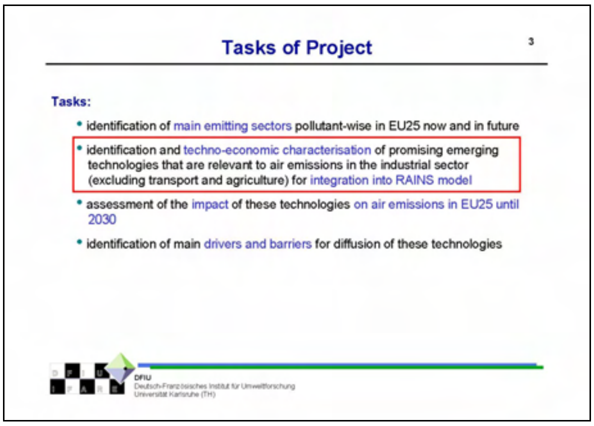
- abatement efficiency
- energy consumption and CO_2 impact (GAINS model)
- penetration rate

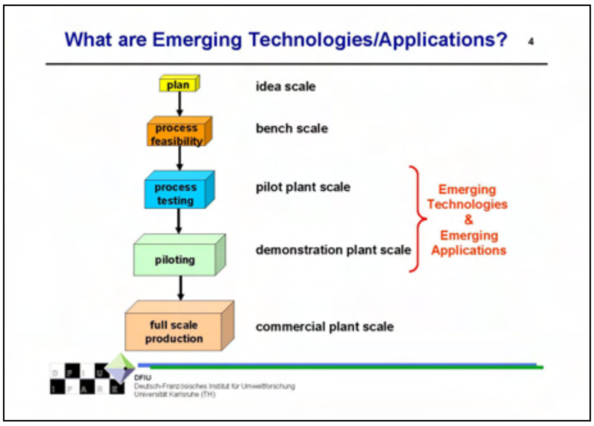
If possible, provide cost assessments

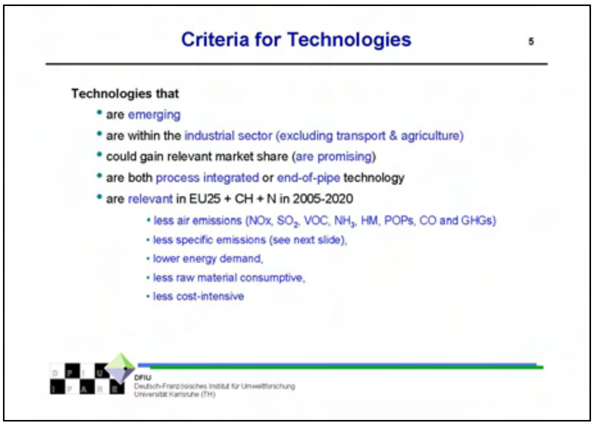
Kick-off meeting – PG 2050 Group - Paris – June 7th, 2007

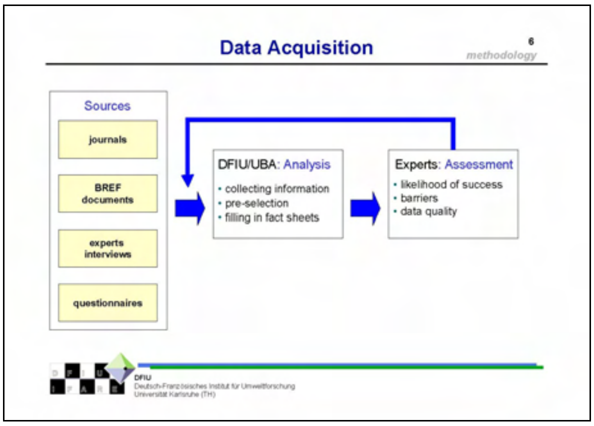
7.4.4 Overview of EU-Project: "Assessment of the air emissions impact of emerging technologies" - 2003-2004 (Michael HIETE - IFARE)

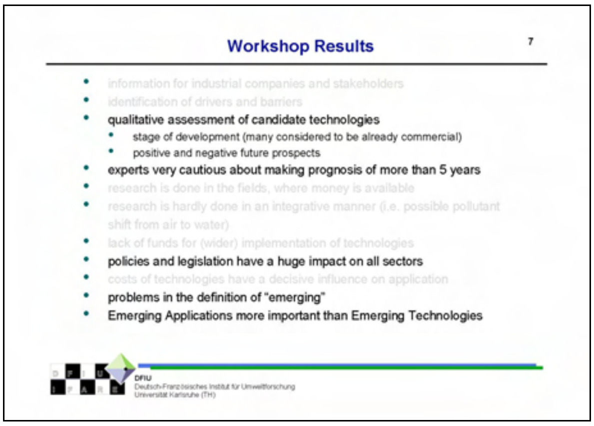


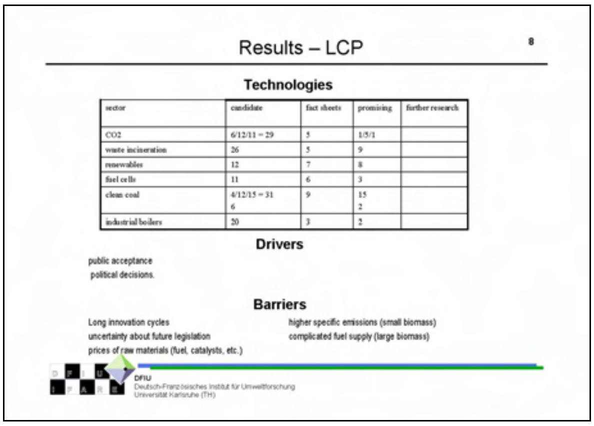


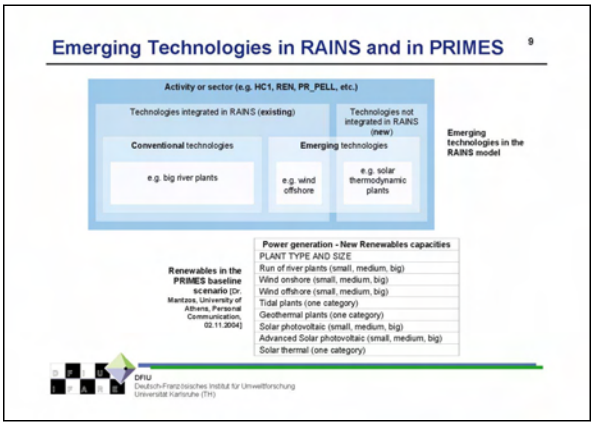


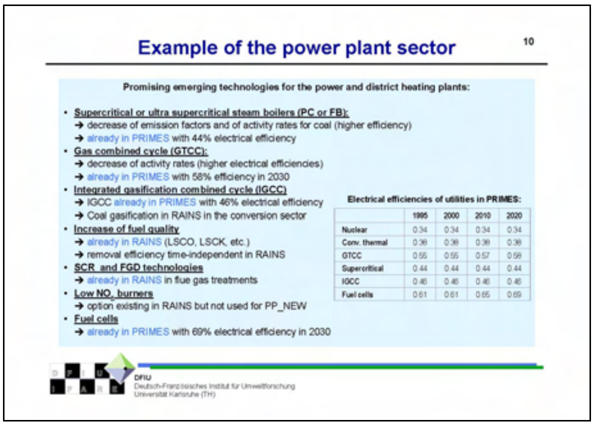





Workshop Results
7
information for industrial companies and stakeholders
identification of drivers and barriers
qualitative assessment of candidate technologies
stage of development (many considered to be already commercial)
positive and negative future prospects
experts very cautious about making prognosis of more than 5 years
research is done in the fields, where money is available
research is hardly done in an integrative manner (i.e. possible pollutant shift from air to water)
lack of funds for (wider) implementation of technologies
policies and legislation have a huge impact on all sectors
costs of technologies have a decisive influence on application
problems in the definition of "emerging"
Emerging Applications more important than Emerging Technologies
DFIU
Deutsch-Französisches Institut für Umweltforschung
Universität Karlsruhe (TH)


Results – LCP
8
Technologies
sector
candidate
fact sheets
promising
further research
CO2
6/12/11 = 29
5
1/5/1
waste incineration
26
5
9
renewables
12
7
8
fuel cells
11
6
3
clean coal
4/12/15 = 31
6
9
15
2
industrial boilers
20
3
2
Drivers
public acceptance
political decisions.
Barriers
Long innovation cycles
uncertainty about future legislation
prices of raw materials (fuel, catalysts, etc.)
higher specific emissions (small biomass)
complicated fuel supply (large biomass)
DFIU
Deutsch-Französisches Institut für Umweltforschung
Universität Karlsruhe (TH)


Emerging Technologies in RAINS and in PRIMES
9
Activity or sector (e.g. HC1, REN, PR_PELL, etc.)
Technologies integrated in RAINS (existing)
Technologies not integrated in RAINS (new)
Conventional technologies
Emerging technologies
e.g. big river plants
e.g. wind offshore
e.g. solar thermodynamic plants
Emerging technologies in the RAINS model
Renewables in the PRIMES baseline scenario [Dr. Mantzos, University of Athens, Personal Communication, 02.11.2004]
Power generation - New Renewables capacities
PLANT TYPE AND SIZE
Run of river plants (small, medium, big)
Wind onshore (small, medium, big)
Wind offshore (small, medium, big)
Tidal plants (one category)
Geothermal plants (one category)
Solar photovoltaic (small, medium, big)
Advanced Solar photovoltaic (small, medium, big)
Solar thermal (one category)
DFIU
Deutsch-Französisches Institut für Umweltforschung
Universität Karlsruhe (TH)


Example of the power plant sector
10
Promising emerging technologies for the power and district heating plants:
Supercritical or ultra supercritical steam boilers (PC or FB):
→ decrease of emission factors and of activity rates for coal (higher efficiency)
→ already in PRIMES with 44% electrical efficiency
Gas combined cycle (GTCC):
→ decrease of activity rates (higher electrical efficiencies)
→ already in PRIMES with 58% efficiency in 2030
Integrated gasification combined cycle (IGCC)
→ IGCC already in PRIMES with 46% electrical efficiency
→ Coal gasification in RAINS in the conversion sector
Increase of fuel quality
→ already in RAINS (LSCO, LSCK, etc.)
→ removal efficiency time-independent in RAINS
SCR and FGD technologies
→ already in RAINS in flue gas treatments
Low NOx burners
→ option existing in RAINS but not used for PP_NEW
Fuel cells
→ already in PRIMES with 69% electrical efficiency in 2030
Electrical efficiencies of utilities in PRIMES:
1995
2000
2010
2020
Nuclear
0.34
0.34
0.34
0.34
Conv. thermal
0.38
0.38
0.38
0.38
GTCC
0.55
0.55
0.57
0.58
Supercritical
0.44
0.44
0.44
0.44
IGCC
0.46
0.46
0.46
0.46
Fuel cells
0.61
0.61
0.65
0.69
DFIU
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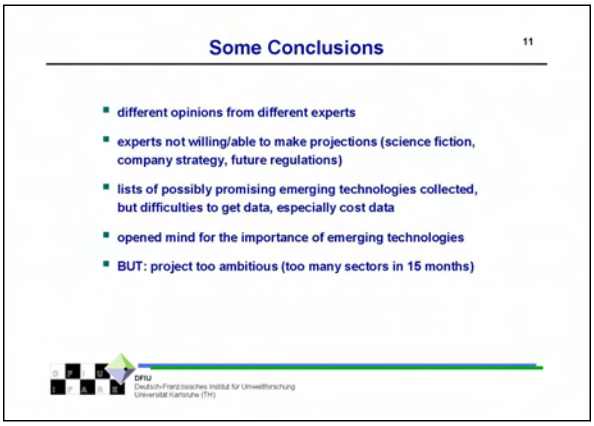
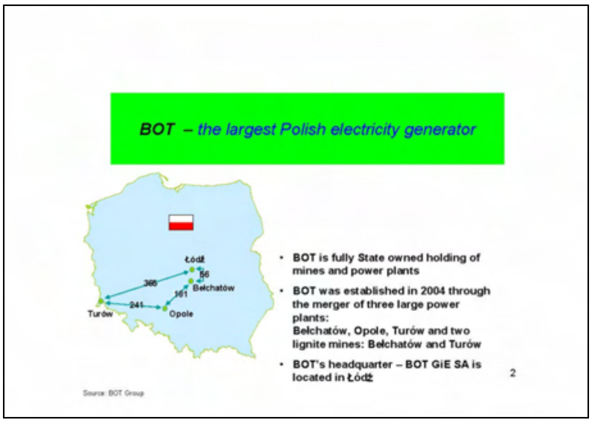
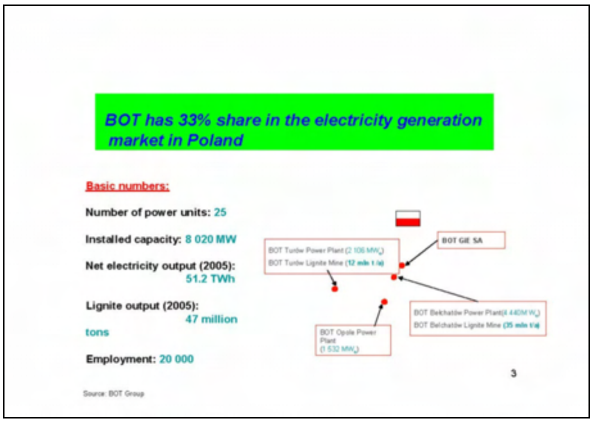
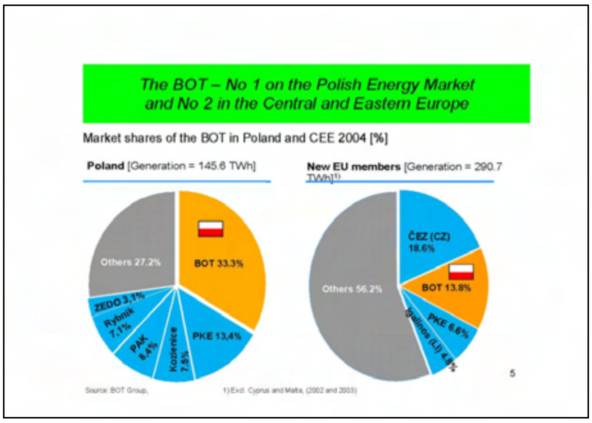
Universität Karlsruhe (TH)

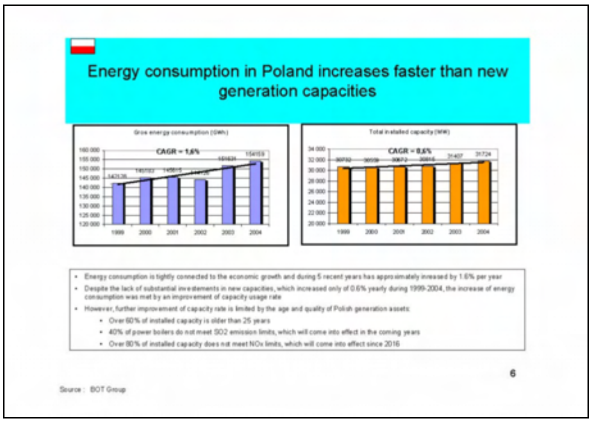

Some Conclusions
11
different opinions from different experts
experts not willing/able to make projections (science fiction, company strategy, future regulations)
lists of possibly promising emerging technologies collected, but difficulties to get data, especially cost data
opened mind for the importance of emerging technologies
BUT: project too ambitious (too many sectors in 15 months)
DFIU
Deutsch-Französisches Institut für Umweltforschung
Universität Karlsruhe (TH)

