# 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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**About ADEME**

The French Environment and Energy Management Agency (ADEME) is a public agency under the joint supervision of the French Ministries for Ecology, Energy, Sustainable Development and Spatial Planning, and for Higher Education and Research. It participates in the implementation of public policies in the fields of the environment, energy and sustainable development. The agency makes its expertise and consultancy skills available to business, local communities, public authorities and the general public and helps them to finance projects in five areas (waste management, soil preservation, energy efficiency and renewable energies, air quality and noise abatement) and to make progress with their sustainable development procedures.

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# Summary

## Outcome of EGTEI work on Emerging Technologies / Techniques for Large Combustion Plants >500 MWth up to 2030

### Background

**1-** In the framework of the Convention on Long-Range Transboundary Air Pollution, EGTEI has been mandated by UN ECE to initiate work on emerging technologies in order to assess what could be done technically and economically to reduce atmospheric emissions in the future. Emerging technologies could be considered in different scenarios (BAU, optimisation scenarios). For example, the application of emerging technologies could contribute to lower the emissions of the so-called Maximum Technically Feasible Reductions (MTFR) scenario and hence could reduce the gap still present between the effect level obtained with the MTFR scenario and the no-emissions effect level. The move from RAINS to GAINS, for modelling of emissions impacts, offers the opportunity to improve assessment of the impacts and costs of emerging technologies on emissions reduction over time. A significant improvement in modelling could be achieved by replacing the current assumption, that the efficiency of abatement techniques is constant over time, with information from the technical improvements of existing technologies and abatement techniques.

**2-** An EGTEI expert sub-group (LCP2030 sub-group) dedicated to emerging technologies/techniques and to improvement of existing technologies/techniques, with a time frame up to 2030, has been created by EGTEI for the duration of the work.

**3-** The priority sector considered was the energy sector and especially large combustion plants (LCP) >500 MWth.

### Objectives

**4-** The following items were explored by the expert sub-group for providing techno-economic information about:

a) emerging technologies,

b) emerging abatement techniques,

c) emerging applications of existing abatement techniques,

d) improvement of existing technologies,

e) improvement of existing abatement techniques.

**5-** Techniques/technologies not yet commercialised, and techniques/technologies in a very early commercialisation phase are considered as emerging. The emissions covered in the framework of the LCP2030 sub-group are: $SO_2$, $NO_x$, PM and $CO_2$.

**6-** The main objective of the work is to characterise these techniques/technologies technically and economically (emission reduction potential, costs).

### Methodology

**7-** On the basis of the IPPC BREF document on large combustion plants and the EU project "Assessment of the air emissions impact of emerging technologies" carried out for the European Commission in 2003/2004 by IFARE and UBA Vienna with the participation of ITA and CITEPA, a list of potential technologies/techniques was established. The list was then reviewed by the experts in order to identify technologies/techniques to be analysed with priority. The information collected came directly from experts of the LCP2030 sub-group or from interviews with other experts.

**8-** The following sections outline the main views of the experts on the development of emerging technologies/techniques and the improvement of existing technologies/techniques.

## Emerging technologies

**9-** Several emerging technologies were explored by the LCP2030 sub-group. Based on expert views and available data, the following emerging technologies were identified as priorities: IGCC and oxy-combustion, two technologies which could benefit from the deployment of Carbon Dioxide Capture and Storage (CCS).

### *IGCC (Integrated Gasification Combined Cycle)*

**10-** The net efficiency for existing IGCC plants operating on coal is around 43% (LHV basis). IGCC could reach 50% efficiency (LHV basis) around 2015.

**11-** Investment is estimated at between 1 and 1.5 M€/MWth (demonstration plant). A study[1] by the International Energy Agency considers that the specific investment for IGCC is about 20% higher than for pulverised combustion. There is however more uncertainty in IGCC costs as there are no recently built coal IGCC plants and the existing ones were constructed as demonstration plants. Suppliers have plans to bring the capital cost to within 10% of that of pulverised coal combustion.

**12-** The challenges are reliability, availability and investment. According to experts, IGCC technologies could be commercially available around 2020 with CCS.

### *Oxy-combustion*

**13-** Oxy-combustion enables the capture of $CO_2$ by direct compression of flue gas without further chemical capture or separation.

**14-** Optimisation of the competitiveness of the oxy-combustion process for power generation requires several developments:
- adaptation of cryogenic air separation units for more energy-efficient utilisation and operability for use in large oxy-fuel power plants or development of new oxy-combustion technologies like Chemical Looping combustion,
- adaptation of combustion technologies to oxygen firing,
- safe operation under enhanced oxygen firing and carbon dioxide-related safety issues,
- optimisation of heat transfer in the boiler,
- optimisation of the steam cycle in order to compensate efficiency loss due to CCS,
- optimisation of flue gas recirculation.

**15-** Several 10-50 MW demonstration plants worldwide are planned up to 2010, with 100-500 MW demonstration units possible around 2015. Oxy-combustion technologies could be commercially available around 2020.

**16-** The reduction of $NO_x$ emissions (on a mass emissions basis) in oxy-combustion processes is mainly due to the very low concentration of $N_2$ from air in the combustor. The decrease of $NO_x$ formation is then the result of the recirculation of flue gas (interactions between recycled $NO_x$, fuel-N and hydrocarbons released from fuel).

## Improvement of existing technologies

**17-** One of the ways of reducing the emissions of $CO_2$ from fossil-fuel-fired power plants is to improve the overall efficiency of plants. Furthermore, because of the penalty of $CO_2$ capture, CCS makes sense only for highly efficient plants. The following sections outline the main views of the experts on the improvement of existing technologies.

### *Coal-fired power plants*

**18-** A study[1] from IEA entitled "Fossil fuel-fired power generation – case studies of recently constructed coal and gas-fired plants" gives a lot of information on performance and costs of proven technology available today in order to show what has been achieved in modern plants in different parts of the world.

**19-** Currently, sub-critical coal-fired power plants can achieve efficiencies of up to 40%, and supercritical and ultrasupercritical plants efficiencies of up to 45%. From 2020, coal-fired power plants with advanced steam cycle technology (350 bar, 700°C) could reach efficiency of above 50%. The challenge is the development of materials. These steam cycle conditions would be possible with the use of nickel-based alloys.

[1] IEA - Fossil Fuel-Fired Power Generation - Case studies of recently constructed coal and gas-fired plants, 2007

### *Combined Cycle Gas Turbine (CCGT)*

**20-** Today the average efficiency of a 400 MWe CCGT plant is about 58%. In 2008 CCGT units with an efficiency of 59.4% were commercially available. An efficiency rate of 62% may be commercially available in 2015. According to experts, as of 2035 CCGT plants should be able to reach commercial efficiency of 70% by improving component efficiencies and using new materials. The efficiency of CCGT units is likely to reach a ceiling of about 72% towards 2050.

**21-** The increase in efficiency will follow an increase in unit capacity. At present CCGT units (F technology) have a capacity of 430 MWe (in CCGT configuration). Technology of the H generation has a capacity of 530 MWe. Experts project that CCGT units will reach capacities of 600 to 700 MWe in the future.

**22-** Natural-gas-fired combined cycle technology is more efficient and less expensive than systems based on coal. The investment is split 1/3 for the gas turbine and 2/3 for the steam cycle. Roughly, 2/3 of operating costs come from the gas turbine and 1/3 from the steam cycle.

**23-** The most recently built plants are able to reach 20 mg/Nm$^3$ (based on a daily average, standard conditions and an $O_2$ level of 15%) without SCR.

## Emerging abatement techniques

**24-** According to the expert views and the available data, the following emerging abatement techniques were considered by the LCP2030 sub-group as most promising:

- Flowpac for $SO_2$ abatement
- Fine particle abatement techniques
- $CO_2$ abatement techniques
- Oxygen-enhanced low $NO_x$ technology and oxy-combustion for $NO_x$ abatement. For the moment, the data collected for $NO_x$ abatement techniques are not sufficient to draw conclusions.

### *Flowpac (Alstom)*

**25-** Flowpac is a promising end-of-pipe desulphurisation (wet FGD) technology using a bubbling technology instead of circulation pumps. Difficulties and power consumption are minimised by the suppression of recycle pumps, spray nozzles, headers, separate oxidation tanks and thickeners. Power consumption is lower with Flowpac (1.3% of the power capacity) than with the classical wet FGD (1.7/1.75%).

**26-** The process has a compact design and achieves high desulphurisation rates (>99%) with high sulphur content fuels (>1.5%). The $SO_3$ abatement efficiency is around 60-70%.

**27-** Flowpac has a low capital cost due to elimination of spray pumps and associated equipment.

**28-** The system is currently implemented in oil-fired plants (<340 MWe) and needs to be demonstrated with coal-fired plants.

### *Fine particle abatement techniques*

**29-** COHPAC and TOXECON are technologies developed in the USA to capture emissions such as particulate matter, mercury and dioxins. COHPAC in combination with TOXECON can significantly reduce mercury, sulphur dioxide and other toxic emissions (dioxins) with a lower investment.

**30-** The Indigo Agglomerator, developed in the USA, agglomerates fine particles with heavy particles to better capture them. The particles are then easily collected in an electrostatic precipitator. A reduction of fine particle emissions by a factor 10 is achieved. It seems that the agglomerator is used only in plants not equipped with wet FGD.