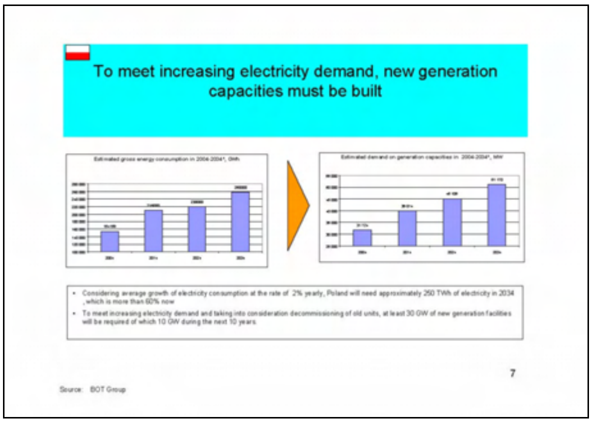
7.4.5 BOT Group, electricity market in Poland and EU environmental challenges (Andrzej Jagusiewicz – Clean Air for Europe)

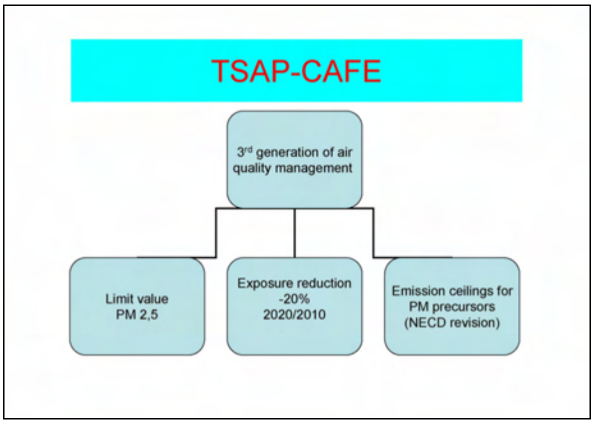


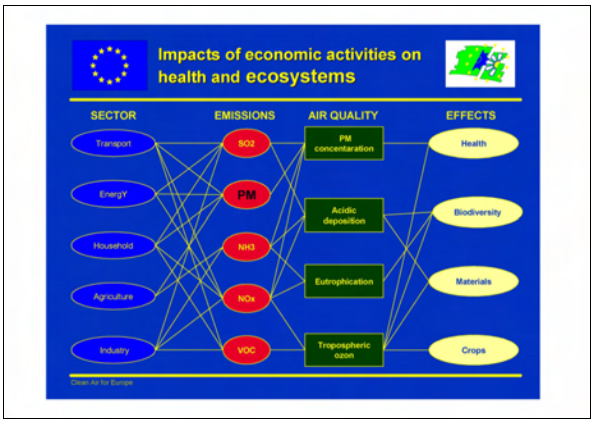


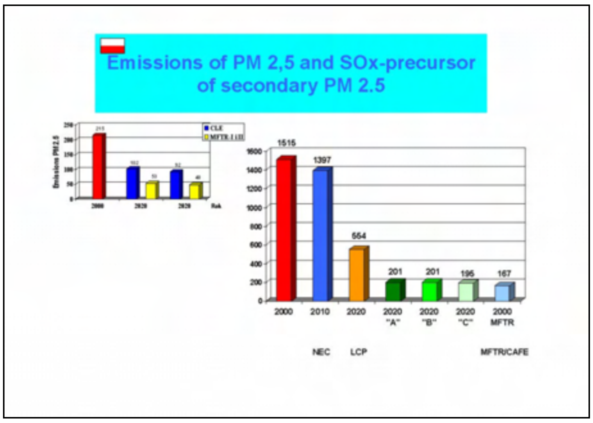


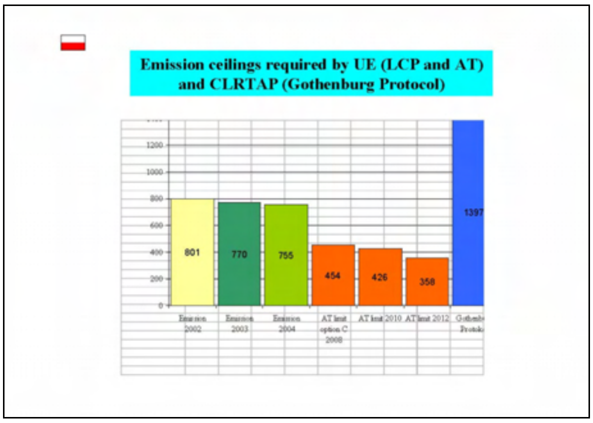


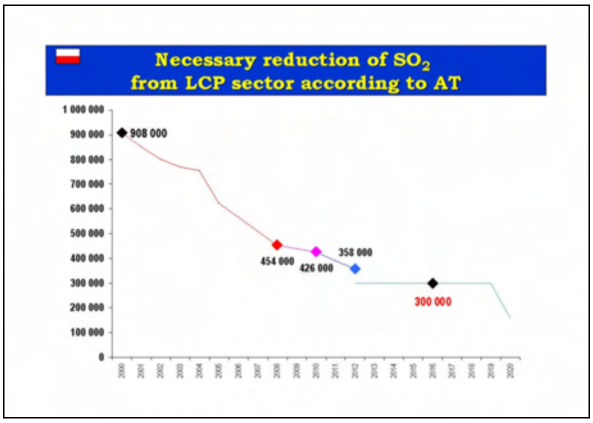


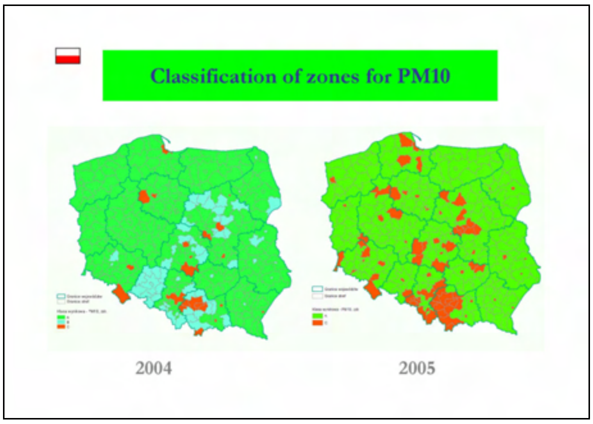


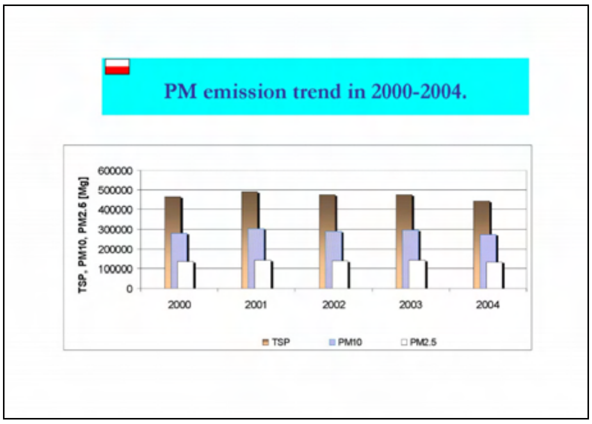

Impacts of economic activities on health and ecosystems
SECTOR
EMISSIONS
AIR QUALITY
EFFECTS
Transport
EnergY
Household
Agriculture
Industry
SO2
PM
NH3
NOx
VOC
PM concentaration
Acidic deposition
Eutrophication
Tropospheric ozon
Health
Biodiversity
Materials
Crops
Clean Air for Europe

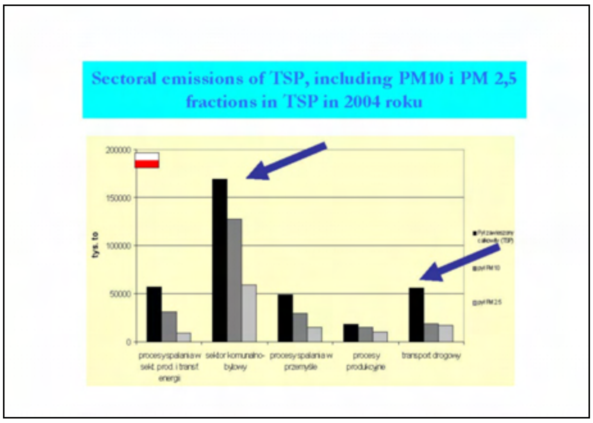

Emissions of PM 2,5 and SOx-precursor of secondary PM 2.5
1515
1397
554
201
201
195
167
2000
2010
2020
2020 "A"
2020 "B"
2020 "C"
2000 MFTR
NEC
LCP
MFTR/CAFE

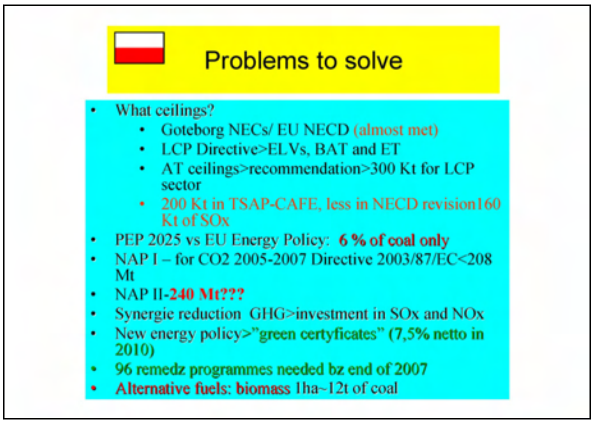

Emission ceilings required by UE (LCP and AT) and CLRTAP (Gothenburg Protocol)
801
770
755
454
426
358
1397
Emission 2002
Emission 2003
Emission 2004
AT limit option C 2008
AT limit 2010
AT limit 2012


Necessary reduction of SO2 from LCP sector according to AT
908 000
454 000
426 000
358 000
300 000


Classification of zones for PM10
2004
2005


PM emission trend in 2000-2004.
TSP, PM10, PM2.5 [Mg]
600000
500000
400000
300000
200000
100000
0
2000
2001
2002
2003
2004
TSP
PM10
PM2.5


Sectoral emissions of TSP, including PM10 i PM 2,5 fractions in TSP in 2004 roku
tys. to
200000
150000
100000
50000
0
procesy spalania w sekt. prod. i transf. energii
sektor komunalno-bytowy
procesy spalania w przemyśle
procesy produkcyjne
transport drogowy


Problems to solve
What ceilings?
Goteborg NECs/ EU NECD (almost met)
LCP Directive>ELVs, BAT and ET
AT ceilings>recommendation>300 Kt for LCP sector
200 Kt in TSAP-CAFE, less in NECD revision160 Kt of SOx
PEP 2025 vs EU Energy Policy: 6 % of coal only
NAP I – for CO2 2005-2007 Directive 2003/87/EC<208 Mt
NAP II-240 Mt???
Synergie reduction GHG>investment in SOx and NOx
New energy policy>"green certyficates" (7,5% netto in 2010)
96 remedz programmes needed bz end of 2007
Alternative fuels: biomass 1ha~12t of coal

7.4.6 Answer to the EGTEI questionnaire (Jean-Pierre RIVRON – LCP expert)

EGTEI QUESTIONNAIRE
sent by Nathalie Thybaud
on the 4th may 2007

Contribution of Jean-pierre RIVRON

Do you know reference document which could be useful for expert panels?

- Emerging technologies according to the IPPC Reference Document on Best available Techniques for LCP (july 2006)
- IFARE document on emerging technologies ordered by European Commission
- Energy Efficiency in Power plants (Frans van aart, Wim Kok, pierre Ploumen) (KEMA power generation § sustainables)
- Energies for the new Millenium (RAG + STEAG)
- German document on CO2 captation and stockage (cf Mr KRUEGER)

Would you recommend to contact other experts?

- **INDUSTRY**
- GDF
- EDF Chatou Research Center
- EDF engineering (La défense)
- EDF fossil fire plant production departement (St denis)
- EDF overseas production department
- SNET
- SUEZ Group
- TOTAL

- **LABORATORY**:IFP
- **MANUFACTURER**
- ALSTOM
- CNIM

Table for EDF existing oil LCP (in France) 2020
(4 x 600MWe + 4 x 700 MWe) in peak use
these units will be almost at their end of life in 2020: impossible to implement techniques (economical barrier)

Pollutant	Abatement techniques	Abatement efficiency	CO2 impact	Maturity	Penetration rate	New or existing plant	Investment (to be checked)	Comments
NOx	Low NOx burners or low NOx combustion	30 to 50%	none	Existing technologie s	10%(1 unit on 8)	existing	15 MEuros/unit + 10 MEuros for precipitator	Operation< 1000 hours/year
NOx	SCR	80%	To be completed	Existing technologie s	0%	existing	30 MEuros/unit O$M increased	Operation< 1000 hours/year
SOx	Low sulphur oil	30 to 50%			100% (evolution in course)	existing	O§M increased	This evolution is already in course

Table for EDF existing coal LCP in France (2020) (3 x 600 MWe) in semi-basis use
these units will be almost at their end of life in 2020: impossible to implement techniques (economical barrier)

Pollutant	Abattement techniques	Abatement efficiency	CO2 impact	Maturity	Penetration rate	New or existing plant	Investment (to be checked)	Comments
NOx	Low-NOx burners or low NOx combustion	50%	none	Existing technologie s	0%	Existing plant	30 MEuros/uni t	
NOx	SCR catalyser managment or SCR other improvement s	20%?	none	Existing technologie s			O§M increased	Thse units are already equipped with SCR (operationnal at the end of 2007)
SOx	Adipic acid injection in the FGD (or other techniques to improve abatement efficiency)	20%?		Existing technologie s			O§M increased	These units are already equipped with FGD and already use low sulphur coal (this last evolution is already in course)
CO2+ NOx+ SO2	Bottom ash dry extractor		-0,3%	Existing technologie s			4 MEuros/uni t	For instance Magaldi ash cooler, almost 100% penetration rate in Italy

Annex 7.5

Documents from the 2nd meeting – 1 October 2007

7.5.1 Agenda

1st October 2007

ADEME Angers - 20, avenue du Grésillé - 49004 ANGERS Cedex 01

Chairman: Gwénaël Guyonvarch

Time schedule	Session
9:30-10:00	Welcome of participants
10:00-10:10	Planning of the meeting (Gwénaël Guyonvarch)
10:10-10:40	Objectives of the sub-group and work in progress (Nathalie Thybaud)
10:40-12:30	Discussions on priority techniques/technologies (all participants)
12:30-14:00	Lunch at ADEME's cafeteria
14:00-14:30	Presentation of new documents for collecting data (Nathalie Thybaud)
14:30-16:00	Identification of the future contributions of experts (all participants)
16:00-16:30	Interview of other experts (all participants)
16:30-17:00	Conclusion and next steps (Gwénaël Guyonvarch)

7.5.2 Meeting report

Participants

Mrs Nadine ALLEMAND (CITEPA),
Mr Jean-Guy BARTAIRE (Co-chairman of EGTEI, EDF),
Mr Pier Lorenzo DELL'ORCO (EDIPOWER s.p.a.),
Mr Jacek GADOWSKI (BOT Gornictwo i Energetyka SA),
Mrs Julie GARET (MEDAD)
Mr Gwénaël GUYONVARCH (ADEME),
Mr Michael HIETE (IFARE),
Mr Pierre KERDONCUFF (IFARE),
Mr Hartmut KRUGER (VGB PowerTech e.V.),
Mr Peter MEULEPAS (Ministry of the Flemish Region, Environmental Administration),
Mrs Carole ORY (EDF),
Mr Tiziano PIGNATELLI (Chairman of EGTEI, ENEA),
Mr Jean-Pierre RIVRON (formerly EDF),
Mrs Dorothée ROSTAL (IFARE),
Ms Kristina SAARINEN (Finnish Environment Institute),
Mrs Simone SCHUCHT (INERIS),
Mrs Nathalie THYBAUD (ADEME).