### *$CO_2$ abatement techniques*

**31-** $CO_2$ emissions from fossil-fuel-fired power plants can be reduced by energy efficiency improvement or capture of $CO_2$ that is released and then stored underground.

**32-** $CO_2$ capture processes lead to an overall plant efficiency loss estimated to be 8-12 percentage points for existing coal power plants. Due to this efficiency drop with $CO_2$ capture, increased efficiency of fossil-fuel fired power plants is the first step. In parallel, a priority is the improvement of energy efficiency of $CO_2$ capture processes and optimisation of the steam cycle for the heat requirements of $CO_2$ capture.

**33-** There are three types of $CO_2$ capture processes:

- post-combustion processes which consist in extracting the $CO_2$ that is diluted in combustion flue gas. Post-combustion is the most advanced technology today. The solvents for $CO_2$ post-combustion capture can be physical, chemical or intermediate. Chemical solvents, such as amines, are most likely to be used. Other post-combustion capture solutions are absorption (new solvents, chilled ammonia), adsorption, anti-sublimation, membranes.
- oxy-combustion processes which consist in 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.
- pre-combustion processes which involve conversion (gasification or partial oxidation) of fuel into a synthesis 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.

**34-** The level and nature of impurities in the $CO_2$ stream can affect its transport and storage. The $CO_2$ purity level will impact the choice of pollutant abatement techniques.

**35-** Some $CO_2$ processes are also sensitive to pollutants. For example, $NO_2$ and $SO_2$ from the flue gas react with amine (post-combustion capture) to form stable, non-regenerable salts and so cause a loss of some amine. With amine, $SO_2$ specification is usually set as $<40$ mg/Nm$^3$ and $NO_2$ specification as $<50$ mg/Nm$^3$ (based on a daily average, standard conditions and an $O_2$ level of 6%).

Limits for $SO_x$ can be achieved by some FGD technologies. Experience at the CASTOR[1] pilot plant (post-combustion capture with amine) shows that limestone gypsum flue gas desulphurisation (FGD) plants can be designed to reduce $SO_2$ emissions down to 10 mg/Nm$^3$ with an increase in capital costs of about 7% and a 27% increase in operating costs.

Limits for $NO_x$ are technically achievable by the use of low-$NO_x$ burners and SCR.

**36-** Other types of CCS technology are available but not of mature status for application to large combustion plants. $CO_2$ capture and storage in power plants is now being demonstrated in a few small-scale pilot plants. Large-scale demonstration plants with carbon dioxide capture and storage (CCS) are planned by around 2015 with the objective of developing CCS by 2020.

**37-** CCS costs are highly project-specific. Many techno-economic studies give information on performance and costs. Nevertheless, data on large-scale $CO_2$ capture implementation are not available. The objective is to reduce CCS costs to below 25€/t of avoided $CO_2$ by 2030.

There is no consensus on which option (post, pre or oxy-combustion) will be least costly in the future, each has its pros and cons and the costs appear to be comparable.

## Improvement of abatement techniques

**38-** No significant improvements in existing abatement techniques have been identified compared to the information already available in the European BREF document on LCP. The IEA study[2] on fossil-fuel-fired power generation reports some very low emissions for a few recently constructed coal power plants.

**39-** In order to compare existing data with the modelling data and to update them, costs and performances of abatement techniques at existing installations have been provided by the experts.

## Emerging applications of existing abatement techniques

**40-** Only $SO_3$ injection was identified as an emerging application of an existing abatement technique to reduce PM emissions.

(1) Féraud A, Marocco L, Howard T (2006) CASTOR study of technological requirements for flue gas clean-up prior to $CO_2$-capture. In: 8th international conference on greenhouse gas control technologies, Trondheim, Norway, 19-22 Jun 2006. Oxford, UK, Elsevier Ltd., paper 01_05_06.PDF, 6p. (2006) CD-ROM

(2) IEA - Fossil Fuel-Fired Power Generation - Case studies of recently constructed coal and gas-fired plants, 2007

## Other information

**41-** The increasing cost in relation to net efficiency of power plants and the increasing costs of plants and emissions abatement systems are mentioned by the experts.

## Main conclusions and future work

**42-** The efficiency penalties of $CO_2$ capture will become lower for future power plants as the trend to higher efficiencies continues, with efficiencies above 50% now in sight.

**43-** Some technologies/techniques (e.g. catalytic combustion), were considered as outside the scope of the LCP2030 sub-group which considered only power plants with capacities higher than 500 MWth. Future work by the sub-group could consider large combustion plants with lower capacities (e.g. >100 MWth).

# 1. Background and objectives

In the framework of the Convention on Long-Range Transboundary Air Pollution, EGTEI has been mandated by UN ECE to initiate work on emerging technologies in order to assess what could be done technically and economically to reduce atmospheric emissions in the future. Emerging technologies could be considered in different scenarios (BAU, optimisation scenarios). For example, the application of emerging technologies could contribute to lower the emissions of the so-called Maximum Technically Feasible Reductions (MTFR) scenario and hence could reduce the gap still present between the effect level obtained with the MTFR scenario and the no-emissions effect level. The move from RAINS to GAINS, for modelling of emissions impacts, offers the opportunity to improve assessment of the impacts and costs of emerging technologies on emissions reduction over time. A significant improvement in modelling could be achieved by replacing the current assumption, that the efficiency of abatement techniques is constant over time, with information from the technical improvements of existing technologies and abatement techniques.

Initially, two EGTEI expert sub-groups dedicated to emerging technologies/techniques and improvement of existing technologies/techniques were created by EGTEI, with two time horizons, up to 2020 and a longer-term perspective, between 2020 and 2050. Further to the kick-off meeting, the two expert sub-groups have been merged. Indeed, collecting information for the longer-term horizon is challenging; the future energy production system will probably be very different from what can be imagined now. Consequently an EGTEI expert sub-group (LCP2030 sub-group) dedicated to emerging technologies/techniques and improvement of existing technologies/techniques, with a time frame up to 2030, has been created for the duration of the work.

The priority sector considered was the energy sector and especially large combustion plants (LCP) >500 MWth.

The following items were explored by the expert sub-group for providing techno-economic information about:

a) emerging technologies

b) emerging abatement techniques

c) emerging applications of existing abatement techniques

d) improvement of existing technologies

e) improvement of existing abatement techniques.

Techniques/technologies not yet commercialised, and techniques/technologies in a very early commercialisation phase will be considered as emerging. The emissions covered in the framework of the LCP2030 sub-group are: $SO_2$, $NO_x$, PM and $CO_2$.

Two types of measures can be distinguished:

- Primary measures: all measures which allow the reduction or avoidance of possible emissions at the moment of their formation (e.g. low $NO_x$ burner)
- Secondary measures (also called end-of-pipe techniques): all measures which allow the reduction of emissions in the exhaust gas of the processes under consideration (e.g. fabric filter).

Beyond that, combinations of primary and secondary measures may be considered, if their implementation is technically feasible and if a substantial reduction is achievable. Also combinations abating several pollutants at once are possible (e.g. low dust system for $NO_x$).

The main objective of the work is to characterise these techniques/technologies technically and economically (emissions reduction potential, costs).

# 2. Organisation and participants

## The LCP2030 sub-group is chaired by ADEME and reports to EGTEI.

The kick-off meeting of the EGTEI sub-group on emerging technologies in large combustion plants and power generation was held in Paris (at ADEME's offices), on the 7th of June 2007.

The 2nd meeting was hosted by ADEME in Angers, on the 1st of October 2007.

The 3rd meeting was hosted by ENEA in Brussels, on the 25th of January 2008.

The 4th meeting was hosted by CITEPA in Paris, on the 17th of March 2008.

The 5th meeting was hosted by Swedish EPA in Stockholm, on the 28th of April 2008.

The participants in the LCP2030 sub-group include industrial and national administration experts. The following persons have participated in the work:

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.)~~aaz~
Mr Phil CAHILL (RWE npower)
Mr Pier Lorenzo DELL'ORCO (EDIPOWER s.p.a.)
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Ms Andrea KRIZOVA (Czech Hydrometeorological Institute)
Mr Hartmut KRUGER (VGB PowerTech e.V.)
Mr Thomas KRUTZLER (Federal Environmental Agency Austria)
Mr Mats LINDGREN (Swedish EPA)
Mr Peter MEULEPAS (Ministry of the Flemish Region, Environmental Administration)
Mrs Carole ORY (EDF)
Mr Tiziano PIGNATELLI (Co-chairman of EGTEI, ENEA)
Mr Jean-Pierre RIVRON (expert in LCP, formerly EDF)
Mrs Dorothée ROSTAL (IFARE)
Ms Kristina SAARINEN (Finnish Environment Institute)
Mrs Simone SCHUCHT (INERIS)
Mrs Nathalie THYBAUD (ADEME)
Mr Eric VESINE (ADEME)
Mr Julien VINCENT (CITEPA)

# 3. Methodology

Before the kick-off meeting, a questionnaire was established by ADEME and sent to the experts in order to list the documents or studies which might be useful for the LCP2030 sub-group or which could be used as a basis for the work. The main documents identified are:

- IPPC BREF document on large combustion plants and especially the chapters on emerging techniques.
- EU project "Assessment of the air emissions impact of emerging technologies" carried out for the European Commission in 2003/2004 by IFARE and UBA Vienna with the participation of ITA and CITEPA. The study covered all industrial sectors (excluding transport and agriculture). A list of promising candidate technologies was set up for all sectors, but without projections.
- Documents on Carbon Capture and Storage (CCS): IPCC Special Report on Carbon Dioxide Capture and Storage, Strategic Deployment Document (ETP ZEP), $CO_2$ Capture Ready Recommendations of European Power Plant Suppliers Association (EPPSA), …

On the basis of the IPPC BREF document on large combustion plants and the EU project "Assessment of the air emissions impact of emerging technologies" carried out for the European Commission in 2003/2004 by IFARE and UBA Vienna with a participation of ITA and CITEPA, a list of potential technologies/techniques was established.

This list was then reviewed by the experts:

- technologies/techniques to be analysed with high priority were identified,
- some technologies/techniques were removed from the list, for instance 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 sub-group (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 information collected came directly from experts of the LCP2030 sub-group or from interviews with other experts.

# 4. Data collected and experts' views

## 4.1. Emerging technologies

Several emerging technologies were explored by the LCP2030 sub-group: coal IGCC, oxy-combustion, catalytic combustion and co-combustion (waste/biomass).

Based on expert views and the available data, IGCC and oxy-combustion were identified as priorities. These two technologies could benefit from the deployment of carbon dioxide capture and storage (CCS).

### 4.1.1. Coal IGCC (Integrated Gasification Combined Cycle)

Coal IGCC is a combined cycle based on coal gasification and combustion of syngas ($H_2$ + CO) in a gas turbine. The exhaust gases from the gas turbine are then fed into the steam cycle.

Techno-economic data on IGCC are reported in Table 4.1.

The net efficiency for existing IGCC plants operating on coal is around 43% (LHV basis). IGCC could reach 50% efficiency (LHV basis) around 2015.

Investment is estimated at between 1 and 1.5 M€/MWth (demonstration plant). A study(1) by the International Energy Agency considers that the specific investment for IGCC is about 20% higher than for pulverised coal combustion. There is however greater uncertainty in IGCC costs as there are no recently built coal IGCC plants and the existing ones were constructed as demonstration plants. Suppliers have plans to bring the capital cost down to within 10% of that of pulverised coal combustion.

The challenges are reliability, availability and investment. According to experts, IGCC technologies could be commercially available around 2020 with CCS.

(1) IEA - Fossil Fuel-Fired Power Generation - Case studies of recently constructed coal and gas-fired plants, 2007

## Table 4.1 : Techno-economic data on coal IGCC (Integrated Gasification Combined Cycle)

| Short description | Environmental impact: $NO_x$ emission factor | $SO_2$ emission factor | TSP emission factor | $CO_2$ emission factor | Technology Efficiency | Maturity | Investment | Fixed operating costs | Variable operating costs | Source of data | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | g/GJ fuel input | g/GJ fuel input | g/GJ fuel input | kg/GJ fuel input | % | | M€/MWth | M€/MWth | M€/MWhth | | |
| 585 MWth single unit(1) | 11.9 (100 mg/kWhe) | 14.3 (120 mg/ kWhe) | not available | 92.1 (773 g/ kWhe) | 42.9 (LHV basis - based on 90's GT technology) | | 0.726(2) (1991) equipment only | 0.032(3) (1999) | 5.77E-6(4) (1999) | Edipower (information on Buggenum IGCC plant) | $CO_2$ emission factor based on full oxidation of carbon content in a.r. feedstock = 62.83% |
| 670 MWth single unit(5) | 7.88 (66 mg/kWhe) | 47.4 (397 mg/ kWhe) | 2.39 (20 mg/ kWhe) | 96.3 (807 g/ kWhe) | 43 (LHV basis - based on 90's GT technology) | | 1.0 (1998) Including project management, construction and start-up | not available | 4.859E-6 (only fuel) | Edipower (from data published by Elcogas Puertollano IGCC plant) | $CO_2$ emission factor based on full oxidation of carbon content in a.r. feedstock = 59.21% |
| | 43(6) | 30(6) | 4.3(6) (TSP, $PM_{10}$, $PM_{2.5}$) | | 50(7) (modern IGCC power plant) | Commercially possible but with economic barriers | 1.48(7) (2004) | | | EU-project(8) IFARE/UBA 2003/2004 | |

(1) 1GT+1 dry feed entrained flow slagging gasifier; fed with coal mix (design feed LHV=25 MJ/kg a.r., S=1.5% d.a.f.; integrated ASU (air from GT compressor to ASU, $N_2$ from ASU to syngas saturator for NOx primary reduction); additional steam generation by hi-T heat recovery from gasification, after quench with recirculated syngas; syngas clean-up based on hybrid solvent (Sufinol); sulphur recovery by Claus process w/ tail gas incineration

(2) Equipment: coal prep. + ASU + gasific. & gas cool. + AGR + SRU + CCPP + CWS + WWT + BOP + DCS

(3) Fixed operating costs: operation personnel only (130 units excluding maintenance personnel: 35 units on average); on yearly basis

(4) Variable operating costs: Fuel (feedstock + aux. fuel) + utilities & chemicals + by-product disposal

(5) 1GT+1 dry feed entrained flow slagging gasifier; fed with low rank coal/petcoke mix (design feed LHV=22.55 MJ/kg a.r., S=3.21% a.r.; integrated ASU ($N_2$ from ASU to GT combustion chamber for $NO_x$ primary reduction); additional steam generation by hi-T heat recovery from gasification, after quench with recirculated syngas; syngas clean-up based on chemical solvent (MDEA); sulphur recovery by Claus process w/ offgas recirculation

(6) European Community, 2003

(7) The Royal Academy of Engineering, 2004

(8) EU-project "Assessment of the air emissions impact of emerging technologies" - IFARE/UBA - 2003/2004

### 4.1.2. Oxy-combustion

Oxy-combustion enables the capture of $CO_2$ by direct compression of flue gas without further chemical capture or separation.

Optimisation of the competitiveness of the oxy-combustion process for power generation requires several developments:

- adaptation of cryogenic air separation units for more energy-efficient utilisation and operability for use in large oxy-fuel power plants or development of new oxy-combustion technologies like Chemical Looping combustion,
- adaptation of combustion technologies to oxygen firing,
- safe operation under enhanced oxygen firing and carbon dioxide-related safety issues,
- optimisation of heat transfer in the boiler,
- optimisation of the steam cycle in order to compensate efficiency loss due to CCS,
- optimisation of flue gas recirculation.

Several 10-50 MW demonstration plants are planned worldwide up to 2010, with 100-500 MW demonstration units possible around 2015. Oxy-combustion technologies could be commercially available around 2020.

The reduction of $NO_x$ emissions (on a mass emissions basis) in oxy-combustion processes is mainly due to the very low concentration of $N_2$ from air in the combustor. The decrease of $NO_x$ formation is then the result of the recirculation of flue gas (interactions between recycled $NO_x$, fuel-N and hydrocarbons released from fuel).

### 4.1.3. Catalytic combustion

Because of the state of development (pilot-scale 1.5 MWe gas turbine, plants for application on a 170 MWe gas turbine under development), catalytic combustion was considered as outside the scope of this sub-group which looked at plants with capacities larger than 500 MWth.

### 4.1.4. Co-combustion

Co-combustion plants, which already exist, are not considered as emerging by the experts. Nevertheless, this information is included because this technology is expected to be increasingly important in the future due to $CO_2$ emissions constraints.

The following tables, extracted from the LCP BREF document, report on experience with the co-combustion of secondary fuel in coal-fired power stations with a wide range of co-firing ratios. Most of these examples involve co-combustion of less than 10% on a thermal basis. References with higher co-combustion rates concern fluidised bed boilers or the co-combustion of separately pulverised wood in pulverised-coal-fired boilers. Large-scale demonstration projects have been carried out with sewage sludge and wood chips.