Mr Mats LINDGREN (Swedish EPA), Ms Katja KRAUS (German Federal Environmental Agency), Ms Andrea KRIZOVA (Czech Hydrometeorological Institute) were excused.

Background

The LCP2030 subgroup had its kick-off meeting on 7 June 2007. The aim of the subgroup is to provide techno-economic information about i) emerging technologies, ii) emerging abatement techniques, iii) emerging applications of existing abatement techniques, iv) improvement of existing technologies and v) improvement of existing abatement techniques in the sector of large combustion plants (LCP), i.e. >500 MWth, until 2030.

Context

The 2nd meeting was hosted by ADEME and chaired by G. GUYONVARCH. After a brief introduction, G. GUYONVARCH presented the aims of this meeting:

- review the list of technologies/techniques including their ranking,
- check the data structure for contributions on technologies/techniques,
- list the contributions to be received.

JG BARTAIRE explained the temporal framework set by the WGSR which will meet in April and September 2008. To allow translations into French and Russian the final document must be available 90 days before the meeting in September 2008, i.e. in June 2008. Nevertheless it is possible to provide a draft document in English as information for the meeting in April 2008. Therefore, the final report of the LCP2030 subgroup must be available in April 2008 (see below).

JG BARTAIRE reminded that GAINS offers now the possibility of varying efficiencies over time (evolution of existing technologies).

Results of the discussion

After a brief discussion, it was concluded to stick to the time horizon 2030 for this subgroup.

Carbon capture and sequestration (CCS) is relevant to this subgroup as it affects not only CO_2 emissions and energetic efficiency but also air pollutants. Information on CCS can be found e.g. on the European Technology Platform for Zero Emission Fossil Fuel Power Plants (ETP ZEP) http://www.zero-emissionplatform.eu/website/.

For some of the technologies, e.g. IGCC, the application rates are calculated in PRIMES so that cost data for these technologies might not be needed for RAINS.

N. THYBAUD presented a technology/techniques list for further discussion. This first list was compiled based on the information provided by the experts. The group went through this list technology/technique by technology/technique. As a result of the discussion:

- technologies/techniques to be analysed with high priority were identified,
- some technologies/techniques were removed from the list, e.g. when the technologies/techniques proved to be of no interest (e.g. not in operation anymore) or when they were not within the scope of this subgroup (e.g. applied only below 500 MWth),
- some technologies/techniques were added (often these were technologies that are limited to one or a few countries),
- for some technologies/techniques the name was changed (e.g. from the supplier's product name to a name describing the process),
- contributors of information for technologies/techniques were identified.

The results of this discussion are documented in the attached Excel sheet.

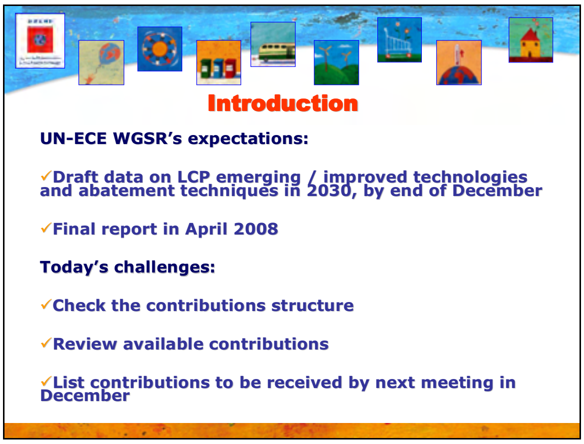
Then N. THYBAUD presented the tables developed to facilitate a systematic collection of information about the technologies/techniques. It was concluded that:

- The item "CO_2 abatement efficiency" will be changed in order to better reflect the impact on GHG emissions, e.g. from limestone use in flue gas desulphurisation.
- Fixed operating costs are given in the EGTEI methodology as percentage of investment.
- Brief guidelines on how to use the tables will be developed in order to help the experts.

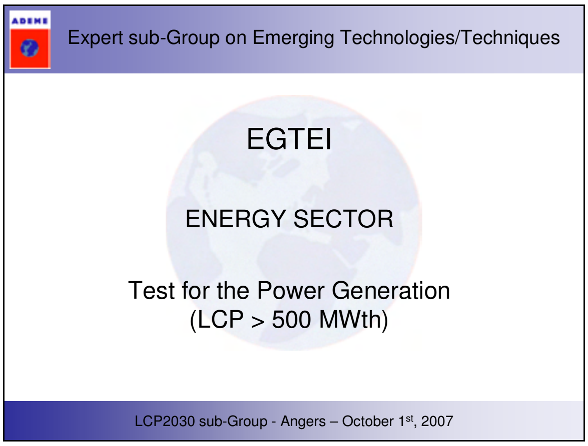
Schedule:

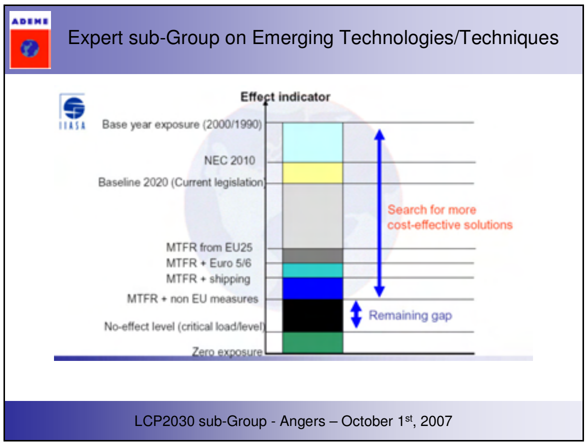
- December 2007: receive listed contributions
- January 25th 2008: 3rd LCP2030 meeting in Brussels
- March 2008: finalize contributions
- April 2008: presentation of a draft to the WGSR
- May 2008: 4th LCP2030 meeting (in Poland ?)
- June 2008: finalize document in English
- September 2008: (translate the document in Russian and French if resource found) and present it to the WGSR

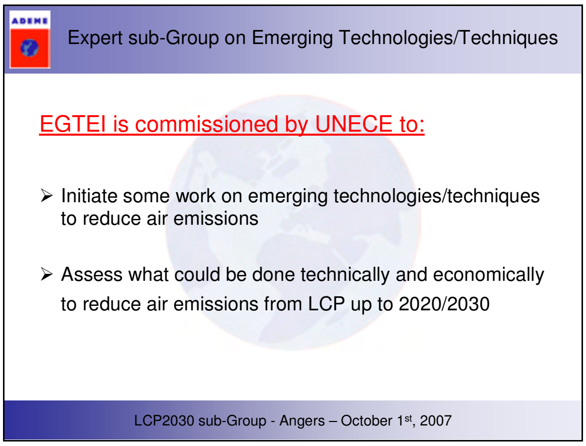
7.5.3 Aim of the meeting (Gwénaël GUYONVARCH - ADEME)

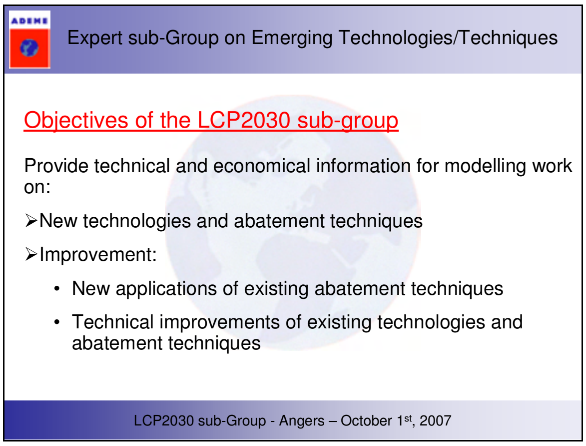


7.5.4 List of technologies and techniques (Nathalie THYBAUD - ADEME)









Expert sub-Group on Emerging Technologies/Techniques

Objectives of the LCP2030 sub-group

Focus on:

- LCPs > 500 MWth
- Primary and secondary measures
- PM, SO_x, NO_x and CO_2 abatement

Estimate the CO_2 emissions due to abatement techniques

LCP2030 sub-Group - Angers – October 1st, 2007

Expert sub-Group on Emerging Technologies/Techniques

First steps

Establish a list of potential technologies/techniques

Comments of experts on:

- classification (emerging abatement technique, existing abatement technique …)
- priority technologies/techniques to consider
- available data

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Expert sub-Group on Emerging Technologies/Techniques

List of emerging technologies

Technology/Technique	Source	I have data/information		
		IFARE	EDIPOWER	Czech Republic
Coal: Lignite predrying with low temperature heat	BREF			
Coal: IGCC	EU-Project	x	x	
Gas: Catalytic combustion	BREF			
Gas: Steam cooling	BREF			
Gas: Recuperative options (intercooled, HAT, TOPHAT, CHAT)	BREF			
Liquid: Fuel cell	BREF			
Biomass: IGCC	BREF			
Co-Combustion (Waste/Biomass)			x	
Liquid CO2 storage for electricity peak demand from variable wind powe	EU-Project			
Oxycombustion		x		
Chemical looping combustion				
Other				

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Expert sub-Group on Emerging Technologies/Techniques

List of emerging abatement techniques

Technology/Technique	Source	I have data/information		
		IFARE	EDIPOWER	Czech Republic
SO2				
Flowpac	EU-Project	x		
Limestone Injection Dry Scrubbing (LIDS)	EU-Project	x		
Duct Sorbent Injection - Coolside	EU-Project	x		
Other				
NOx				
Oxygen Enhanced Low-NOx Technology	EU-Project			
Oscillating Combustion	EU-Project			
Other				
SOx+NOx				
Parsons Flue-gas Clean-up	BREF			
Lurgi CFB	BREF			
US gas-phase oxidation process	BREF			
Limestone Injection Multistaged Burner (LIMB)	EU-Project	x		
SOx-NOx-Rox-Box (SNRB)	EU-Project	x		
Other				

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Expert sub-Group on Emerging Technologies/Techniques

Technology/Technique	Source	I have data/information		
		IFARE	EDIPOWER	Czech Republic
PM				
Advanced PM1 Agglomeration ESP	EU-Project			
Other				
CO2 Capture				
Chemical solvent scrubbing	EU-Project	x		
Physical solvent scrubbing	EU-Project			
Adsorption	EU-Project			
Membranes				
Cryogenics				
Direct air capture technology for CO2	EU-Project			
Other				
CO2 Storage				
Enhanced Coal Bed Methane (ECBM)	EU-Project			
Enhanced Gas Recovery: CO_2-EGR	EU-Project	x		
Enhanced Oil Recovery: CO_2-EOR	EU-Project	x		
Deep Saline Aquifer	EU-Project	x		
Depleted Oil and Gas Reservoirs				
Unmineable coal beds				
Mineralization				
Other				

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Expert sub-Group on Emerging Technologies/Techniques

List of emerging applications of existing abatement techniques

Not yet identified!

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Expert sub-Group on Emerging Technologies/Techniques

List of existing technologies improvement

Technology/Technique	Source	I have data/information		
		IFARE	EDIPOWER	Czech Republic
Coal: Pulverised Coal (PC)	BREF		x	x
Coal: Bubbling Fluidised bed combustion (BFBC)	BREF			
Coal: Circulating Fluidised bed combustion (CFBC)	BREF			
Coal: Pressurised fluidised bed combustion (PFBC)	BREF	x		
Coal: Grate firing (GF)	BREF			x
Coal: Integrated gasification combined cycle	BREF	x		
Coal: Co-generation (CHP)	BREF			
Coal: Combined cycle combustion (repowering)	BREF			
Gas: Gas turbines	BREF		x	
Gas: Gas fired boilers and heaters	BREF			x
Gas: Combined cycle	BREF		x	
Gas: Co-generation (CHP)	BREF		x	
Biomass: Grate firing (GF)	BREF			x
Biomass: Bubbling Fluidised bed combustion (BFBC)	BREF			
Biomass: Circulating Fluidised bed combustion (CFBC)	BREF			
Biomass: Pulverised Coal (PC)	BREF			
Biomass: Spreader-stoker	BREF			
Biomass: Co-generation (CHP)	BREF			
Liquid fuels: Co-generation (CHP)	BREF			
Other				
Pulverized Coal Firing, (ultra) supercritical (PCF - USC),		x		
Pressurized Pulverized Coal Combustion (PPCC)		x		

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Expert sub-Group on Emerging Technologies/Techniques

List of existing abatement techniques improvement

Technology/Technique	Source	I have data/information		
		IFARE	EDIPOWER	Czech Republic
SO2				
Low sulphur fuels or fuels with basic ash	BREF		x	x
Adsorbents in fluidised bed combution	BREF			x
Wet lime/limestone scrubbers	BREF		x	x
Seawater scrubber	BREF			
Magnesium wet scrubber	BREF			
Ammonia wet scrubber	BREF			
Spray dry scrubbers	BREF			x
Furnace sorbent injection	BREF			x
Duct sorbent injection (dry FGD)	BREF		x	x
Hybrid sorbent injection	BREF			
Circulating fluid bed (CFB) dry scrubber	BREF			
Sodium sulphite bisulphite process	BREF			
Magnesium oxide process	BREF		x	
Other				
Fuel exchange				x
Burner exchange or combustor modification				x
Reconstruction of boilers or stacks				x

LCP2030 sub-Group - Angers – October 1st, 2007

Expert sub-Group on Emerging Technologies/Techniques

List of existing abatement techniques improvement

Technology/Technique	Source	I have data/information		
		IFARE	EDIPOWER	Czech Republic
NOx				
Low excess air	BREF			
Air staging (biased burner firing (BBF))	BREF			
Air staging (burners out of service (BOOS))	BREF		x	
Air staging (overfire air (OFA))	BREF		x	
Flue-gas recirculation	BREF		x	
Reduced air preheat	BREF			
Fuel staging (reburning)	BREF			
Air-staged low NOx burner	BREF		x	
Flue-gas recirculation low NOX burner	BREF		x	
Fuel-staged low NOX burner	BREF			
Selective catalytic reduction (SCR)	BREF		x	
Selective non-catalytic reduction (SNCR)	BREF		x	
Other				
Fuel exchange				x
Burner exchange or combustor modification				x
Reconstruction of boilers or stacks				x