## Table 4.2: Experience with co-combustion in LCPs in Austria

| Country | Power (MWe) | Secondary fuel | Co-firing degree thermal % | Handling of co-combustion fuel | Remarks |
|---|---|---|---|---|---|
| Austria | 124 | Biomass (bark) | 3 | The boiler has two air-cooled forward pushing grates at the bottom of the boiler with a capacity of 5 MW each | In operation since 1994 |
| | 137 | Biomass | 3 | Gasification, gas burners and reburning | Gasified biomass is co-combusted as reburning fuel. In operation since 1997 |

## Table 4.3: Experience with co-combustion in LCPs in Denmark

| Country | Power (MWe) | Secondary fuel | Co-firing degree thermal % | Handling of co-combustion fuel | Remarks |
|---|---|---|---|---|---|
| Denmark | 77.5 | Straw | 50 | Fluidised bed combustion | Plant designed for coal/straw fuel mix |
| | 125 | Pulverised wood | 20 | Separate wood burners | Pulverised wood was burned in two specially adapted burners. No negative effects were noticed and it is expected that higher co-firing percentages should be possible. $NO_x$ emissions were reduced by 35% and the quality of fly ash remained good. |

## Table 4.4: Experience with co-combustion in LCPs in Germany

| Country | Power (MWe) | Secondary fuel | Co-firing degree thermal % | Handling of co-combustion fuel | Remarks |
|---|---|---|---|---|---|
| Germany | 170 | Sewage sludge | 11 | | |
| | 195 | Sewage sludge | 3.5 | | |
| | 235 | Sewage sludge | 3.5 | | |
| | 280 | Biomass pellets | max. 10 mass | Separate wood mills, wood burners | The biomass is pulverised in hammer mills and the boiler has a grate at the bottom. |
| | 382 | Sewage sludge | 5 | | |
| | 565 | Sewage sludge | 0 | | |
| | 805 | Sewage sludge | <0.5 | | |
| | 913 | Sewage sludge | 1 | | |
| | 930 | Sewage sludge | 5 | | |
| | 1 074 | Sewage sludge | 1.5 | | |
| | 1 280 | Sewage sludge | 0.07 | | |
| | 1 933 | Sewage sludge | 1.1 | | |

## Table 4.5: Experience with co-combustion in LCPs in Finland

| Country | Power (MWe) | Secondary fuel | Co-firing degree thermal % | Handling of co-combustion fuel | Remarks |
|---|---|---|---|---|---|
| Finland | >40 boilers | REF, RDF, selected municipal waste | | | |

## Table 4.6: Experience with co-combustion in LCPs in Italy

| Country | Power (MWe) | Secondary fuel | Co-firing degree thermal % | Handling of co-combustion fuel | Remarks |
|---|---|---|---|---|---|
| Italy | 320 MWe | RDF | | Pulverised with coal | RDF is obtained from municipal solid wastes by mean of milling, magnetic separation of metallic material, trommeling and classification to separate organic fraction and inerts |
| | 48 MWth | RDF | 10 - 15% based on 33 MWth only | Two solutions :<br>1) pulverised with coal<br>2) dedicated feeding line | Co-firing has shown a higher level of unburned matter |

## Table 4.7: Experience with co-combustion in LCPs in The Netherlands

| Country | Power (MWe) | Secondary fuel | Co-firing degree thermal % | Handling of co-combustion fuel | Remarks |
|---|---|---|---|---|---|
| The Netherlands | 403 | Phosphor oven gas<br>Sludge | 3 | Separate gas burners<br>Pulverised with coal | In operation since 1996<br>Large-scale tests |
| | 518 | Liquid organic residue | 1 | | In operation since 1995 |
| | 518 | Biomass pellets | 5 | Pulverised with coal | In operation since 1998 |
| | 600 | Waste wood | 3 | Separately milled, wood burners | In operation since 1995 |
| | 600 | Waste wood | 5 | Gasification with gas cleaning, gas burners | In commissioning in 2000 |
| | 630 | Dried sewage sludge | 3 | Pulverised with coal | Several large scale tests |
| | 645 | Paper sludge | max. 10 mass | Pulverised with coal | In operation since 1997 |

## Table 4.8: Experience with co-combustion in LCPs in the US

| Country | Power (MWe) | Secondary fuel | Co-firing degree thermal % | Handling of co-combustion fuel | Remarks |
|---|---|---|---|---|---|
| US | | Wood (willow) | max. 10 mass | Separate wood mills, wood burners | |
| | | Wood | max. 5 mass | Pulverised with coal | |
| | 2x25 | Wood /RDF | 50/15 | Bubbling fluidised bed combustion | |
| | 54 | Wood | Max. 40 | | Short test, natural gas support burner |
| | 100 | Wood (saw-dust, lopping) | max. 13.5 mass | | Large-scale test, increased excess air, decreased steam temperatures |
| | 350 | Refuse-derived fuel | 6 | | |
| | 560 | Waste wood | 5 | | Cyclone combustor |

Other information from EDIPOWER with a co-firing ratio of less than 10% is reported in table 4.9.

## Table 4.9: Techno-economic data on co-combustion

| Short description | Environmental impact | | | | Technology Efficiency | Investment | Fixed operating costs | Variable operating costs | Source of data | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | $NO_x$ emission factor | $SO_2$ emission factor | TSP emission factor | $CO_2$ emission factor | | | | | | |
| | g/GJ fuel input | g/GJ fuel input | g/GJ fuel input | kg/GJ fuel input | % | M€/MWth | M€/MWth | M€/MWhth | | |
| Co-combustion (coal+RDF) 2x330 MWe[(1)] Max use of RDF = 8.2% mass basis | 88.3 (virtually not affected by co-combustion) | 123.6 (125.2 when 100% coal-fired) | 0.376 (0.959 when 100% coal-fired) | 99.5 (103 when 100% coal-fired) | 35 (LHV basis; no impact from co-combustion) | not available[(2)] | not available | not available[(3)] | Edipower (in part taken from and in part deduced from information published by Enel on an experimental campaign in a power plant in northern Italy) | Unexpected better TSP abatement w/ respect to 100% coal firing (lower ESP efficiency foreseen): this is probably due to increased efficiency of dust abatement by the scrubbers. Reported data are for the boiler with the best environmental performance |
| Co-combustion (low ash/low sulphur coal +wood pellets) 1x320 MWe (800 MWth)[(4)] 10% biomass co-firing ratio LHV basis | 72.9 (no reduction w/ respect to 100% coal firing) | 113.3 (slightly increased w/ respect to 100% coal firing due to greater sulphur content in the fuel mix) | 12.76 (no reduction w/ respect to 100% coal firing) | 100.5 (more than 10% is attributable to "renewable" thermal input and thus neutral as regards GHG potential; specific $CO_2$ production of wood biomass is 5% greater than that of coal due to lower LHV) | 36.5 | 0.15[(5)] | not available | not available | Edipower (from a feasibility study w/ partnership of KEMA for implementation in a power plant in Italy) | Cost data refer to 2007; study not yet completed |

(1) tangentially fired multi-fuel boilers. Each boiler equipped w/ 5 burner levels & 5 coal mills. RDF is separately milled and injected downstream coal mills and upstream burners (which are common to the two fuels). Each boiler equipped with ESP+SCR+seawater pre-scrubber + limestone WFGD.

Average characteristics of RDF: LHV = 18.2 MJ/kg; humidity = 8.55% by wt; ash = 18.4% by wt; S = 0.33% by wt; Cl = 0.45% by wt

Characteristics of coal: LHV = 24.3 MJ/kg; S = 0.55% by wt; C = 68.3% by wt

(2) In a study dated 2006 on RDF co-combustion implementation in one 320 MWe Edipower coal fired unit, investment in the range 2.5-3 M€ was estimated for an RDF thermal input of 29.3 MW

(3) SCR, if installed, is to be included in the O&M cost

(4) boiler equipped w/ frontal burners. ESP and DeNOx SCR downstream boiler. Reference fuel characteristics: wood LHV=16.1 MJ/kg; S=0.14%wt; 0.9% ash; 25% moisture; C=46.2% and coal LHV=20.5 MJ/kg; S=0.11%wt; 0.9% ash; 10% moisture; C=56.3%

(5) roughly estimated; referred to "green" thermal input; includes burners modification plus storage and milling/feeding systems modification and integration

# 4.2. Improvement of existing technologies

One of the ways of reducing $CO_2$ emissions from fossil-fuel-fired power plants is to improve the overall efficiency of plants. Furthermore, because of the penalty of $CO_2$ capture, CCS makes sense only for highly efficient plants. The following sections give data and outline the main views of the experts on the improvement of existing technologies.

## 4.1.1. Coal-fired power plants

A study(1) from IEA entitled "Fossil fuel-fired power generation – case studies of recently constructed coal and gas-fired plants" gives a lot of information on performance and costs of proven technology available today in order to show what has been achieved in modern plants in different parts of the world.

### 4.2.1.1 Pulverised Combustion (PC)

The following tables, extracted from the IEA study, show the main features of the pulverised-coal-fired plants that were studied and their efficiency, emissions and costs. More information is available in the executive summary (annex 7.1).

Currently, sub-critical coal-fired power plants can achieve efficiencies of up to 40% and supercritical and ultrasupercritical plants efficiencies of up to 45%. From 2020, coal-fired power plants with an advanced steam cycle (350 bar, 700°C) could reach efficiencies of above 50%. The challenge is the development of materials. These steam cycle conditions could be made possible by the use of nickel-based alloys.