Expert sub-Group on Emerging Technologies/Techniques

List of existing abatement techniques improvement

Technology/Technique	Source	I have data/information		
		IFARE	EDIPOWER	Czech Republic
SO2+NOx				
Activated carbon process	BREF			
The NOXSO process	BREF			
Other solid adsorption/regeneration processes	BREF			
WSA-SNOX process	BREF		x	
DESONOX process	BREF			
SNRB process	BREF			
Electron beam irradiation	BREF			
Alkali injection	BREF			
Wet scrubber with additives to achieve NOx emoval	BREF			
Other				
PM				
Electrostatic precipitators (ESP)	BREF		x	x
Wet electrostatic precipitators	BREF			
Fabric filters (baghouses)	BREF		x	x
Centrifugal precipitation (cyclones)	BREF			x
Wet scrubber	BREF			
Other				
Fuel exchange				x
Burner exchange or combustor modification				x
Reconstruction of boilers or stacks				x

Expert sub-Group on Emerging Technologies/Techniques

Conclusion

Take decisions on technologies/techniques prioritised by the sub-group

Discussion on criteria of choice:

- performance improvement
- reduction of costs
- available data
- …

7.5.5 List of contributors for information on technologies and techniques

Type	Technology/Technique	Source	We have data/information			Contributor
			IFARE	EDIPOWER	Czech Republic	
Ia Emerging Technologies						
	Coal: Lignite predrying with low temperature heat	BREF				VGB
	Coal: IGCC	EU-Project	x	x		EDF, BOT?
	Gas: Catalytic combustion	BREF	x (EU project)			
	Gas: Steam cooling	BREF				AART Kema?
	Gas: Recuperative options (intercooled, HAT, TOPHAT, CHAT)	BREF				AART Kema?
	Biomass: IGCC	BREF				EDF? Sweden?
	Co-Combustion (Waste/Biomass)			x		EDF? ENBW?
	Oxycombustion		x			VGB
	Chemical looping combustion					Alstom? EDF?
	Other					
	Coal: Underground gasification					BOT
	Coal: Low grade coal pre-processing					BOT?
Ib Emerging Abatement Techniques						
	SO2					
	Flowpac	EU-Project	x			Sweden? Alstom?
	Limestone Injection Dry Scrubbing (LIDS)	EU-Project	x			
	Duct Sorbent Injection - Coolside	EU-Project	x			VGB
	Other					
	NOx					
	Oxygen Enhanced Low-NOx Technology	EU-Project				AIR LIQUIDE?
	Oxy-fuel combustion					EDIPOWER (Babcock UK, ENEL?), AIR LIQUIDE?
	Oscillating Combustion	EU-Project				CITEPA (Pillard?)
	Dual-fuel combustion					?
	Other					
	SOx+NOx					
	Parsons Flue-gas Clean-up	BREF				(BREF Ref)
	CFB (flue-gas recirculating fluidized bed)	BREF				Alstom Lurgi, EDF/SNET?
	US gas-phase oxidation process	BREF				(BREF Ref)
	Limestone Injection Multistaged Burner (LIMB)	EU-Project	x			
	SOx-NOx-Rox-Box (SNRB)	EU-Project	x			
	Other					
	PM					
	Advanced PM1 Agglomeration ESP	EU-Project				EDF? VGB?
	Acoustics agglomeration					EDF? VGB? IFARE
	Other					
	CO2 Capture					ADEME
	Chemical solvent scrubbing	EU-Project	x			
	Physical solvent scrubbing	EU-Project				
	Adsorption	EU-Project				
	Membranes					
	Cryogenics					
	Direct air capture technology for CO2	EU-Project				
	Other					
	CO2 Storage					ADEME
	Enhanced Coal Bed Methane (ECBM)	EU-Project				
	Enhanced Gas Recovery: CO_2-EGR	EU-Project	x			
	Enhanced Oil Recovery: CO_2-EOR	EU-Project	x			
	Deep Saline Aquifer	EU-Project	x			
	Depleted Oil and Gas Reservoirs					
	Unmineable coal beds					
	Mineralization					
	Other					
II Emerging Applications of Existing Abatement Techniques						
	PM					
	SO3 injection					SNET? EDF? VGB? BOT
IIIa Improvement of Existing Technologies						
	Coal: Pulverised Coal (PC)	BREF		x	x	
	Coal: Circulating Fluidised bed combustion (CFBC)	BREF				Belgium
	Coal: Pressurised fluidised bed combustion (PFBC)	BREF	x			
	Coal: Co-generation (CHP)	BREF				(BREF Ref)
	Oil: Combined cycle combustion (repowering)	BREF		x		EDF?
	Gas: Gas turbines	BREF		x		

	Gas: Gas fired boilers and heaters	BREF			x	
	Gas: Combined cycle	BREF		x		EDF?
	Gas: Co-generation (CHP)	BREF		x		
	Biomass : co-combustion			x (waste)		VGB?
	Liquid fuels: Co-generation (CHP)	BREF				(BREF Ref)
	Other					
	Pulverized Coal Firing, (ultra) supercritical (PCF - USC),		x			
	Pressurized Pulverized Coal Combustion (PPCC)		x			VGB?
	IGCC with tar gasification	BREF refineries		x?		EDF? Bref refineries? Concawe?
IIIb Improvement of Existing Abatement Techniques						
	PM2.5					EDF? expert group on PM?
	Electrostatic precipitators (ESP)	BREF		x	x	
	Wet electrostatic precipitators	BREF				VGB?
	Fabric filters (baghouses)	BREF		x	x	
	Centrifugal precipitation (cyclones)	BREF			x	
	Wet scrubber	BREF				EDF?
	Other					
	Fuel exchange				x	
	Burner exchange or combustor modification				x	
	Reconstruction of boilers or stacks				x	
	SO2					EDF?
	Low sulphur fuels or fuels with basic ash	BREF		x	x	
	Adsorbents in fluidised bed combustion	BREF			x	
	Wet lime/limestone scrubbers	BREF		x	x	VGB
	Jet bubbling reactor			x		
	Seawater scrubber	BREF				EDF? EGTEI expert? Alstom?
	Magnesium wet scrubber	BREF				Alstom?
	Ammonia wet scrubber	BREF				Alstom?
	Spray dry scrubbers	BREF			x	
	Furnace sorbent injection	BREF			x	
	Duct sorbent injection (dry FGD)	BREF		x	x	
	Hybrid sorbent injection	BREF				
	Circulating fluid bed (CFB) dry scrubber	BREF				
	Magnesium oxide process	BREF		x		
	Other					
	Fuel exchange				x	
	Burner exchange or combustor modification				x	
	Reconstruction of boilers or stacks				x	
	NOx					
	Low excess air	BREF				EDF?
	Air staging (biased burner firing (BBF))	BREF				(BREF Ref)
	BoostedOFA			x		
	Air staging (burners out of service (BOOS))	BREF		x		
	Air staging (overfire air (OFA))	BREF		x		
	Flue-gas recirculation	BREF		x		
	Reduced air preheat	BREF				(BREF Ref)
	Fuel staging (reburning)	BREF	x background doc)			
	Air-staged low NOx burner	BREF		x		
	Flue-gas recirculation low NOX burner	BREF		x		
	Fuel-staged low NOX burner	BREF	x background doc)			Babcock, Pillard?
	Selective catalytic reduction (SCR) for conventional boilers	BREF		x		VGB, EDF?
	SCR for gas combined cycle plants			x		Egtei expert (austria)
	Selective non-catalytic reduction (SNCR)	BREF		x		
	Hybrid SCR and SNCR for conventional boilers			x		
	Other					
	Fuel exchange				x	
	Burner exchange or combustor modification				x	
	Reconstruction of boilers or stacks				x	
	SO2+NOx					
	Activated carbon process	BREF				(BREF Ref)
	The NOXSO process	BREF				(BREF Ref)
	Other solid adsorption/regeneration processes	BREF				(BREF Ref)
	SNRB process	BREF	x			
	Electron beam irradiation	BREF				Research!
	Other					

7.5.6 Tables for contribution (Nathalie THYBAUD - ADEME)

Expert sub-Group on Emerging Technologies/Techniques

EGTEI

ENERGY SECTOR

Test for the Power Generation
(LCP > 500 MWth)

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Expert sub-Group on Emerging Technologies/Techniques

Data to be collected

Two types of table for contributions:

- Table for technologies focuses on environmental impact, energy efficiency, maturity, deployment horizon, …
- Table for abatement techniques: a sheet by pollutant, request for more details (CO_2 impact, applicability, penetration rate, …)

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Expert sub-Group on Emerging Technologies/Techniques

Excel sheets for abatement techniques (1/2)

	[illegible]	[illegible]	[illegible]				[illegible]		[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
		%	%	%	%	%	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]										
[illegible]										
[illegible]										

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Expert sub-Group on Emerging Technologies/Techniques

Excel sheets for abatement techniques (2/2)

	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]		
			%	%	%	%		%	[illegible]		[illegible]	[illegible]
Emerging abatement techniques												
New application of existing abatement techniques												
Improvement of existing abatement techniques												

LCP2030 sub-Group - Angers – October 1st, 2007

Expert sub-Group on Emerging Technologies/Techniques

Excel sheets for abatement technologies (1/2)

	[illegible]	[illegible]				
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]						
[illegible]						

LCP2030 sub-Group - Angers – October 1st, 2007

Expert sub-Group on Emerging Technologies/Techniques

Excel sheets for abatement technologies (2/2)

	Energy efficiency of technology	Maturity[1]	Deployment horizon (2020, 2030)	Investment costs		Fixed operating costs	Variable operating costs
	%			M€/MW_{th}		M€/MW_{th}	M€/MWh_{th}
Emerging technologies							
Improvement of existing technologies							
…							
…							

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Expert sub-Group on Emerging Technologies/Techniques

Next steps

Identification of the future experts contributions

If necessary, interview of other experts

Contributions expected for the 3rd meeting: January 2008

- Draft report (January 2008)

4th meeting: March 2008

- Final report (April 2008)

LCP2030 sub-Group - Angers – October 1st, 2007

Annexes 7.6

Documents from the 3rd meeting – 25 January 2008

7.6.1 Agenda

25th January 2008

ENEA - EU Liaison Office - Rue de Namur 72 - 1000 BRUXELLES

Chairman: Gwénaël Guyonvarch

Time schedule	Session
9:30-10:00	Welcome of participants
10:00-10:10	Agenda of the meeting (Gwénaël Guyonvarch)
10:10-10:40	Objectives and work in progress (Nathalie Thybaud)
10:40-12:30	Presentation of the first contributions and discussion (all participants)
12:30-14:00	Lunch
14:00-15:30	Planning and identification of next contributions (all participants)
15:30-16:00	Conclusion and next steps (Gwénaël Guyonvarch)

7.6.2 Meeting report

Participants

Mrs Nadine ALLEMAND (CITEPA),
Mr Mark Barret (UCL University College London),
Mr Jean-Guy BARTAIRE (Co-chairman of EGTEI, EDF),
Mr Giorgio BILIATO (EDIPOWER s.p.a.),
Mr Phil CAHILL (RWE npower),
Mr Gwénaël GUYONVARCH (ADEME),
Mr Michael HIETE (IFARE),
Mr Pierre KERDONCUFF (IFARE),
Mr Peter MEULEPAS (Ministry of the Flemish Region, Environmental Administration),
Mrs Carole Ory (EDF),
Mr Tiziano Pignatelli (Co-chairman of EGTEI, ENEA),
Mrs Simone SCHUCHT (INERIS),
Mrs Nathalie THYBAUD (ADEME).

Mr Jean-Pierre RIVRON, Mr Jacek GADOWSKI, Mr Mats LINDGREN, Mr Hartmut KRUGER, Mr Hein DE WILDE, Mrs Anna KRIZOVA, Mrs Julie GILLES were excused.

Background

The LCP2030 subgroup had its kick-off meeting on 7 June 2007 in Paris and its second meeting on 1 October 2007 in Angers. The aim of the subgroup is to provide techno-economic information about i) emerging technologies, ii) emerging abatement techniques, iii) emerging applications of existing abatement techniques, iv) improvements of existing technologies and v) improvement of existing abatement techniques in the sector of large combustion plants (LCP), i.e. >500 MWth, until 2030.

Context

The 3rd meeting was hosted by ENEA in Brussels and chaired by G. GUYONVARCH. In his introduction G. GUYONVARCH explained the background of the LCP2030 subgroup and the schedule of the LCP2030 subgroup (cf. presentation). In order to present the work done by the LCP2030 subgroup at the WGSR meeting in April 2008 it is important to send the documents to EGTEI at the end of March (however, as the minimum period of 90 days in advance to allow for translations into French and Russian is not met, this presentation can be only informal). It was decided to make a presentation for the WGSR but not to provide a document or to provide just an informal document. To be on schedule contributions are therefore expected by the end of February (see below).

In the following presentation N. THYBAUD reminded the general aims of the subgroup (see attachment). Then, she explained the current status of work. A methodology and a list of possible technologies and techniques have already been developed by the subgroup. Furthermore, during the last meeting in Angers the technologies and techniques were prioritised and organisations willing to provide information on the technologies/techniques were determined. So far contributions were provided on Carbon Capture and Sequestration (ADEME), on several techniques/technologies (JP Rivron) and on SO_x-NO_x-Rox-Box, LIMB and Catalytic Combustion (IFARE).

Results of the discussion

The group went through the technologies/techniques list including the promised contributions, and updated it when necessary (see attachment).

N. THYBAUD presented the contribution for Carbon Capture and Sequestration (CCS). It was proposed to focus on selected technologies/techniques only.

M. HIETE gave a presentation on contributions for SO_x-NO_x-Rox-Box, LIMB and Catalytic Combustion. As a result of the discussion SO_x-NO_x-Rox-Box is not considered anymore as a priority. Main problems are hazardous waste as by-product and rather low abatement efficiencies. LIMB is also not a priority anymore as it has problems in terms of reliability and mediocre abatement efficiency. Catalytic combustion is not considered within the scope of the LCP2030 group, as application for >500 MWth seems unlikely.

M. BARRETT presented results of a study prepared for the NGO Acid Rain in which the costs and health benefits of reducing air emissions from power plants in Europe were analysed. In the study, costs to achieve BAT level were determined for each power plant. The effects on electricity production costs were also analysed. The study shows among other things that a few power plants in Europe emit a large part of NO_x and SO_2 emissions in Europe.

The 4th meeting of LCP2030 subgroup will take place on Monday, March 17th, 2008 in Paris at CITEPA and the 5th meeting on Monday, April 28th, 2008 in Stockholm. The contributions about technologies/techniques are expected before the end of February. A draft report should be presented to WGSR in April 2008. The final report is expected by June 2008 and will be presented during the WGSR meeting in September 2008.