(1) IEA - Fossil Fuel-Fired Power Generation - Case studies of recently constructed coal and gas-fired plants, 2007

## Table 4.10: Main features of the eight coal-fired plants studied and basis for selection from IEA study entitled "Fossil fuel-fired power generation – case studies of recently constructed coal and gas-fired plants"

| 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: Nordjyllandsvaerket 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; actived 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 $NO_x$ |
| **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)<br>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

## Table 4.11: Costs, emissions and efficiencies of the case-study plants and comments from IEA study entitled "Fossil fuel-fired power generation – case studies of recently constructed coal and gas-fired plants"

| **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: Nordjyllandsvaerket 3** | 1500 (2006) for new 800MWe excluding owners costs or IDC | $NO_x$ 146 mg/$Nm^3$<br>$SO_2$ 13 mg/$Nm^3$<br>Dust 18 mg/$Nm^3$ | 384 | 29/582/580/580 | 47 LHV<br>(no heat load)<br>44.9 HHV<br>(no heat load) | 47 LHV<br>(not annual)<br>44.9 HHV<br>(not annual) | High steam parameters<br>Cold sea water cooling<br>Double reheat<br>Low auxiliary power<br>Extremely low emissions<br>No solid waste for disposal |
| **Europe – Germany: Niederaussem K** | 1175 (2002)<br>Total project cost | $NO_x$ 130 mg/$Nm^3$<br>$SO_2$ <200 mg/$Nm^3$<br>Dust <50 mg/$Nm^3$ | 965 | 27/580/600 | 43.2 LHV<br>37 HHV | 43.2 LHV<br>(base load)<br>37 HHV<br>(base load) | Lignite fuel, 50-60% moisture content<br>High steam parameters<br>Large cooling tower for low condenser pressure<br>Innovative heat recovery systems<br>Low auxiliary power |
| **North America – Canada: Genesee 3** | 1100 (2005)<br>Overnight cost | $NO_x$ 170 mg/$Nm^3$<br>$SO_2$ 295 mg/$Nm^3$<br>Dust 19 mg/$Nm^3$ | 450 | 25/570/570 | 41.4 LHV<br>40 HHV | 41 LHV<br>(base load)<br>39.6 HHV<br>(base load) | Moderately high steam parameters<br>Low auxiliary power<br>First N American sliding pressure supercrit.<br>Sub-bituminous coal |
| **Asia – Japan: Isogo New Unit 1** | 1800 (2006)<br>Total project cost incl. New Unit 2 under construction | $NO_x$ 20 mg/$Nm^3$<br>$SO_2$ 6 mg/$Nm^3$<br>Dust 1 mg/$Nm^3$ | 568 | 25/600/610 | 42 LHV<br>40.6 HHV | 42 LHV<br>(base load)<br>40.6 HHV<br>(base load) | High steam parameters<br>Moderately warm sea water cooling<br>Low auxiliary power<br>Low power demand FGD<br>Extremely low emissions<br>No solid waste for disposal |

## Table 4.12: Costs, emissions and efficiencies of the case-study plants and comments from IEA study entitled "Fossil fuel-fired power generation – case studies of recently constructed coal and gas-fired plants" (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)<br>Basis uncertain | $NO_x$ 83 mg/Nm$^3$<br>$SO_2$ 80 mg/Nm$^3$<br>Dust 10 mg/Nm$^3$ | 2x774 | 25/566/566 | 43.3 LHV<br>41.9 HHV | 41 LHV (capacity factor not known)<br>39.7 HHV<br>(capacity factor not known) | Moderately high steam parameters<br>Very low emissions<br>Low auxiliary power |
| **Asia – China: Wangqu 1, 2** | 580 (2006)<br>Overnight cost | $NO_x$ 650 mg/Nm$^3$<br>$SO_2$ 70 mg/Nm$^3$(des)<br>Dust 50 mg/Nm$^3$ | 2x600 | 24/566/566 | 41.4 LHV<br>40 HHV | New plant – no operating history | Moderately high steam parameters<br>Low auxiliary power<br>Advanced low-$NO_x$ lean coal combustion system |
| **Asia – India: Suratgarh 1-5** | 822 (2002)<br>Basis uncertain | $SO_2$ unabated<br>Dust 50 mg/Nm$^3$<br>(unit 5) | 5x227 | 15/540/540 | 37.1 LHV<br>35.1 HHV | 33.9 LHV<br>(base load)<br>32.1 HHV<br>(base load) | Subcritical cycle<br>High ash coal |
| **Africa – South Africa: Majuba 1-6** | 410 (2001)<br>Total project cost | $SO_2$ unabated<br>Dust 50 mg/Nm$^3$ | 3x612 (dry);<br>3x669 (wet) | 17/540/540 | 35-37 LHV<br>33.8-35.7 HHV | 34 LHV<br>(two-shifting)<br>32.8 HHV<br>(two-shifting) | Subcritical cycle<br>High ash coal<br>Dry cooling from water supply constraints |
| **Europe – United Kingdom: Natural gas plant: Enfield** | 950 (1999)<br>Total project cost | $NO_x$ 128 mg/Nm$^3$<br>$SO_2$ negligible<br>Dust zero | 373 | Advanced GTCC | 58 LHV<br>52 HHV | 52 LHV<br>(40% capacity factor)<br>47 HHV<br>(40% capacity factor) | Combined cycle with reheat gas turbine<br>Low auxiliary power<br>Zero solid waste |
| **IGCC general review** | PCC+20% | $NO_x$ 50-75 mg/Nm$^3$<br>$SO_2$ ~20 mg/Nm$^3$<br>Dust <1 mg/Nm$^3$ | 300/module | IGCC | 40-43 LHV<br>38-41 HHV | | Combined cycle<br>Syngas-fired gas turbine<br>Inert solid waste |

### 4.2.1.2 Pressurised Fluidised Bed Combustion (PFBC)

In fluidised bed combustion, coal is mixed with a sorbent and combusted with air in a reaction vessel. The incoming air stream fluidises the reactor contents. Most of the $SO_2$ produced by the oxidation of the sulphur in the coal is captured by the sorbent. The resultant ash is a dry, benign solid that can be disposed of easily or used in agricultural and construction applications.

Techno-economic data on PFBC are reported in table 4.13.

## Table 4.13 : Techno-economic data on PFBC (Pressurised Fluidised Bed Combustion)

| Short description | Environmental impact | | | | Technology Efficiency | Maturity | Investment | Fixed operating costs | Variable operating costs | Source of data |
|---|---|---|---|---|---|---|---|---|---|---|
| | $NO_x$ emission factor | $SO_2$ emission factor | TSP emission factor | $CO_2$ emission factor | | | | | | |
| | g/GJ fuel input | g/GJ fuel input | g/GJ fuel input | kg/GJ fuel input | % | | M€/MWth | M€/MWth | M€/MWhth | |
| Pressurised fluidised bed combustion | 50-80 | 80-95 | 99.9 PM (TSP, $PM_{10}$, $PM_{2.5}$) | | 40 (72 MW, HKW Cottbus, Germany, 1999) | commercial | 1 100 €/kW installed for 450MW installed (2005) | 0.15 c€/kWe for 450MW installed (2005) | | W. Fichtner, Pulverised Coal Firing, (ultra) supercritical (PCF - USC) - Pressurised Fluidised Bed Combustion (PFBC) - Pressurised Pulverised Coal Combustion (PPCC) - Questionnaire "Assessment of the Air Emissions Impact of Emerging Technologies", personal communication, 2004<br><br>Clean Coal Techniques, Coal Power for Progress, World Coal Institute<br><br>Enzensberger, Norbert (2003) Entwicklung und Anwendung eines Strom- und Zertifikatemarktmodells für den europäischen Enegiesektor, Dissertation an der Universität Karlsruhe. |

## 4.1.2. Combined Cycle Gas Turbine (CCGT)

A detailed expert view of the evolution of Combined Cycle Gas Turbine technology for electricity production is given in annex 7.2.

Techno-economic data on CCGT from EDIPOWER are reported in table 4.14.

Nowadays, the average efficiency of a 400 MWe CCGT unit is about 58%. In 2008, CCGT plants with an efficiency of 59.4% are commercially available. In 2015, it is possible to consider that an efficiency of 62% could be commercially available. According to experts, in 2035 CCGT plants should be able to reach commercial efficiency of 70% by improving component efficiencies and by using new materials. The efficiencies of CCGT plants should reach a ceiling of about 72% towards 2050.

The increase in efficiency will follow an increase in unit capacity. At present CCGT units (F technology) have a capacity of 430 MWe (in CCGT configuration). Technology of the H generation has a capacity of 530 MWe. Experts foresee that CCGT units could reach capacities of 600 to 700 MWe in the future.

Natural-gas-fired combined cycle technology is more efficient and less expensive than systems based on coal. The investment is split 1/3 for the gas turbine and in 2/3 for the steam cycle. Roughly 2/3 of operating costs come from the gas turbine and 1/3 from the steam cycle.

The most recently built plants are able to reach 20 $mg/Nm^3$ (based on a daily average, standard conditions and an $O_2$ level of 15%) without SCR.

## Table 4.14 : Techno-economic data on Combined Cycle Gas Turbine (CCGT)

| Short description | Environmental impact | | | | Technology Efficiency | Investment | Fixed operating costs | Variable operating costs | Source of data | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | $NO_x$ emission factor | $SO_2$ emission factor | other (to be specified) | $CO_2$ emission factor | | | | | | |
| | g/GJ fuel input | g/GJ fuel input | g/GJ fuel input | kg/GJ fuel input | % | M€/MWth | M€/MWth | M€/MWhth | | |
| 1375 MWth. (760 MWe); 2 x GTs size 250 MWe. F class + 1 RH ST w/ ACC | 26.7 (173 mg/kWhe) | | 19.1 (CO) (124 mg/kWhe) | 57.7 (374 g/kWhe) | 55.5 | 0.237 (2002) | Not available | Not available | Edipower | |
| 1393 MWth. (793 MWe) repowering of an oil-fired unit by retrofitting the existing common 320 MWe. RH ST w/ WCC; 2 x GTs size 270 MWe. F class | 21.3 (design) (135 mg/kWhe) | | 21.3 (CO) (design) (135 mg/kWhe) | 56.1 (355 g/kWhe) | 56.9 | 0.199 | Not available | Not available | Edipower | Under commissioning. Plant is equipped with HRSG duct firing, but emissions refer to operation w/o duct firing. Investment, referring to year 2004, includes GT packages, HRSG packages, ST&gen. refurbishment, new DCS, BOP necessary for integration in the existing power station. |
| 679 MWth. (375 MWe) 1 GT size 250 MWe F class + 1 RH ST w/ ACC | 28.8 (188 mg/kWhe) | | 16.4 (CO) (107 mg/kWhe) | 56.1 (367 g/kWhe) | 55.1 | 0.247 (2003) | Not available | Not available | Edipower | |

### 4.1.3. Impact of increased energy efficiency on $CO_2$ and pollutant emissions

The following results refer to a study carried out in February 2004, "Concept study reference power plant North Rhine Westphalia (RPP NRW)" and provided by VGB (H. KRUEGER).

The reference efficiency reported for combustion plants in the EU 27 countries is 36%. Improvement due to the application of several techniques could lead to an efficiency of 50%. As a result of lower energy consumption $CO_2$, $NO_x$ and PM emissions can be reduced.

The impact of increased energy efficiency on $CO_2$ and pollutant emissions is shown in tables 4.15 and 4.16.

## Table 4.15 : Impact of energy efficiency increase on $CO_2$

| Energy content, standard coal: 29.3 MJ/kg<br><br>$O_2$ in air: 20.938% | Short description Pulverised coal combustion, (technical description, type of fuel), Flue gas conditions: 1013 hPa, 0 °C, 6% $O_2$…) | $CO_2$ annual average: 11.307 % Hard coal C content: 84.25% | | | Energy consumption of the technique | | $CO_2$ eq. impact (from energy consumption) | Equipment lifetime | Invest-ment for new plants | Fixed operating costs | Variable operating costs | Source of data |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Abatement efficiency | Abated emission factor | Abated emission factor | Electricity | Fossil fuel (to be precised) | | | | | | |
| | | % | kg/GJe output | kg/GJ fuel input | kWh/GJ fuel input | MJ/GJ fuel input | $tCO_2$ eq./GJ fuel input | hour | M€/MWth | M€/MWth | M€/MWhth | |
| **Emerging abatement techniques** | | | | | | | | | | | | |
| **basis world: 33%** | existing 3x200 MWe | -8.33% | | | | | | | | | | |
| **basis EU 27: 36%** | existing 2x300 MWe | basis | 3542.15 | 1275.17 | | | | | | | | |
| **Effic. improvement: 45.90%** | RPPNRW 600MWe | 27.50% | 2778.15 | No change | 10 | | 0.007 | 200 000 | 0.396 | 0.058M€ /year | 0.044M€ /year | VGB 2003 |
| **47.30%** | RPPNRW 600MWe coal | 31.39% | 2695.93 | No change | | | | | 0.417 | | 0.0434M€ /year | VGB 2003 |
| **50%** | AD 700 | 38.89% | 2550.35 | No change | | | | | | | | |
| **basis world: 50%** | AD 700 | 51.52% | 3864.16 | | | | | | | | | |
| **56%** | IGCC next step | 55.56% | 2277.09 | No change | | | | | | | | |
| **basis world: 50%** | AD 700 | 69.70% | | | | | | | | | | |

## Table 4.16 : Impact of energy efficiency increase on pollutant emissions

| Energy content, standard coal: 29.3 MJ/kg<br><br>$O_2$ in air: 20.938% | Short description Pulverised coal combustion, (technical description, type of fuel), Flue gas conditions: 1013 hPa, 0 °C, 6% $O_2$…) | Impact on pollutant emissions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | TSP annual average: 10 mg/m³ | | | $NO_x$ annual average: 100 mg/m³ | | | $SO_2$ annual average: 150 mg/m³ | | |
| | | Abatement efficiency | Abated emission factor | Abated emission factor | Abatement efficiency | Abated emission factor | Abated emission factor | Abatement efficiency | Abated emission factor | Abated emission factor |
| | | % | g/GJe output | g/GJ fuel input | % | g/GJe output | g/GJ fuel input | % | g/GJe output | g/GJ fuel input |
| **Emerging abatement techniques** | | | | | | | | | | |
| **basis world: 33%** | existing 3x200 MWe | | | | | | | | | |
| **basis EU 27: 36%** | existing 2x300 MWe | EU basis | 109.02 | 39.25 | EU basis | 1090.20 | 392.47 | EU basis | 1635.30 | 588.71 |
| **Effic. improvement: 45.90%** | RPPNRW 600MWe | 27.50 | 85.51 | No change | 27.50 | 855.06 | No change | | 1282.59 | No change |
| **47.30%** | RPPNRW 600MWe coal | 31.39 | 82.98 | No change | 31.39 | 829.75 | No change | | 1244.63 | No change |
| **50%** | AD 700 | 38.89 | 78.49 | No change | 38.89 | 784.95 | No change | | 1177.42 | No change |
| **basis world: 50%** | AD 700 | | 118.93 | | | 1189.31 | | | 1783.97 | |
| **56%** | IGCC next step | 55.56 | 70.08 | No change | 55.56 | 700.84 | No change | 55.56 | 1051.27 | |
| **basis world: 50%** | AD 700 | | | | | | | | | |

### 4.1.4. Impact of energy efficiency and plant sizes on costs

The cost increases related to net efficiency of power plants and the impact of plant sizes on the cost of reduction techniques (SCR, FGD) are presented in the report by Jean-Pierre RIVRON entitled "Technical and economical data on depollution systems" in annex 7.3.

## 4.3. Emerging abatement techniques

Several emerging abatement techniques were explored by the LCP2030 sub-group: Flowpac, limestone injection multistaged burner (LIMB), $SO_x$-$NO_x$-Rox-Box (SNRB), fine particle collector and $CO_2$ abatement techniques.

According to the expert views and the available data, the following emerging abatement techniques were considered by the LCP2030 sub-group as most promising:

- Flowpac for $SO_2$ abatement
- Fine particle abatement techniques
- $CO_2$ abatement techniques.

### 4.3.1. Flowpac (Alstom)

Flowpac is a promising end-of-pipe desulphurisation (wet FGD) technology using a bubbling technology instead of circulation pumps.

Difficulties and power consumption are minimised by the suppression of recycle pumps, spray nozzles, headers, separate oxidation tanks and thickeners. Power consumption is lower with Flowpac (1.3% of the power capacity) than with classical wet FGD (1.7/1.75%).

The process has a compact design and achieves high desulphurisation rates (>99%) with high sulphur content fuels (>1.5%). $SO_3$ abatement efficiency is around 60-70%.

Flowpac has a low capital cost due to elimination of spray pumps and associated equipment. In 2003, the investment for Flowpac technology for desulphurisation of two 600MWe coal units was 58 €/kWe (70 M€ for 2x600MWe coal units). This cost was 6% lower than for classical wet desulphurisation (61€/kWe; 74 M€ for 2x600MWe coal units).

The system is currently implemented in oil-fired plants (<340MWe) and needs to be demonstrated with coal-fired plants.

For more information see annex 7.3 "Report on technical and economical data on depollution systems" (Jean-Pierre RIVRON, March 2008).

### 4.3.2. Fine particle abatement techniques

COHPAC and TOXECON are technologies developed in the USA to capture emissions such as particulate matter, mercury and dioxins. COHPAC in combination with TOXECON offers the ability to significantly reduce mercury, sulphur dioxide and other toxic emissions (dioxins) at a lower investment cost.

The Indigo Agglomerator, developed in the USA, agglomerates fine particles with heavy particles to better capture them. The particles are then easily collected in an electrostatic precipitator. A reduction of fine particle emissions by a factor of 10 is achieved. It seems that the agglomerator is used only in plants not equipped with wet FGD.

For more information see annex 7.3 "Report on technical and economical data on depollution systems" (Jean-Pierre RIVRON, March 2008).

### 4.3.3. $CO_2$ abatement techniques

$CO_2$ emissions from fossil-fuel-fired power plants can be reduced by energy efficiency improvement or capture of $CO_2$ that is released and then stored underground.

$CO_2$ capture processes lead to an efficiency loss estimated to be 8-12 percentage points for existing coal power plants. Due to the efficiency drop with $CO_2$ capture, increasing the efficiency of fossil-fuel-fired power plants is the first step. In parallel, a priority is the improvement of the energy efficiency of $CO_2$ capture processes and optimisation of the steam cycle for the heat demands for $CO_2$ capture.

There are three types of $CO_2$ capture processes:

- Post-combustion processes which consist in extracting the $CO_2$ that is diluted in the combustion flue gas. Post-combustion is the most advanced technology today. The solvents for $CO_2$ post-combustion capture can be physical, chemical or intermediate. Chemical solvents, such as amines, are most likely to be used. Other post-combustion capture solutions are absorption (new solvents, chilled ammonia), adsorption, anti-sublimation, membranes.
- Oxy-combustion processes which consist in 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.
- Pre-combustion processes which involves conversion (gasification or partial oxidation) of fuel into a synthesis 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.

The level and nature of impurities in the $CO_2$ stream can affect its transport and storage. The $CO_2$ purity level will impact the choice of pollutant abatement techniques.