7.6.3 Status of the work (Nathalie THYBAUD - ADEME)

Expert sub-Group on Emerging Technologies/Techniques

EGTEI

ENERGY SECTOR

Test for the Power Generation (LCP > 500 MWth)

LCP2030 sub-Group - Brussel – January 25th, 2008

Expert sub-Group on Emerging Technologies/Techniques

Objective of the LCP2030 sub-group

Provide technical and economical information for modelling work on:

- **New technologies and abatement techniques**
- **Improvement:**
  - **New applications of existing abatement techniques**
  - **Technical improvements of existing technologies and abatement techniques**

LCP2030 sub-Group - Brussel – January 25th, 2008

Expert sub-Group on Emerging Technologies/Techniques

Objective of the LCP2030 sub-group

Focus on:

- **LCPs > 500 MWth**
- **Primary and secondary measures**
- **PM, SOx, NOx and CO_2 abatement**

Estimate the CO_2 emissions due to abatement techniques

LCP2030 sub-Group - Brussel – January 25th, 2008

Expert sub-Group on Emerging Technologies/Techniques

October 1st meeting conclusions

Ranking of the technologies and techniques (first priority, secondary, cancelled)

Expected contributions listed:

- **from LCP2030 members**
- **from other experts**

Frame of contributions finalized (with guideline document)

LCP2030 sub-Group - Brussel – January 25th, 2008

Expert sub-Group on Emerging Technologies/Techniques

Schedule

January 25th 2008:	3rd LCP2030 meeting in Brussels - presentation of contributions - planning of other contributions and interview of other experts
March 2008:	finalize contributions
April 2008:	presentation of a draft to the WGSR
May 2008:	4th LCP2030 meeting (in Poland ?)
June 2008:	finalize document in English
September 2008:	(translate the document in Russian and French if resource found and present it to the WGSR)

LCP2030 sub-Group - Brussel – January 25th, 2008

Expert sub-Group on Emerging Technologies/Techniques

New schedule

End of February	Contributions expected
March 17th 2008	4th LCP2030 meeting (CITEPA - Paris)
March 2008:	finalize contributions
April 28th 2008	5th LCP2030 meeting (Stockholm)
April 2008:	presentation of a draft to the WGSR
June 2008:	finalize document in English
September 2008:	(translate the document in Russian and French if resource found and present it to the WGSR)

LCP2030 sub-Group - Brussel – January 25th, 2008

Expert sub-Group on Emerging Technologies/Techniques

List of emerging technologies (first priority)

Technology prioritised by the sub-group	Comment	Contributor
Lignite predrying with low temperature heat	first priority due to importance in Germany (CO2); VGB document	VGB
Low grade coal pre-processing	added to the list as a priority; US-technology; maybe interesting for Poland	BOT?
Underground gasification of coal	added to the list as a priority; Australian technology; maybe interesting for Poland	BOT?
IGCC (coal)	considered as still emerging as not yet commercial even though two plants (Netherlands, Spain) exist	IFARE, EDIPOWER, EDF, BOT?
IGCC (biomass)		EDF?, Sweden?
Co-Combustion (Waste/Biomass)		EDIPOWER, EDF?, EnBW?
Oxycombustion		IFARE, VGB

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Expert sub-Group on Emerging Technologies/Techniques

List of emerging abatement techniques (first priority)

Technique prioritised by the sub-group	Comment	Contributor
SO2		
Flowpac	only 1 pilot plant (ALSTOM)	IFARE, Sweden?, ALSTOM?
Limestone Injection Dry Scrubbing (LIDS)		IFARE
Duct Sorbent Injection - Coolside	mostly smaller plants or plants operating 2000-3000 h/year	IFARE, VGB, BOT
NOx		
Oxygen Enhanced Low-NOx Technology	given higher priority	AIR LIQUIDE?
Oxy-fuel combustion	added to the list with first priority; also VGB document?	EDIPOWER (Babcock UK, ENEL?), AIR LIQUIDE?
Oscillating Combustion		CITEPA (Pillard?)
Dual fuel combustion	added to the list with first priority; example in Japan (VGB?)	?

LCP2030 sub-Group - Brussel – January 25th, 2008

Expert sub-Group on Emerging Technologies/Techniques

List of emerging abatement techniques (first priority)

Technique prioritised by the sub-group	Comment	Contributor
SOx+NOx		
CFB (flue-gas recirculating fluidized bed)	changed from Lurgi CFB; given higher priority	ALSTOM, Lurgi, EDF/SNET?
US gas-phase oxidation process	given higher priority	(BREF Ref)
Limestone Injection Multistaged Burner (LIMB)		IFARE
SOx-NOx-Rox-Box (SNRB)		IFARE
PM		
Advanced PM1 Agglomeration ESP / ultrasonic acoustic agglomeration	given higher priority; so far no plants in Europe but might be interesting in future; originally developed for nuclear plants	EDF?, VGB?, IFARE?
CO2 Capture and Storage (CCS)		ADEME

LCP2030 sub-Group - Brussel – January 25th, 2008

Expert sub-Group on Emerging Technologies/Techniques

List of emerging applications of existing abatement techniques (first priority)

Technique prioritised by the sub-group	Comment	Contributor
SO3 injection (PM abatement)	formerly when ESP was not yet effective enough SO3 was injected; nowadays emerging for smaller PM ???	SNET? EDF? VGB? BOT

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Expert sub-Group on Emerging Technologies/Techniques

List of existing technologies improvement (first priority)

Technology prioritised by the sub-group	Comment	Contributor
Coal: Pulverised Coal (PC)		EDIPOWER, Czech Republic
Coal: Circulating Fluidised bed combustion (CFBC)		Belgium
Coal: Pressurised fluidised bed combustion (PFBC)		IFARE
Gas: Gas turbines		EDIPOWER
Gas: Gas fired boilers and heaters		Czech Republic
Gas: Combined cycle		EDIPOWER, EDF?
Gas: Co-generation (CHP)		EDIPOWER
Biomass: co-combution	added to the list with first priority	VGB?, EDIPOWER (waste)
Pulverized Coal Firing, (ultra) supercritical (PCF - USC)		IFARE
Pressurized Pulverized Coal Combustion (PPCC)		IFARE, VGB?
IGCC with tar gasification	added to the list with first priority	EDF?, BREF Refineries, CONCAWE?

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Expert sub-Group on Emerging Technologies/Techniques

List of existing abatement techniques improvement (first priority)

Technique prioritised by the sub-group	Comment	Contributor
PM		EDF?
Electrostatic precipitators (ESP)		EDIPOWER, Czech Republic, VGB?
Fabric filters (baghouses)		EDIPOWER, Czech Republic
Centrifugal precipitation (cyclones)		Czech Republic
Fuel exchange		Czech Republic
Burner exchange or combustor modification		Czech Republic
Reconstruction of boilers or stacks		Czech Republic

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Expert sub-Group on Emerging Technologies/Techniques

List of existing abatement techniques improvement (first priority)

Technique prioritised by the sub-group	Comment	Contributor
SO2		
Low sulphur fuels or fuels with basic ash		EDIPOWER, Czech Republic
Adsorbents in fluidised bed combustion		Czech Republic
Wet lime/limestone scrubbers		EDIPOWER, Czech Republic
Jet bubbling reactor	added to the list with first priority	EDIPOWER
Spray dry scrubbers		Czech Republic
Furnace sorbent injection		Czech Republic
Duct sorbent injection (dry FGD)		EDIPOWER, Czech Republic
Magnesium oxide process		EDIPOWER
Fuel exchange		Czech Republic
Burner exchange or combustor modification		Czech Republic
Reconstruction of boilers or stacks		Czech Republic

LCP2030 sub-Group - Brussel – January 25th, 2008

Expert sub-Group on Emerging Technologies/Techniques

List of existing abatement techniques improvement (first priority)

Technique prioritised by the sub-group	Comment	Contributor
NOx		
Air staging (burners out of service (BOOS))		EDIPOWER
Air staging (overfire air (OFA))		EDIPOWER
Flue-gas recirculation		EDIPOWER
Air-staged low NOx burner		EDIPOWER
Flue-gas recirculation low NOx burner		EDIPOWER
Selective catalytic reduction (SCR) for conventional burners		EDIPOWER, VGB, EDF?
Selective catalytic reduction (SCR) for gas combined cycle plants	added to the list with first priority	EGTEI expert (Austria)
Hybrid SCR and SNCR for conventional burners	not economic due to ammonia slip	EDIPOWER
Fuel exchange		Czech Republic
Burner exchange or combustor modification		Czech Republic
Reconstruction of boilers or stacks		Czech Republic

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Expert sub-Group on Emerging Technologies/Techniques

Work in progress

Contributions expected by the end of December

Contributions from:

- **IFARE (LIMB, SNRB, …)**
- **J-P RIVRON (Efficiency improvement, SCR, FGD from VGB document – data to be validated by VGB)**
- **ADEME (CO_2 capture)**

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7.6.4 Contribution on Carbon Capture and Storage (CCS) (Nathalie THYBAUD - ADEME)

Expert sub-Group on Emerging Technologies/Techniques

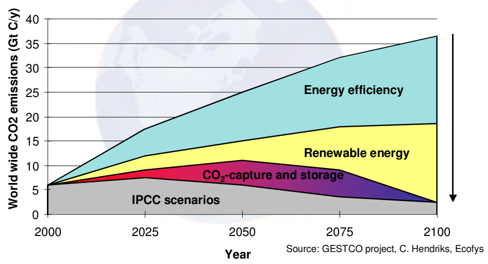
CO_2 capture and storage (CCS)

Techno-economic studies

LCP2030 sub-Group - Brussel – January 25th, 2008

Expert sub-Group on Emerging Technologies/Techniques

Role of CCS for limiting GHG in the atmosphere



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Cost of CCS

How much it costs to avoid a tonne of carbon dioxide entering the atmosphere?

US$/t CO_2 avoided	Natural Gas Combined Cycle reference plant	Pulverized Coal reference plant
Power plant with capture and geological storage		
Natural Gas Combined Cycle	40-90	20-60
Pulverized Coal	70-270	30-70
Integrated Gasification Combined Cycle	40-220	20-70

IPCC Special Report on Carbon Dioxide Capture and Storage, September 2005

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Cost of CCS (2)

Costs of Enhanced Oil Recovery instead of normal geological storage can be obtained by subtracting:

- **20 to 30 US$/t CO_2**

How much CCS would increase the cost of electricity, compared to current prices?

- **0.02 to 0.03 US$/kWh**

IPCC Special Report on Carbon Dioxide Capture and Storage, September 2005

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Cost of CCS and efficiency penalty

Cost of CCS mainly due to CO_2 capture cost (70% of the CCS costs)

Efficiency drop

- **11 to 22% for Natural Gas Combined Cycle power plants**
- **14 to 25% for IGCC**
- **24 to 40% for Pulverized Coal power plant with supercritical steam cycle**

IPCC Special Report on Carbon Dioxide Capture and Storage, September 2005

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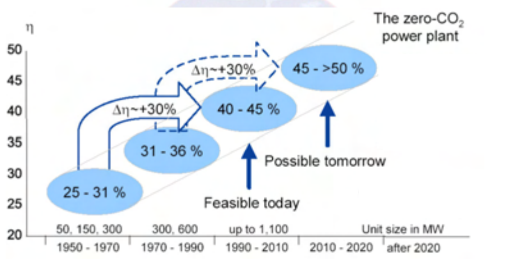
Increased efficiency is necessary for CCS



Eurocoal

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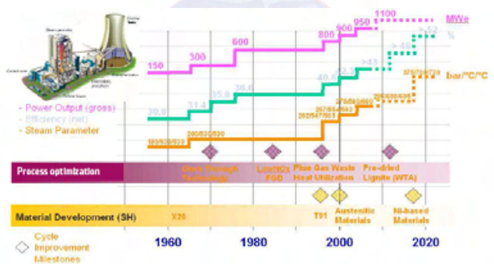
Advanced cycle for new power plants



Alstom

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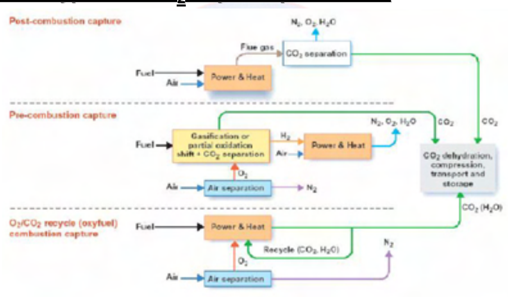
Three types of CO_2 capture processes



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Post-combustion capture

Consist of separating the CO_2 from the exhaust gases using a solvent for example. The most advanced technology today.

Post-combustion capture solutions:

- **absorption (amine, chilled ammonia …)**
- **adsorption**
- **frosting/defrosting at low temperature**
- **…**

CO_2 frosting on the evaporator fins.

Liquid CO_2 after defrosting.

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Oxy-combustion capture

Consist of burning a fuel in oxygen instead of air. The gases produced by the oxy-combustion process are mainly water and CO_2, which is easy to capture at the end of the process

A new and promising form of oxy-combustion:

- **chemical looping**

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Pre-combustion capture

Gasification of a fuel rich in carbon (coal for example) into a synthetic gas (carbon monoxide and hydrogen)

Several stages of transformation and purification are then needed to transform the gas, remove the CO_2 and obtain a stream of pure hydrogen that can then be burned in a combined cycle power station

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CCS deployment

Proposition of ZEP Technology Platform:

- **up to 12 large-scale demonstration plants with CCS built by around 2015 with the objective of developing CCS until 2020**

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Expert sub-Group on Emerging Technologies/Techniques

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)

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Expert sub-Group on Emerging Technologies/Techniques

Comparison with and without CO_2 capture and costs of avoiding CO_2 emissions

	Without capture	With capture	Difference due to capture
Plant performance			
Fuel input, MW (LHV)	1729	1729	0
Gross power output, MW	842	758	-84
Ancillary power consumption and losses, MW	50	148	98
Net power output, MW	792	610	-182
Efficiency and emissions			
Thermal efficiency, % (LHV)	45.8	35.3	10.5
Increase in fuel use per kWh, %			30
CO_2 capture efficiency, %		85	
CO_2 emissions, g/kWh	872	170	702
CO_2 captured, g/kWh		962	
Costs			
Capital cost, €/kW net power	1006	1567	561
Electricity cost, €c/kWh (excluding CO_2 storage)	3.46	5.39	1.93
Cost of CO_2 avoidance, €/tCO_2 (excluding storage)			27.5

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

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Expert sub-Group on Emerging Technologies/Techniques

More performances and costs data in excel sheets

Next steps:

- **homogenize data (units)**
- **consolidate data with new studies or interview of experts**

LCP2030 sub-Group - Brussel – January 25th, 2008

7.6.5 Contributions on SNRB, LIMB and catalytic combustion (Michael HIETE - IFARE)

EGTEI- Emerging Technologies sub-Group

Current Status of Work

Ia Emerging Abatement Techniques

1- So_x-No_x-Rox Box (SNRB)

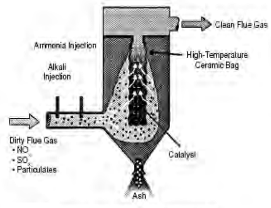
2- Limestone Injection Multistage Burner (LIMB)

Ib Emerging Abatement Technologies

1- Catalytic Combustion

Ia/ SO_x-NO_x-Rox BOx (SNRB TM)

- **Technology**
  SO_x-NO_x-Rox Box™ (SNRB™) process (Babcock & Wilcox)
- **Pollutants**
  SO_2, NO_x and particulates
- **Process description**
  Process that combines hydrated lime and ammonia injection upstream of hot catalytic baghouse (box) where the solid product calcium sulphite and sulphate and particulate (Rox) are removed, and the NOx is reduced to nitrogen and water .



The SO_x-NO_x-Rox Box (SNRB) process.