Some $CO_2$ processes are also sensitive to pollutants. For example, $NO_2$ and $SO_2$ from flue gas react with amine (post-combustion capture) to form stable, non-regenerable salts and so cause a loss of some amine. With amine, $SO_2$ specification is usually set as <40 mg/Nm$^3$ and $NO_2$ specification as <50 mg/Nm$^3$ (based on a daily average, standard conditions and an $O_2$ level of 6%).

Limits for $SO_x$ can be achieved by some FGD technologies. Experience at the CASTOR(1) pilot plant (post-combustion capture with amine) shows that limestone gypsum flue gas desulphurisation (FGD) plants can be designed to reduce $SO_2$ emissions down to 10 mg/Nm$^3$ with an increase in capital costs of about 7% and a 27% increase in operating costs. Limits for $NO_x$ are technically achievable by the use of low-NOx burners and SCR.

Other types of CCS technology are available but not of mature status for application to large combustion plants. For example, a new technology for $CO_2$ capture by anti-sublimation, was presented by Ms Rima EL HITTI of the Ecole des Mines de Paris (cf. annex 7.8). It is based on the principle that $CO_2$ anti-sublimates at a cold surface with a temperature of about -110°C.

$CO_2$ capture and storage in power plants is now being demonstrated in a few small-scale pilot plants. Large-scale demonstration plants with carbon dioxide capture and storage (CCS) are planned by around 2015 with the objective of developing CCS by 2020.

CCS costs are highly project-specific. Many techno-economic studies give information on performance and costs. Nevertheless, data on large-scale $CO_2$ capture implementation are not available. The objective is to reduce CCS costs to below 25€/t of avoided $CO_2$ by 2030.

There is no consensus on which option (post, pre or oxy-combustion) will be least costly in the future, each has pros and cons and the costs appear to be comparable.

The efficiency penalties of $CO_2$ capture will become lower for future power plants as the trend to higher efficiencies continues, with efficiencies above 50% now in sight.

(1) Féraud A, Marocco L, Howard T (2006) CASTOR study of technological requirements for flue gas clean-up prior to CO2-capture. In: 8th international conference on greenhouse gas control technologies, Trondheim, Norway, 19-22 Jun 2006. Oxford, UK, Elsevier Ltd., paper 01_05_06.PDF, 6p. (2006) CD-ROM

### 4.3.4. $SO_x$-$NO_x$-Rox Box (SNRB™)

The $SO_x$-$NO_x$-Rox Box process combines hydrated lime and ammonia injection upstream of a hot catalytic baghouse (box) where the solid product – calcium sulphite and sulphate – and particulates (Rox) are removed, and the $NO_x$ is reduced to nitrogen and water.

The SNRB process has proven to be a highly efficient control system for $SO_2$, $NO_x$ and particulates. Typical performances are 80-90% $SO_2$ removal, 90% $NO_x$ removal and 99.99% particulates removal.

Commercialisation of the technology is expected to develop with an initial larger-scale application equivalent to 50-100MWe.

SNRB was not considered by the experts as promising mainly due to the hazardous waste by-product.

Data on SNRB from IFARE are reported in table 4.17.

## Table 4.17 : Data on SNRB

| Short description | $NO_x$ | Impact on other emissions | | | Maturity | Investment | Fixed operating costs | Variable operating costs | Source of data | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $SO_2$ | TSP | Other pollutant (to be specified) | | | | | | |
| | Abatement efficiency | Abatement efficiency | Abatement efficiency | Abatement efficiency | | | | | | |
| | % | % | % | % | | M€/MWth | M€/MWth | M€/MWhth | | |
| $SO_x$-$NO_x$-Rox-Box (SNRB) | 90 | 80-90 | 99.99 | HF 84<br>HCL 95 | pilot | | | | B&W technical paper, Paul S. Nolan, Flue Gas Desulphurization Technologies for Coal-fired Power Plants, January 2000.<br><br>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 large-scale application equivalent to 50-100MWe |

### 4.3.5. Limestone Injection Multistage Burner (LIMB)

Initially, limestone was injected through staged low-$NO_x$ burners. Studies have shown that moderate levels of $SO_2$ emission control were possible by injecting sorbent within certain windows, according to the boiler's time temperature profile.

Data on LIMB from IFARE are reported in table 4.18.

LIMB was not considered by the experts as promising as it has problems in terms of reliability and mediocre abatement efficiency.

### Table 4.18 : Data on LIMB

| Short description | $NO_x$ | Impact on other emissions | | | Maturity | Investment | Fixed operating costs | Variable operating costs | Source of data | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $SO_2$ | TSP | Other pollutant (to be specified) | | | | | | |
| | Abatement efficiency | Abatement efficiency | Abatement efficiency | Abatement efficiency | | | | | | |
| | % | % | % | % | | M€/MWth | M€/MWth | M€/MWhth | | |
| Limestone Injection Multistage Burner (LIMB) | 40-50 | 65-70 | | | demonstration | | | | B&W technical paper, Paul S. Nolan, Flue Gas Desulphurization Technologies for Coal-fired Power Plants, January 2000.<br><br>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 independent power plant in Canada. The low-$NO_x$ burners have an estimated value of 388 million dollars. |

## 4.4. Improvement of existing abatement techniques

No significant improvements in existing abatement techniques have been identified compared to the information already available in the European BREF document on LCP. The IEA study on fossil-fuel-fired power generation reports some very low emissions for a few recently constructed coal power plants.

In order to compare existing data with the modelling data and to update them, costs and performances of abatement techniques at existing installations have been provided by the experts (Tables 4.19, 4.20, 4.21, 4.22).

## Table 4.19 : Techno-economic data on $NO_x$ abatement techniques

| | Short description (technical description, type of fuel,…) | $NO_x$ | | Impact on other emissions | | | | | | Source of data |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $SO_2$ | | TSP | | Other pollutant (to be precised) | | |
| | | Abatement efficiency | Abated emission factor | Abatement efficiency | Abated emission factor | Abatement efficiency | Abated emission factor | Abatement efficiency | Abated emission factor | |
| | | % | g/GJ fuel input | % | g/GJ fuel input | % | g/GJ fuel input | % | g/GJ fuel input | |
| **Improvement of existing abatement techniques** | | | | | | | | | | |
| **SCR conventional boiler** | 2x160 MWe existing units retrofitted w/ Hi-dust SCR reagent: $NH_3$ 25% in water<br>design fuel: oil 3% S | 89 (design) | 28.1 (emission) (284g/MWhe)<br>225 (abated) | 0.5-1% conversion $SO_2$ to $SO_3$ | | | | | | Edipower<br>Power plant Italy |
| **Air staging (burners out of service-BOOS)** | 4x160 MWe existing units retrofitted w/ BOOS<br>operating fuel: oil 1% S | 55 | 112 (emission)<br>(1125g/MWhe)<br>140 (abated) | | | | | | | Edipower<br>Power plant Italy |
| **SCR for gas combined cycle - downstream GT** | CCPP w/ 2xGT 250 MWe size F class<br>Fuel: natural gas | 50 (design) | 16.4 (design)<br>(107g/MWhe) | | | | | | | Edipower<br>Power plant Italy |

| | Short description (technical description, type of fuel,…) | Energy consumption of the technique | | $CO_2$ eq. impact (from energy consumption) | Equipment lifetime | Investment | Fixed operating costs | Variable operating costs | Source of data | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Electricity | Fossil fuel (to be precised) | | | | | | | |
| | | kWh/GJ fuel input | MJ/GJ fuel input | $tCO_2$/GJ fuel input | year | M€/MWth | M€/MWth | M€/MWhth | | |
| **Improvement of existing abatement techniques** | | | | | | | | | | |
| **SCR conventional boiler** | 2x160 MWe existing units retrofitted w/ Hi-dust SCR reagent: $NH_3$ 25% in water design fuel: oil 3% S | 0.25 (including increase of ID fan power which impacts almost 90%) | | 1.846E-4 (based on: power plant net efficiency=36%; 85% Carbon content; LHV=41.9 MJ/kg) | design 30 | 0.0238 | | 3.36E-7 | Edipower Power plant Italy | SCR retrofit under construction variable costs based on ammonia 25% water solution unit cost = 225 €/t |
| **Air staging (burners out of service-BOOS)** | 4x160 MWe existing units retrofitted w/ BOOS operating fuel: oil 1% S | | | | operating since 6 yrs | 0.00012 | | | Edipower Power plant Italy | investment is an estimate Operating system retrofitted (6yrs track record) |
| **SCR for gas combined cycle - downstream GT** | CCPP w/ 2xGT 250 MWe size F class Fuel: natural gas | 0.121 (almost 90% due to increase in GT backpressure due to SCR installation) | | 4.44E-4 (based on: power plant net efficiency=55%; 71.6% carbon content; LHV=46.8 MJ/kg) | design 30 | 0.0044 | | 2.04E-8 (reagent) | Edipower Power plant Italy | Tender (project not executed) Variable costs based on ammonia 25% water solution unit cost = 180 €/t |