Implementation experience

- **Location**
  Dilles Bottom, Belmont County, OH (Ohio Edison Company's R.E. Burger Plant, Unit No. 5)
- **Year/ Scale**
  1995 / Pilot
- **Capacity/Production**
  5-MWel
- **Coal :**
  Bituminous coal blend, 3.7% S

Ia/ SO_x-NO_x-ROx BOx (SNRB TM)

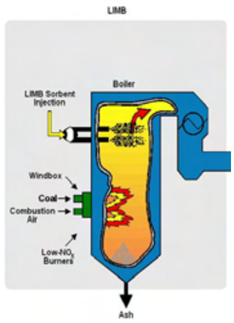
	Short description (technical description, type of fuel,...)	NOx: Abatement efficiency (%)	NOx: Abated emission factor (g/GJ fuel input)	Impact on other emissions – SO_2: Abatement efficiency (%)	SO_2: Abated emission factor (g/GJ fuel input)	TSP: Abatement efficiency (%)	TSP: Abated emission factor (g/GJ fuel input)	Other pollutant (to be precised): Abatement efficiency (%)	Other pollutant: Abated emission factor (g/GJ fuel input)	Energy consumption of the technique: Electricity (kWh/GJ fuel input)	Fossil fuel (to be precised) (MJ/GJ fuel input)	CO2-e impact[1] (from energy consumption) (tCO_2/GJ fuel input)	Equipment lifetime (year)	Maturity[2]
Emerging abatement techniques														
Sox-Nox-Rox-Box (SNRB)	Process that combines hydrated lime and ammonia injection upstream of hot catalytic baghouse (box) where the solid product calcium sulphite and sulphate and particulate (Rox) are removed, and the Nox is reduced to nitrogen and water.	90		80-90		99,99		HF 84 HCL 95						2

Deployment horizon (2020, 2030)	Penetration rate[3] (at the deployment horizon): For new plants (%)	Penetration rate: For existing plants (%)	Applicability rate[3] (at the deployment horizon): For new plants (%)	Applicability rate: For existing plants (%)	Type of potential implementation	Retrofit factor for existing plants (to be included in investment costs of existing plants) (%)	Investment ($M€/MW_{th}$): For new plants	Investment: For existing plants	Fixed operating costs ($M€/MW_{th}$)	Variable operating costs ($M€/MWh_{th}$)	Source of data	Remarks
											B&W technical paper, Paul S. Nolan, Flue Gas Desulphurization technologies for coal-fired Power Plants, January 2000 U.S Department of Energy, Assistant Secretary for Fossil Energy, EPRI, Clean Coal Technology Programs – Program Update 2003, December 2003	Commercialisation of the technology is expected to develop with an initial larger scale application equivalent to 50-100MWe

No information is available wether this process is actually applied to a large combustion plant. Therefore, no information on the general performance of the SNRB process can be given

Ib/ Limestone Injection Multistage Burner (LIMB)

- **Technology**
  limestone injection multistage burner (LIMB) system(Babcock & Wilcox)
- **Pollutants**
  SO_2
- **Process description**
  Injection of a sorbent (limestone) within certain windows, within a boiler's time temperature prrofile.



Implementation experience

- **Location**
  Lorain, Lorain County, OH (Ohio Edison's Edgewater Station, Unit No. 4)
- **Year/ Scale**
  1992/ full-scale
- **Capacity/Production**
  105 MWel
- **Coal :**
  Ohio bituminous, 1.6, 3.0, and 3.8% S

Ib/ Limestone Injection Multistage Burner (LIMB)

	Short description (technical description, type of fuel,...)	NOx: Abatement efficiency (%)	NOx: Abated emission factor (g/GJ fuel input)	Impact on other emissions – SO_2: Abatement efficiency (%)	SO_2: Abated emission factor (g/GJ fuel input)	TSP: Abatement efficiency (%)	TSP: Abated emission factor (g/GJ fuel input)	Other pollutant (to be precised): Abatement efficiency (%)	Other pollutant: Abated emission factor (g/GJ fuel input)	Energy consumption of the technique: Electricity (kWh/GJ fuel input)	Fossil fuel (to be precised) (MJ/GJ fuel input)	CO2-e impact[1] (from energy consumption) (tCO_2/GJ fuel input)	Equipment lifetime (year)	Maturity[2]
Emerging abatement techniques														
Limestone Injection Multistage Burner (LIMB)	Initially, limestone was injected through staged Low-NOx burners. Studies have shown that moderate levels of SO2 emission control were possible by injecting sorbent within certain windows within a boiler's time-temperature profile	40-50		65-70										3

Deployment horizon (2020, 2030)	Penetration rate[3] (at the deployment horizon): For new plants (%)	Penetration rate: For existing plants (%)	Applicability rate[3] (at the deployment horizon): For new plants (%)	Applicability rate: For existing plants (%)	Type of potential implementation	Retrofit factor for existing plants (to be included in investment costs of existing plants) (%)	Investment ($M€/MW_{th}$): For new plants	Investment: For existing plants	Fixed operating costs ($M€/MW_{th}$)	Variable operating costs ($M€/MWh_{th}$)	Source of data	Remarks
											B&W technical paper, Paul S. Nolan, Flue Gas Desulphurization technologies for coal-fired Power Plants, January 2000 U.S Department of Energy, Assistant Secretary for Fossil Energy, EPRI, Clean Coal Technology Programs – Program Update 2003, December 2003	LIMB has been sold to an independant power plant in Canada. The low -No_x burners have an estimated value of 388 million (dollars)

Ib/ Catalytic combustion

- Technology that combusts fuel flamelessly
- Pilot scale 1.5 MWel gas turbine
- Plants for application on a 170 MWel gas turbine are being developed
- No_x levels of less than 10 mg/Nm3 are expected

Ib/ Catalytic combustion

	Short Description (technical description, type of fuel, thermal power ...)	Environmental Impact: NO_x emission factor (g/GJ fuel input)	SO_2 emission factor (g/GJ fuel input)	TSP emission factor (g/GJ fuel input)	other (to be precised) (g/GJ fuel input)	CO_2 emission factor (kg/GJ fuel input)	Technology Efficiency (%)	Maturity[1]
Emerging technologies								
Catalytic Combustion	Technology that combusts fuel flamelessly and has a lower peak of temperature							2

Deployment horizon (2020, 2030)	Investment ($M€/MW_{th}$)		Fixed operating costs ($M€/MW_{th}$)	Variable operating costs ($M€/MWh_{th}$)	Source of data	Remarks
					On the Technical and Economic Issues Involved in the Co-Firing of Coal and Waste in a Conventional PF-Fired Power Station, S.N. Ireland, B. Mcgrellis, N. Harper, Fuel 83, Elsevier Ldt., 2004 Design Concept to Reduce Fuel Nox in Catalytic Combustion of Gasified Biomass, J.C.G. Andrae, P.H. Björnbom, P. Glarborg, AIChE Journal, vol. 49 , no 8 , pp. 2149 - 2157 [9 pages.], August, 2003 Reference Document on Best Available Techniques for Large Combustion Plants, Integrated Pollution Prevention and Control, July, 2006	Catalytic combustion has been demonstrated only at pilot scale on a 1.5 Mwe gas turbine. Plants for application on a 170 Mwe gas turbine are being developed.

Annex 7.7

Documents from the 4th meeting – 17 March 2008

7.7.1 Agenda

17th March 2008

CITEPA - 7 Cité Paradis - 75010 Paris

Chairman: Gwénaël Guyonvarch

Time schedule	Session
9:30-10:00	Welcome of participants
10:00-10:10	Agenda of the meeting (Gwénaël Guyonvarch)
10:10-10:30	Schedule and state of progress (Nathalie Thybaud)
10:30-12:30	Presentation of the contributions and discussion (all participants)
12:30-14:00	Lunch
14:00-14:30	Presentation of the contributions and discussion (all participants)
14:30-15:30	Informal report for presentation to WGSR (April 2008)
15:30-16:00	Conclusion and next steps (Gwénaël Guyonvarch)

7.7.2 Meeting report

Participants

Mrs Nadine ALLEMAND (CITEPA),
Mr Giorgio BILIATO (EDIPOWER s.p.a.),
Mr Phil CAHILL (RWE npower),
Mr Gwénaël GUYONVARCH (ADEME),
Mr Pierre KERDONCUFF (IFARE),
Mr Hartmut KRUGER (VGB)
Mr Mats LINDGREN (Swedish Environment Agency)
Mr Peter MEULEPAS (Ministry of the Flemish Region, Environmental Administration),
Mrs Carole Ory (EDF),
Mr Tiziano Pignatelli (Chairman of EGTEI, ENEA),
Mr Jean-Pierre RIVRON,
Mrs Dorothée ROSTAL (IFARE)
Ms Kristina SAARINEN (SYKE, Finland)
Mrs Simone SCHUCHT (INERIS),
Mrs Nathalie THYBAUD (ADEME).

Background

The LCP2030 subgroup had its kick-off meeting on June 7th 2007 in Paris and on March 17th the fourth meeting was held. The subgroup aims at providing techno-economic information about i) emerging technologies, ii) emerging abatement techniques, iii) emerging applications of existing abatement techniques, iv) improvements of existing technologies and v) improvement of existing abatement techniques in the sector of large combustion plants (LCP), i.e. >500 MWth, until 2030.

Presentations and discussions

The fourth meeting was hosted by France in Paris and chaired by G. GUYONVARCH. In his introduction G. GUYONVARCH reminded of the background of the LCP2030 subgroup and the schedule of the LCP2030 subgroup (cf. presentation).
The subgroup has to keep in mind the necessity to report to the next WGSR in September 2008. The documents are expected to be finished in June 2008 to enable translation in time. A short summary will be presented by the LCP2030 subgroup at the WGSR meeting in April 2008.

A state of progress of collected data was presented by different contributors:

H. KRUGER provided numerous documents to the sub-group. One of them concerns the CO_2 abatement options for a pulverised coal combustion plant. The reference efficiency for combustion plants in the EU 27 accounts for 36%. Improvement due to the application of several techniques described by H. KRUGER enables to achieve an efficiency of 50%. As a result of the reduction of energy consumption CO_2, NO_x and PM emissions can be reduced. Those techniques are described in the document and refer to a study carried out in 2004, "Concept study reference power plant North Rhine Westphalia".

As the group is working for UNECE, it was asked to try to define to what extent the emerging technologies could be used outside the EU. This should depend on stringency of regulations.

Costs of reduction increased in high proportion within recent years due to an increase in raw material costs and the huge demand in building of new capacities both from China and the EU to renew the old fleet of plants. It was recommended to provide the associated year to the respective estimation of costs. The definition of life time was also discussed as discrepancies may occur between LCP 2030 experts and IIASA which consider 30 years.

JP RIVRON made a presentation based on data provided by VGB. He presented very interesting figures on the dependency between plant sizes and costs of reduction techniques for SCR, FGD. Furthermore he presented results of the study "Concept study reference power plant North Rhine Westphalia". Efficiencies and costs are provided for different emerging techniques both for PM and NO_x, e.g. new developments proposed by some manufacturers for PM reduction (indigo technique) or the flowpack system developed by Alstom for NO_x. It was noticed that for electricity producers, it is not possible to invest in techniques not associated with a large number of references. This is an obstacle for electricity producers. Techniques with only one reference cannot be chosen even if efficiency is high.

G. BILIATO presented data based on the experience of EDIPOWER such as efficiency and costs of several SO_2, PM and NO_x reduction techniques and IGCC. Costs of SCR are recognized to be very site specific. He promised some additional information, e.g. the year of investments.

D. ROSTAL provided data collected by IFARE mainly on SO_2 reduction techniques such as the flowpack technique. The acoustic agglomeration of PM will not be kept in the subgroup.

A document from the International Energy Agency could be useful for the group. Its availability will be checked.

Nathalie Thybaud still expects information from Alstom and Air liquide.

Next steps

The 5th meeting of LCP2030 subgroup will take place on Monday April 28th, 2008 in Stockholm. During this meeting the promising techniques will be validated by the group and missing data will be identified. The structure of the future report will be discussed. Nathalie Thybaud will prepare the slides and a summary of the state of progress of the study.

An informal report will be presented to WGSR in April 2008.

The final report is expected for June 2008 and will be presented during the WGSR meeting in September 2008.

7.7.3 Status of the work (Nathalie THYBAUD - ADEME)

Expert sub-Group on Emerging Technologies/Techniques

EGTEI

ENERGY SECTOR

Test for the Power Generation (LCP > 500 MWth)

LCP2030 sub-Group - Paris – March 17th, 2008

Expert sub-Group on Emerging Technologies/Techniques

Objective of the LCP2030 sub-group

Provide technical and economical information for modelling work on:

- New technologies and abatement techniques
- Improvement:
  - New applications of existing abatement techniques
  - Technical improvements of existing technologies and abatement techniques

LCP2030 sub-Group - Paris – March 17th, 2008

Expert sub-Group on Emerging Technologies/Techniques

Reporting

WGSR meeting on 14th-17th April 2008:

- informal document on work done by LCP2030 sub-group

EGTEI meeting in Stockholm on 29th April 2008

WGSR meeting on September 2008:

- final document in English and French and Russian (90 days in advance for translation)

LCP2030 sub-Group - Paris – March 17th, 2008

Expert sub-Group on Emerging Technologies/Techniques

Schedule of LCP2030 sub-group

End of February	Contributions expected
March 17th 2008	4th LCP2030 meeting (CITEPA - Paris)
End of March:	informal document for WGSR meeting on 14th-17th April 2008
End of April:	finalize contributions
April 28th 2008	5th LCP2030 meeting (Stockholm)
June 2008:	finalize document in English and then translation into Russian and French for WGSR meeting on September 2008

LCP2030 sub-Group - Paris – March 17th, 2008

Expert sub-Group on Emerging Technologies/Techniques

Conclusions on the contributions presented in Brussels on January 25th 2008

- SNRB: not considered as a priority (hazardous waste as by-product, rather low abatement efficiencies)
- LIMB: not considered as a priority (problems of reliability, mediocre abatement efficiency)
- Catalytic combustion: no application for plant > 500 MWth
- CO_2 capture: research of techno-economic data on demonstration plants

New contributions expected by the end of February

LCP2030 sub-Group - Paris – March 17th, 2008

Expert sub-Group on Emerging Technologies/Techniques

State of progress

Contribution and presentation:

- IFARE (IGCC (coal), PFBC, Flowpac)
- EDIPOWER (air staging (BOOS), SCR for conventional burners, SCR for gas combined cycle plants, wet lime/limestone scrubbers, Jet bubbling reactor, ESP, fabric filters, IGCC (coal), co-combustion (waste/biomass), combined cycle)
- J-P RIVRON (EDF data and data from VGB document (Efficiency improvement, SCR, FGD)
- VGB
- Autria (Thomas Krutzler) – SCR for gas combined cycle plants

LCP2030 sub-Group - Paris – March 17th, 2008

Expert sub-Group on Emerging Technologies/Techniques

State of progress

Pending contribution:

- Czech Republic (Andrea Krizova)
- IFARE (Flowpac, oxycombustion, LIDS, acoustics agglomeration)
- BOT (Jacek Gadowski)
- ...

LCP2030 sub-Group - Paris – March 17th, 2008

Expert sub-Group on Emerging Technologies/Techniques

State of progress

New contact:

- Air Liquide (France) – March 20th 2008
- CONCAWE (Lourens Post) – IGCC with tar gasification
- ALSTOM
- ...

LCP2030 sub-Group - Paris – March 17th, 2008

7.7.4 Contributions on $DeNO_x$ and $DeSO_x$ costs, plant costs increasing, Fine particles collector, SO_3 injection, Flowpac (Jean-Pierre RIVRON)

EGTEI Emerging Technologies sub-Group

17 march 2008

Paris meeting : Citepa

Jean-Pierre RIVRON

ESTIMATION OF DENOX AND DESOX COSTS FOR A 300 MWel HARD COAL UNIT ACCORDING VGB POWERTECH DOCUMENTS

Date of the estimation: 2006

- **Reference documents**
- DENOX-kosten var,1,2,4,5 HtKr, entw1,entw2, entw Heit and Heit.K
- Rea kosten O.xls original word document
- FGD overall costs VGB PowerTech E.doc
- Ermittlung der REA kosten Heit/Heit Kr.doc
- **Power unit characteristics**
- LCP capacity: 300 MWel / 726,4 MWth
- Efficiency (net caloric value): 41,3%
- Net caloric value of coal: 25000KJ/Kg
- Effective full load operation hours per year: 6000h
- Electrical production per year: 1,8TWh
- Coal consumption: 104,6 t/h
- Primary energy input per year: 15690 TJ
- Flue gas emission per coal Kg: 10 m3/Kg
- Flue gas flow: 1 046 005 m3/h
- Specific energy consumption: 0,9%
- Internal costs of electricity: 0,03 Euro/KWh
- NO2 concentration at DENOX inlet: 700 mg/m3
- NO2 concentration at DENOX outlet: 200 mg/m3
- S content of coal: 1%

Relation of FGD costs to the unit capacity

REA-Investitionskosten ohne Eigenleistung
(REA kosten 0.xls)
Efficiency 41,3%

Electrical capacity of the unit MWel	Thermal capacity of the unit MWth	Investment MEuro	Investment+10% for additional investor costs: engineering, foudation, connections… MEuro	FGD specific cost MEuro/MWel	FGD specific cost MEuro/MWth
Leitung in MWel					
1000	2421	60	66	0,066	0,027
800	1937	52	57,2	0,072	0,030
600	1453	43	47,3	0,079	0,033
400	968,5	32,5	35,8	0,090	0,037
300	726	27,5	30,3	0,101	0,042
200	484	20	22	0,110	0,045
100	242	12,5	13,8	0,138	0,057

RELATION OF THE SCR COSTS TO THE UNIT CAPACITY
DENOX kosten var.xls
Efficiency 41,3%

Electrical capacity of the unit MWel	Thermal capacity of the unit MWth	Investment MEuro		SCR specific cost MEuro/MWel	SCRspecific cost MEuro/MWth
Leitung in MWel					
1000	2421	58,5		0,059	0,024
800	1937	47		0,059	0,024
600	1453	35,5		0,059	0,024
400	968,5	24,1		0,060	0,025
300	726	18,3		0,061	0,025
200	484	12,6		0,063	0,026
100	242	6,8		0,068	0,028

Size effect

Electrical capacity MWel	Thermal capacity MWth	SCR investment MEuro	FGD investment MEuro	SCR specific cost MEuro/MWth	FGD specific cost MEuro/MWth	SCR size effect	FGD size effect
1000	2421	58,5	66	0,024	0,027	0,86	0,47
800	1937	47	57,2	0,024	0,030	0,86	0,53
600	1453	35,5	47,3	0,024	0,033	0,86	0,58
400	968,5	24,1	35,8	0,025	0,037	0,89	0,65
300	726	18,3	30,3	0,025	0,042	0,89	0,74
200	484	12,6	22	0,026	0,045	0,93	0,79
100	242	6,8	13,8	0,028	0,057	1	1

REFERENCE POWER PLANT RPP NRW

The following data are extracted from the VGB document « Concept study Reference Power Plant North Rhine-Westphalia (RPP NRW) (February 2004)

Brief overview

The concept of the "Reference Power Plant North Rhine-Westphalia" (RPP NRW) is based on a hard coal fired 600 MW plant with optimised plant technology and efficiency of 45,9%.Efficiency of over 48% could also be achieved with certain technical measures. However, that would require different site conditions and also different economic boundary conditions than can currently assume. With efficiency of 45,9%, the NRW reference power plant is clearly above the average of hard coal power plants currently in operation in Germany (average efficiency around 38%). Thus, its use can make a considerable contribution to attaining targets for the reduction of CO2.

This NRW Reference Power Plant study was produced with the aim of developing a concept for a sustainable hard coal-fired power plant that takes these challenges into account.

A number of innovative proposals have been included in the plant design.

The building of the RPP NRW will involve a total order volume of around Euros 480 million

RPP NRW

Price basis 2003	Fixed cost ct/KWh	Variable cost ct/KWh	Cost of electricity ct/KWh
RPP NRW Reference case	1,9	1,45	3,35
CCPP gas Combined cycle	1	2,5	3,5
MLP Modern Lignite Plant	2,3	1	3,3
700°C Plant	2,5	1,3	3,8
IGCC	2,8	1,3	4,1

Cost of generating power
No CO_2 cost impact
Gas price 1,2 ct/KWh
Price of hard coal 48 euros/t
Lignite price 31 euros/t

The volume of investments in the reference power plant RPP NRW

Aspect	Unit	Amount
Price of the plant	Euro/KW (gross)	798
Installed gross capacity	MW	600
Order volume	Million euros	478,8
Period of use	Years	35
Owner's own contribution (5% of the order volume)	Million euros	23,9
Flat rate for imponderables (3% of the order volume)	Million euros	14,4
Total sum of investment	Million euros	517,1
Specific sum of investment	Euros/KW	798x1,08=861,8

Power plant concept RPP NRW

Gross capacity	600MW
Type of boiler	Tower-type boiler with vertical tubes and steam coil air heater
Heat recovery	Utilization of mill air heat recuperation
Flue gas discharge	Discharge via cooling tower
Turbine model	H30-40/M30-63/N30-2x16m2
Main steam parameters	285 bar/600°C/620°C
Condenser pressure	45 mbar
Generator	Water/hydrogen cooling
Feed water heating stages	8 feed water heaters+external desuperheater
Feed water final temperature	303,4°C
Feed water pump concept	3x50% electric motor-driven feed water pumps, variable-speed drive with planetary gearing

Operating concept RPP NRW

The following major boundary conditions have been specified for the operating concept:

-Service life: 200 000 operating hours

-Base load for the first 15 years at 7500 h/year, then intermediate load at 5500 full load operating hours per year

-2860 starts over the entire period of usage

Preferred variant(§13 and14)

A total power plant price of 798 Euros/ KW (gross) was offered for the preferred variant (45,9% of net efficiency) (861,8 Euros/KW in taking into account +8% for owner contribution and imponderables)

	Preferred variant RPP NRW
Gross installed capacity	600MW
Net installed capacity	555,5MW
Net efficiency	45?9%
Main steam parameters	285bar/600°C/620°C
Feed water end temperature	303,4°C
Price of the plant	478,5 MEuros
Boiler type	Benson tower boiler with vertical tubes
Utilization of waste heat	Use of mill air heat
Flue gas cleaning	SRC-DENOX, electrostatic precipitator, flue flue gas desulphurisation using limestone
Flue gas discharge	Discharge via cooling tower
Steam turbine	Three-casing steam turbine with simple intermediate heating and low-pressure stages made of titanium alloy
Generator stages	Cooled by water/hydrogen
Economiser stages	Eight economisers+external desuperheater
Feed water pump concept	3x50% electric motor-driven feed water pumps , variable-speed drive with planetary gearing
Condenser pressure	45 mbar, wet closed-circuit coming via natural-draft cooling tower
Price of the plant Specific plant price	478,5 MEuros 798 Euros/KWgross

Increasing of cost in relation with net efficiency RPP NRW

Net efficiency	Total power plant price
Preferred Variant 45,9%	798 Euro/KWbrutto
45,9 to 46,1%	798 Euro/KWbrutto + Appr. 20 Euro/KWbrutto per % pt
46,1 to 46,2%	798 Euro/KWbrutto + Appr. 25 Euro/KWbrutto per % pt
46,2 to 46,5%	798 Euro/KWbrutto + Appr. 30 Euro/KWbrutto per % pt
46,5 to 47,3%	798 Euro/KWbrutto + Appr. 35 Euro/KWbrutto per % pt

Increasing of cost in relation with net efficiency RPP NRW

Efficiency	Calculation	Specific power price	Total specific power price x1,08	600 MWel plant total price
45,9%		798 Euro/KW	861,8 Euro/KW	517 MEuros
46,1%	+20 Euro/KWx0,2%= +4 Euro/KW	802 Euro/KW	866,2 Euro/KW	520 MEuros
46,2%	+25 Euro/KWx0,1%= +2,5 Euro/KW	804,7 Euro/KW	868,ç Euro/KW	521 MEuros
46,5%	+30 Euro/KWx0,3%= + 9 Euro/KW	903,7 Euro/KW	878,6 Euro/KW	527 MEuros
47,3%	+ 35 Euro/KWx0,8%= + 28 Euro/KW	931,7 Euro/ KW	908,8 Euro/KW	545,3 MEuros

PLAN COSTS INCREASINGS

Precautions to take when talking about plant costs

It is always difficult to talk about costs and to compare costs, because a lot of parameters impact plant costs; following are some parameters which have to be taken into account:

-New plant or existing plant
-Different kinds of costs
-Conditions and performances of depollution
-Size effect
-Series effect

Evolutions of costs

Boiler costs (and depollution systems) have multiplied by 1, 5 to 2 between 2003 and 2007; these are two main reasons for the increase:

-Increasing of steel costs

For example, the increase of the cost of steel was +54% between 2000 and 2007.

-Market tension

The small number of depollution manufacturers and the proximity of the regulatory term (2015) to apply LCP Directive regulation increase the market tension on the prices of the depollution systems and also on the new plant prices.

Conclusion

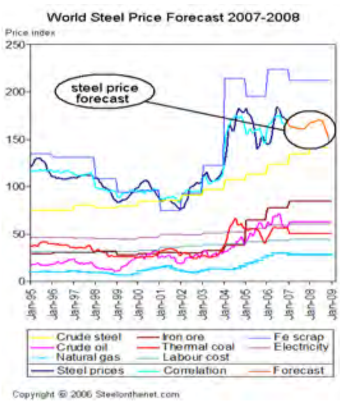
Costs can only be meanfull when fixed in the real context. The costs given in the following tables have to be considered estimated.

-Increasing of steel costs

For example, the increase of the cost of steel was +54% between 2000 and 2007. (+58% during year 2007). This steel price is correlated with ferrous scrap prices and energy prices.

The lowest recent price was is in January 2002 (price index 80). The price index in January 2008 is 160; steel price has doubled.

Considering that a large part of the cost of a plant is dependant on steel prices, this shows how difficult it is to compare depollution prices at different periods.
An other example of cost increase is the SCR catalyst price which has grown in 2 years at least by +20%.



-Market tension

The small number of depollution manufacturers and the proximity of the regulatory term (2015) to apply LCP Directive regulation increase the market tension on the prices of the depollution systems and also on the new plant prices.

This market tension explains together with the steel cost increase the global increase of costs of plants and depollution systems at present.

This market tension is felt by different ways: the classical price revision formula are no longer representative; there is no longer reduction in price if you buy several units in series; there is a market saturation until 2014 and even beyond because new countries of the European union are granted a delay in applying the European regulation. The delays to build a plant are becoming very long. Manufacturers are at present free to choose the tenders they wish to answer

SOME DEPOLLUTION SYSYEM COSTS : FGD

Unit capacity MWe	Unit efficiency %	Unit capacity MWth	Fue	Depollution lsystem	Depollution investment costs MEuros	Estimation year	Specific cost* Euro/Kwe	Specific cost* Euro/Kwth	Existing unit or new unit	Sources Comments
1000	41,3	2421	coal	FGD	66	2006	66	27	new	VGB
800		1937			57,2		72	30		VGB
600		1453			47,3		79	33		VGB
400		968,5			35,8		90	37		VGB
300		726			30,3		101	42		VGB
200		484			22		110	45		VGB
100		242			13,8		130	57		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

FINE PARTICLES COLLECTOR EMERGING TECHNOLOGIES

Technology name	Manufacturer	Technology description	Aimes	Date of implementation
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

SO3 INJECTION

- **Short description**: SO3 injection to lower particles emissions in case of combustion of high resistivity coal ashes (Le Havre 4 600MWe/1580 MWth coal fired unit in 2006)
- **Dust abatement efficiency**: average 50% with possibility of 75 to 85%
- **Dust: abated factor**: 6, 2 g/GJ fuel input
- **Electricity consumption**: 0,013 KWh/GJ fuel input
- **SO3 equipment investment** (engineering included): 0, 0007 MEuro/MWth (1, 1 MEuro)
- **Fixed operating costs**: not significant: 0, 0012 Euro/GJ
- **Variable operating cost**: not really significant; 0, 001 Euro/GJ

- ***References:***
- Le Havre 4 in 2004
- 2563 GWh (gross)
- 5737 operation hours
- 4202 full capacity equivalent operational hours
- 279 tons dust emissions
- 68 mg/m3 yearly average dust emission
- 918899 tons of coal
- 24405 KJ/Kg heating value
- 22426 TJ primary fuel input/ year 2004
- **Dust abated emission factor**
- 50% average abatement due to SO3 injection
- 139500 Kg/year
- 139500000/22426000=6, 2 g/GJ fuel input
- **SO3 system electrical consumption: 50 KW**
- 50KWx5737 hours= 286850 KWh
- 286850/22426000=0,013 KWh/GJ
- **Fixed costs**
- Maintenance: 2, 5% investment cost (estimation)
- 1, 1MEurox0, 025=27500 Euros/year
- 27500/22426000GJ=0, 0012 Euro/GJ
- **Variable costs (sulphur cost)**
- 5100 Euros/1000 full equivalent capacity operational hours
- 21400 Euros for 4202 full capacity equivalent hours (2004)
- 21400/22426000GJ=0,001 Euro/GJ

FLOWPAC

- **Description**
- Flowpac process is a wet desulphurisation process developed by ALSTOM. It is a turbulent bubble bed reactor. The flue-gas is injected into a slurry through numerous submerged pipes while limestone slurry is fed into the turbulent bubbled bed reactor and air for oxidation is blown into slurry. The absorber type is a good example of a simplified FGD process. It eliminates the need for recycle pumps, spray nozzles and headers, separate oxidation tanks and thickeners, thereby minimising difficulties as well as power consumption.

FLOWPAC

- **Performances**
- The process has a compact design and allows to reach high desulphurisation rates (> 99%) with high sulphur content fuels (>1, 5%).
- 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%)
- According 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.

FLOWPAC

- **References**
- Few Flowpac absorbers are built in the world. The prototype was built in 1996 on unit 3 of the Karlshamm power station in Sweden (3 x 340 MWe oil plant). The gas flow is 1080000 Nm3/h the design oil sulphur content is 3, 5%.
- 3 other Flowpac (3x150 MWe) have been built recently at Lietuvos Elektrine Power Plant (Lituany) and forecast to start in 2008 (according to Alstom references). The gas flow is 1800000 Nm3/h and the design sulphur content is 3, 5%
- *Lietuvos plant: 4x150MWe+4x300MWe=1800MWe: 5 FGD have been implemented in Lietuvos : boilers1+ 2 (2x150 MWe);boilers 5A+5B (300MWe); boilers 6A+6B(300MWe); boilers 7A+7B (300MWe); boiler 8A(300MWe); fuel:natural gas, heavy oil(sulphur content up to 3,5%),orimulsion (sulphur content up to 3%)*
- An other Flowpac will be started in 2009 at Amagervaerket plant in Copenhagen (owner/operator Energi E2) (150MW; 540000 Nm3/h; 1, 3% sulphur content)
- There is no reference for capacity > 340 MWe and no operational reference for coal unit. A prototype of 15 MW is in test in Sweden. For a unit of 600 MWe, Alstom proposes 2x300 Flowpac in parallel without reference.
- From the expert point of view, this kind of process is to be advised for oil units < 340 MWe until more experiences.