## Table 4.20 : Techno-economic data on $SO_2$ abatement techniques

| | Short description (technical description, type of fuel,…) | $SO_2$ | | Impact on other emissions | | | | | | Source of data |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $NO_x$ | | TSP | | Other pollutant (to be precised) | | |
| | | Abatement efficiency | Abated emission factor | Abatement efficiency | Abated emission factor | Abatement efficiency | Abated emission factor | Abatement efficiency | Abated emission factor | |
| | | % | g/GJ fuel input | % | g/GJ fuel input | % | g/GJ fuel input | % | g/GJ fuel input | |
| **Improvement of existing abatement techniques** | | | | | | | | | | |
| **Wet lime/limestone scrubber** | single FGD (common absorber w/ 3 spray levels) downstream 2 units 160MWe each<br><br>design fuel: oil 3% S; absorbent: limestone slurry | 95.8 (design) | 56.3 (emission)<br><br>(568g/MWhe) | 0.5-1% conversion $SO_2$ to $SO_3$ | | not available (heavily influenced by particulate load and size at entry). From a study by CRIEPI of Japan dated 1987 on operating power stations, removal efficiency is just over 90% only for particulate size greater than 2 microns. | | | | Edipower<br><br>Power plant Italy |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Jet Bubbling Reactor** | Single FGD downstream 2 units 160 MWe each; design fuel: oil 3% S; absorbent: limestone slurry | 95.8 (design) | 56.3 (emission)<br>(568g/MWhe)<br>1346 (abated) | | | >90% on average (also submicronic); less influenced by particulate size than WFGD removal efficiency (as resulting from mentioned the study of Japan Central Research Inst. for Electr. Power Industry). | | | | Edipower<br>Power plant Italy |
| **Wet lime/limestone scrubber** | 2x300 MWe conventional lignite fired units each equipped w/ 2 ESP in parallel and 1 limestone WFGD; design fuel LHV = 5.024 MJ/kg AF; design fuel S content = 2.39% AF | 95.8 (design) | 184 (emission)<br>(2077g/MWhe) | | | 50% (design) | 13.8 (emission)<br>(158g/MWhe) | | | Edipower<br>Power plant East EU |
| **Low Sulphur/Ash Fuel** | 2x320 MWe Conventional coal fired units. Fuel switched from about 1% to about 0.1% Sulfur content (and to less than 1% ash content) | 98.2 (design) | 71.5 (emission)<br>363 (abated) | | | 88.50% | 5.36 (emission)<br>46.6 (abated) | | | Edipower<br>Power plant Italy |

## Table 4.21 : Techno-economic data on $SO_2$ abatement techniques (continued)

| | Short description (technical description, type of fuel,…) | Energy consumption of the technique | | $CO_2$ eq. impact (from energy consumption) | Equipment lifetime | Investment | Fixed operating costs | Variable operating costs | Source of data | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Electricity | Fossil fuel (to be precised) | | | | | | | |
| | | kWh/GJ fuel input | MJ/GJ fuel input | $tCO_2$/GJ fuel input | year | M€/MWth | M€/MWth | M€/MWhth | | |
| **Improvement of existing abatement techniques** | | | | | | | | | | |
| **Wet lime/limestone scrubber** | single FGD (common absorber w/ 3 spray levels) downstream 2 units 160MWe each<br><br>design fuel: oil 3% S; absorbent: limestone slurry | 1.37<br><br>(included increase in ID fan power consumption that impacts about 55%) | | 10.04E-4<br>(based on a power plant net efficiency of 36% and on a 83% Carbon content in the fuel and a fuel LHV=41.9 MJ/kg) | design 30 | 0.043<br><br>(estimated as part of an EPC LSTK contract including $DeSO_x$ and $DeNO_x$; includes also GGH beyond WFGD system) | | 3.3714E-7<br>($CaCO_3$ consumption) | Edipower<br><br>Power plant Italy | Retrofit project under execution<br><br>To produce gypsum pursuant to Eurogypsum quality requirements, particulate capture inside absorbers is not desiderable. |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Jet Bubbling Reactor** | Single FGD downstream 2 units 160 MWe each; design fuel: oil 3% S; absorbent: limestone slurry | 1.508<br><br>(included increase in ID fan power consumption that impacts about 68%; slurry preparation not included) | | 11.05E-4<br>(based on a power plant net efficiency of 36% and on a 83% Carbon content in the fuel and a fuel LHV=41.9 MJ/kg) | design 30 | 0.045<br><br>(estimated as part of an EPC LSTK contract including $DeSO_x$ and $DeNO_x$; includes also GGH beyond WFGD system) | | 3.3714E-7<br>($CaCO_3$ consumption) | Edipower<br><br>Power plant Italy | Tender; project not executed<br><br>In this type of application (one common FGD for two boilers) JBR could have lower power consumption at part load |
| **Wet lime/limestone scrubber** | 2x300 MWe conventional lignite fired units each equipped w/ 2 ESP in parallel and 1 limestone WFGD; design fuel LHV = 5.024 MJ/kg AF; design fuel S content = 2.39% AF | 4.03 (included limestone slurry preparation that impacts about 10 %; ID fan not included) | | 8.066E-3<br>(based on complete oxydation of 16% C by wt in the fuel and on a net power plant efficiency of 31.8%) | design 30 | 0.03148 | | 2.04E-8<br>(reagent) | Edipower<br><br>Power plant East EU | Project under execution<br><br>Cost referred to 2005 |
| **Low Sulphur/Ash Fuel** | 2x320 MWe Conventional coal fired units. Fuel switched from about 1% to about 0.1% Sulfur content (and to less than 1% ash content) | | | 9E-3<br>(based on different specific Carbon content of the fuels: 28.45% low S/ash coal vs 25.98% old coal) | Since 6 years | | | | Edipower<br><br>Power plant Italy | |

## Table 4.22 : Techno-economic data on PM abatement techniques

| | Short description (technical description, type of fuel,…) | TSP | | Impact on other emissions | | | | | | Source of data |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $SO_2$ | | $NO_x$ | | Other pollutant (to be precised) | | |
| | | Abatement efficiency | Abated emission factor | Abatement efficiency | Abated emission factor | Abatement efficiency | Abated emission factor | Abatement efficiency | Abated emission factor | |
| | | % | g/GJ fuel input | % | g/GJ fuel input | % | g/GJ fuel input | % | g/GJ fuel input | |
| **Improvement of existing abatement techniques** | | | | | | | | | | |
| **ESP** | 4x160 MWe units; one ESP (3 fields - abatement surface: 7600 $m^2$) on each unit; fuel: oil 1% Sulphur | 85% (82.5% design) | 6.47 (emission) 36.58 (abated) | | | | | | | Edipower Power plant Italy |
| **Fabric Filters** | 2 unitsx320 MWe coal fired power plant (max 1% S) | 99.9% (design) | 4.34 (emission) 4336 (abated) | | | | | | | Edipower Power plant Italy |
| **ESP** | 2x300 MWe conventional lignite fired units each equipped w/ 2x3-fields-ESP in parallel and 1 limestone WFGD; design fuel LHV = 5.024 MJ/kg AF; design fuel S content = 2.39% AF | 99.9% (design) | 27.6 (emission) 31360 (abated) | | | | | | | Edipower Power plant East EU |

| | Short description (technical description, type of fuel,…) | Energy consumption of the technique | | $CO_2$ eq. impact (from energy consumption) | Equipment lifetime | Investment | Fixed operating costs | Variable operating costs | Source of data | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Electricity | Fossil fuel (to be precised) | | | | | | | |
| | | kWh/GJ fuel input | MJ/GJ fuel input | $tCO_2$/GJ fuel input | year | M€/MWth | M€/MWth | M€/MWhth | | |
| **Improvement of existing abatement techniques** | | | | | | | | | | |
| **ESP** | 4x160 MWe units; one ESP (3 fields - abatement surface: 7600 $m^2$) on each unit; fuel: oil 1% Sulphur | 0.132 | | 9.7E-5 | 6 (operation) design 30 | 0.0133 | | | Edipower Power plant Italy | These ESP's are in operation since year 2003 |
| **Fabric Filters** | 2 unitsx320 MWe coal fired power plant (max 1% S) | 0.46 (mainly ID fan) | | 4.46E-4 (based on 62% C in the fuel; LHV=23.86 MJ/kg; net plant efficiency=35.7%) | design 30 | 0.008235 | | | Edipower Power plant Italy | Tender for a project of conversion of the existing ESP's with FF's in order to increase the abatement efficiency. Cost is referred to 2003 and is based on maintaining filter casing. |
| **ESP** | 2x300 MWe conventional lignite fired units each equipped w/ 2x3-fields-ESP in parallel and 1 limestone WFGD; design fuel LHV = 5.024 MJ/kg AF; design fuel S content = 2.39% AF | 0.31 | | 6.20E-4 (based on: power plant net efficiency=55%; 71.6% carbon content; LHV=46.8 MJ/kg) | design 30 | 0.0062 | | | Edipower Power plant Italy | Project under execution; cost referred to 2005. Reported TSP emission is the one downstream ESP (further 50% reduction expected in WFGD absorber). |

## 4.5. Emerging applications of existing abatement techniques

$SO_3$ injection upstream of a precipitator was the only technology identified as an emerging application of an existing abatement technique to reduce PM emissions.

For more information see annex 7.3 "Report on technical and economical data on depollution systems" , Jean-Pierre RIVRON, March 2008.

# Future work

Some technologies/techniques (e.g. catalytic combustion) were considered as outside the scope of the LCP2030 subgroup which considered only power plants with capacities higher than 500 MWth. Future work by the sub-group could consider large combustion plants with lower capacities (e.g. >100 MWth).

# 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 |