FLOWPAC

- **Costs**
- The investments costs desulphurisation of 2 coal units of 600 MWe were estimated in 2003:
- Flowpac: 58 Euros/kWe (70 MEuros for 2x600MWe coal units), 6% lower than
- Classical wet desulphurisation: 61 Euros/KWe (74 MEuros for 2x600MWe coal units)
- **Sources:**
- EDF: "Procédé de désulfuration humide innovant Flowpac: état des connaissances" (C.Derousseau, I.Gasquet)
- Alstom internet documentation
- IPPC draft reference Document on Best Available Techniques for LCP

Annex 7.8

Documents from the 5th meeting – 28 April 2008

7.8.1 Agenda

28th April 2008

Swedish Environmental Protection Agency - Stockholm

Chairman: Nathalie Thybaud

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
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)

7.8.2 Meeting report

Participants

Mrs Nadine ALLEMAND (CITEPA),
Mr Jean-Guy BARTAIRE (Co-chairman of EGTEI, EDF),
Ms Rima EL HITTI (Ecole de Mines de Paris),
Mr Michael HIETE (IFARE),
Mr Smerkens KOEN (ECN),
Mr Thomas KRUTZLER (Federal Environmental Agency Austria),
Mr Peter MEULEPAS (Ministry of the Flemish Region, Environmental Administration),
Mr Tiziano Pignatelli (Co-chairman of EGTEI, ENEA),
Ms Dorothée ROSTAL (IFARE),
Ms Kristina SAARINEN (Finnish Environment Institute),
Mrs Nathalie THYBAUD (ADEME),
Mr Julien VINCENT (CITEPA)

Background

The LCP2030 subgroup of EGTEI had its kick-off meeting on June 7th 2007 in Paris and further meetings on October 1st 2007 in Angers, January 25th 2008 in Brussels and March 17th 2008 in Paris (cf. www.citepa.org). The aim of this subgroup is to provide techno-economic information about i) emerging technologies, ii) emerging abatement techniques, iii) emerging applications of existing abatement techniques, iv) improvements of existing technologies and v) improvement of existing abatement techniques in the sector of large combustion plants (LCP), i.e. combustion plants having a capacity larger than 500 MWth with a time horizon of 2030.

Presentations and discussions

The fifth meeting was hosted by Sweden in Stockholm and was chaired by N. THYBAUD. In her introduction, N. THYBAUD presented the agenda of the meeting and laid down the objectives of the meeting: i) to present, discuss and validate information already provided, ii) to present and discuss new contributions, iii) to discuss the reporting of the work of the LCP2030 subgroup (especially to WGSR meeting in September 2008) and iv) to discuss next steps. N. THYBAUD had then an introductory presentation about the tasks of the subgroup and definitions used (cf. presentation). In the following the term 'technology' is sometimes used for both technologies and techniques.

Synthesis and validation of the collected data

The group went then technology by technology through the list of contributed information (cf. presentation). The IEA (2007) publication 'Fossil Fuel-Fired Power Generation-Case studies of recently constructed coal and gas-fired plants' was considered as another valuable source of information on technologies. For some technologies, information is still pending (e.g. on oxycombustion). To be considered in the summary to the WGSR, information has to be provided still in May 2008.

Emerging Technologies:

- Commercial availability of IGCC in 2020 depends on the future role of CO_2 sequestration and prices of CO_2 emission certificates. In the Netherlands some new plants are built already CO_2 capture ready.
- Co-combustion plants are already existing. Nevertheless the information will be kept as an increasing importance of this technology is expected in future due to CO_2 emissions constraints. The provided data will be compared with data in the LCP BREF. A problem is the wide range of co-firing ratios.
- Catalytic combustion and oil/biooil combustion was considered as outside the scope of this subgroup which looked at plants with capacities larger than 500 MWth.

Emerging abatement techniques SO_2:

- So far efforts getting information on LIDS from the producer have not been successful.
- Flowpac is expected to have lower electricity consumption, higher efficiencies and needs lower investments. The producer provided no information for reasons of market sensitiveness. So far there is no operation reference in the capacity size considered. This technique is expected to have also an impact on PM emissions.

Emerging abatement techniques NO_x:

Information on oxygen enhanced low NO_x burner and oxy-fuel combustion is pending.

Emerging abatement techniques SO_x-NO_x:

LIMB and SNRB are considered as being outside the scope of the subgroup (cf. meeting in January 2008 in Brussels).

Emerging abatement techniques PM:

- Not enough information was available on **PM1 acoustics agglomeration** (comment: so far PM1 emissions are not explicitly covered in GAINS; only PM2.5 or larger).
- Information on INDIGO, COHPAC and TOXECON was presented by Mr JP RIVRON during the previous LCP2030 meeting (cf. : http://www.citepa.org/forums/egtei/EGTEI-consideration-costs%20increasing.pdf and http://www.citepa.org/forums/egtei/EGTEI%20Emerging%20Technologies%20sub-Group-JP-RIVRON.pdf).
- SO_3 injection before ESP is applied to improve the PM abatement efficiency. It is a current technology. Mr Peter MEULEPAS provided information on current abatement efficiencies in Belgium to LCP>500MWth subgroup.

Impacts of CO_2 capture on air pollutants:

The impact CO_2 capture technologies/techniques have on air pollutants emissions is of high interest. Mr. Rolf Beckers (Federal Environmental Agency Germany) had a presentation on this topic at 'VDI-DIN Reinhaltung der Luft' conference 'Emissionsminderung 2008', 9-10 April 2008, Nuremburg (cf. http://www.vdi-wissensforum.de/fileadmin/pdf/618802.pdf).

Improvement of existing technologies:

Some information is available on improvement of efficiencies of coal combustion plants. This information will be checked against the IEA (2007) publication 'Fossil Fuel-Fired Power Generation-Case studies of recently constructed coal and gas-fired plants'.

Improvement of existing techniques for SO_2 abatement:

Information on a number of techniques is available. There is a strong relationship between FGD costs and plants size (cf. previous meeting http://www.citepa.org/forums/egtei/EGTEI-consideration-costs%20increasing.pdf).

Improvement of existing techniques for NO_x abatement:

Information is available on boost, air staging and SCR for conventional and gas combined cycle plants.

Improvement of existing techniques for PM abatement:

Information from several experts is pending.

Presentation of the new contributions and discussion

Ms Rima EL HITTI of Ecole des Mines de Paris had a presentation on CO_2-capture by anti-sublimation which is considered as emerging (cf. presentation). It is based on the principle that CO_2 re-sublimates at a cold surface with a temperature of about -110°C. Costs are expected to be around 25 €/t CO_2. For estimation of application rates it should be taken into account that according to the proposal for a CCS Directive, CCS will be obligatory only for new plants.

Structure of the report for presentation to WGSR of September 2008

To be officially noted by UNECE, all documents have to be available at least three months before the WGSR meeting in September 2008 for translation into the official UNECE languages. To be able to cope with this time frame an extended, non-technical executive summary in UNECE format will be prepared and should be available at latest at the beginning of June. In addition, a full report of the work of the LCP2030 subgroup will be written, but not finished for June. This report will be officially adopted by EGTEI. There is no particular UNECE format for technical reports. The report's structure will take the following elements into account: background, objective, organisation and participants, methodology, collected information and conclusions, and next steps.

Conclusions and next steps

There will be no other meeting. A continuation of the work of the subgroup LCP2030 down to lower capacities of combustion plants, e.g. 100 MWth, is considered. A collaboration with EIPPBC in Seville is envisaged. To finalise the current work an extended, non-technical executive summary will be prepared for the beginning of June to be noted by WGSR meeting in September 2008. In addition a full report will be written, but not for June (see previous paragraph).

7.8.3 Status of the work (Nathalie THYBAUD - ADEME)

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EGTEI

ENERGY SECTOR

Test for the Power Generation (LCP > 500 MWth)

Synthesis of collected data

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Classification of technologies/techniques

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

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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	

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Emerging technologies - Coal IGCC

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)

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Emerging technologies - Coal IGCC

Efficiency %	Environmental Impact: 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$_{el}$)	Investment M€/MW$_{th}$	Fixed operating costs M€/MW$_{th}$	Variable operating costs M€/MWh$_{th}$	Source of data
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

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Emerging technologies - Coal IGCC

Conclusion

- Net efficiency: 43% (LHV)
  Future developments (2010-2015): 50% efficiency (LHV)
- Low emissions. Mercury removal will be cheaper than for pulverised combustion
- Investment: 1-1.5 M€/MWth (demonstration plant)
  Uncertainty in IGCC costs
  + 20% than pulverised combustion (IEA study)

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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)

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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*

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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

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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

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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

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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			

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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:

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

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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

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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%)

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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

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Emerging abatement techniques – SO_2 - Flowpac

Conclusion

- High SO_2 efficiency
- Low power consumption
- 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

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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			

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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

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Ib) Emerging abatement techniques

Information outside the scope of LCP2030 sub-group

- SNRB: not considered as a priority (hazardous waste as by-product, rather low abatement efficiencies)
- LIMB: not considered as a priority (problems of reliability, mediocre abatement efficiency)

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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

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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

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Ib) Emerging abatement techniques – CO_2 capture

Three types of CO_2 capture processes

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

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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

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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/Nm³ 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

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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

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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

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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

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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)

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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

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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

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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)

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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)			

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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

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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			

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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

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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

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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

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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

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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			

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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

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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

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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

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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

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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)			

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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))

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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

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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

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State of progress

Pending contribution from:

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

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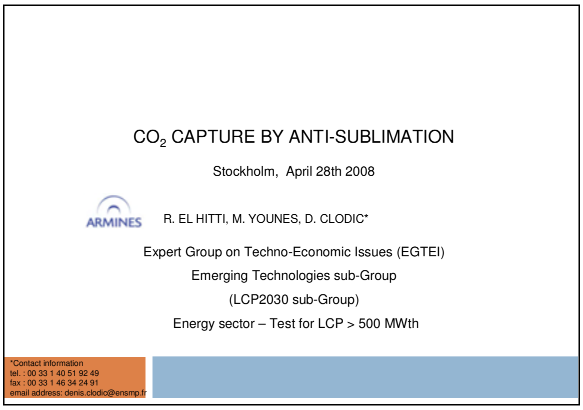
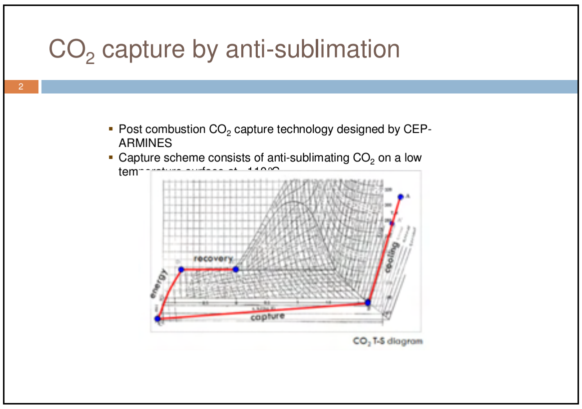
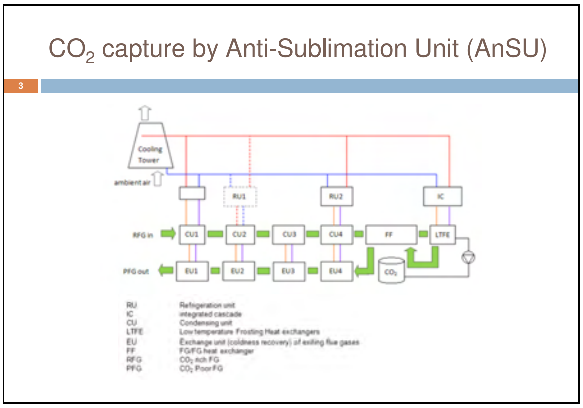
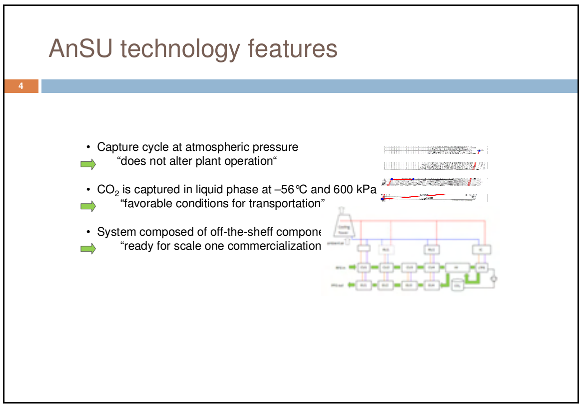
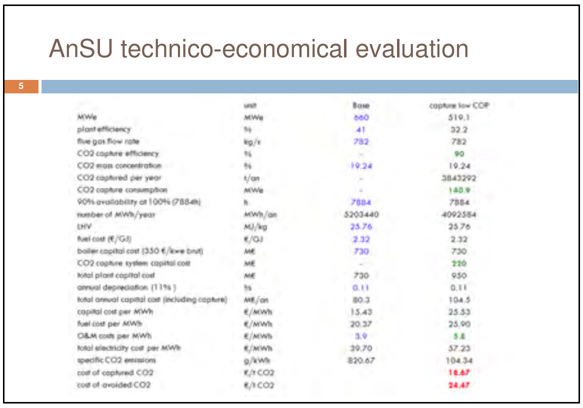
7.8.4 Contribution on CO_2 capture by anti-sublimation (Rima EL HITTI – Ecole des Mines de Paris)











	unit	Base	capture low COP
MWe	MWe	660	519.1
plant efficiency	%	41	32.2
flue gas flow rate	kg/s	782	782
CO2 capture efficiency	%	-	90
CO2 mass concentration	%	19.24	19.24
CO2 captured per year	t/an	-	3843292
CO2 capture consumption	MWe	-	140.9
90% availability at 100% (7884h)	h	7884	7884
number of MWh/year	MWh/an	5203440	4092584
LHV	MJ/kg	25.76	25.76
fuel cost (€/GJ)	€/GJ	2.32	2.32
boiler capital cost (350 €/kwe brut)	M€	730	730
CO2 capture system capital cost	M€	-	220
total plant capital cost	M€	730	950
annual depreciation (11%)	%	0.11	0.11
total annual capital cost (including capture)	M€/an	80.3	104.5
capital cost per MWh	€/MWh	15.43	25.53
fuel cost per MWh	€/MWh	20.37	25.90
O&M costs per MWh	€/MWh	3.9	5.8
total electricity cost per MWh	€/MWh	39.70	57.23
specific CO2 emissions	g/kWh	820.67	104.34
cost of captured CO2	€/t CO2		18.67
cost of avoided CO2	€/t CO2		24.47

EGTEI expert sub-group on Emerging Technologies/Techniques for Large Combustion Plants >500 MWth up to 2030

LCP2030 sub-group final report

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