EUROPEAN UNION

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REPORT

BENCHMARKING LEARNING TOUR TO THERMAL POWER PLANTS AND RESEARCH CENTRES IN GERMANY AND UK

06th February to 17th February 2012

Under the Project
Developing a Cluster for Clean Coal Technologies (CCT) and Carbon Capture and Storage (CCS) Technologies for the Indian Thermal Power Sector

I. **Period of Visit** : 06th February to 17th February 2012 (12 days)

II. **Purpose of the Visit** : Benchmarking Learning tour to pilot plants, demonstration plants, Research Centre etc in CCT and CCS domain in Germany and UK working on oxyfuel combustion, CO_2 Capture and storage and Co-firing biomass

III. Places visited:

(1) Germany:

a) Schwarze Pumpe power station and Oxy fuel Pilot plant, Spremberg
b) CO_2 Storage Facility, Ketzin
c) Staudinger Post Combustion Pilot Plant, Siemens, Offenbach
d) RWE Coal Innovation Centre, Niederaussem Power Plant, Niederaussem

(2) UK:

e) IEA Clean Coal Centre, London
f) British Geological Survey and National Centre for Carbon Capture & Storage (NCCCS), Nottingham
g) University of Nottingham
h) Post Combustion Carbon capture Pilot Plant, Ferry bridge Doosan Power Station, Yorkshire
i) Renfrew test facility, Doosan Power systems, Glasgow

IV. Learning Tour Team:

A team of six members comprising of Senior Engineers from BHEL and Project Management team from TREC-STEP participated in the benchmarking learning tour 06th February to 17th February 2012.

V. Key learnings from the Bench Marking Learning Tour:

- The learning tour provided invaluable opportunity to physically see and understand the demonstrations plants in operation in Germany and UK
- Informative and great learning about Oxyfuel combustion technology and Carbon capture and Storage technologies
- Opportunity to interact with experts for enhancing knowledge in the CCS areas
- Understanding the current situation on CCT and CCS projects in European countries
- Design inputs collected for the improvement of the design of the planned demonstration project in Oxy fuel combustion and Bio-mass co-firing from the visited institutions
- Inputs on safety measures to be undertaken for oxy-fuel combustion was a vital knowledge component
- Comparison of performance parameters with air firing

VI. Visit to pilot plants, demonstration plants, Research Centre etc in CCT and CCS domain in Germany and UK:

1. Schwarze Pumpe power station, Spremberg, Germany:

The team visited Vattenfall power station at Schwarze Pumpe, Germany, the global icon for oxy-fuel CCS initiative on 7th February, 2012. Mr. Lutz Picard, Oxyfuel Pilot Plant, interacted with the team explaining Vattenfall Strategy of CO2-Reduction, Oxyfuel Pilot Plant, CO2 Transport and Storage and Future prospects.

Vattenfall is a European Energy Company with Parent Company Vattenfall AB. Its State owned Headquarter is in Stockholm. Vattenfall had a power generation of 172.5 TWh in 2010 and was ranked third in Europe. Core markets are in Sweden, Germany and Netherlands. Vattenfall energy mix consisted of Coal - 44 %, Nuclear - 25 %, Hydro - 21 %, Natural gas - 8 % &Wind, biomass, oil, and waste- 2 %.

Schwarze Pumpe power station

Oxyfuel pilot plant

Schwarze Pumpe has a 2 x 800 MW power plant operating on lignite. It came into service in 1997-98 and owned by the utility Vattenfall. Lignite is mined from an open cast mine having 12 million tonnes of geological deposits with an age of 12 million years. The properties of lignite are given below.

- Calorific value 8,3 – 9.2MJ/kg
- Carbon content 26 – 27,7 %
- Water content 54 – 55.6 %
- Ash content 2.6 – 6.9 %
- Sulphur content 0.3 – 1.4 %

Vattenfall has a target of CO_2-Reduction by 50 % until 2030. One of the efforts taken in this direction is to go for Oxyfuel combustion systems for CO_2 capture. World's first "carbon-dioxide free" oxy-fuel test facility in pilot scale was constructed on 26 May 2006 in the Schwarze Pumpe industrial area. This is a facility with a thermal power of 30 MW. The resulting carbon dioxide is compressed and liquefied. It is then put into geologic formations and stored at Ketzin so as not to contribute to global warming. The facility was commissioned in 2008 and test runs are planned until 2014. It spreads over an area of 14,500 m2 beside 2 x 800 MW-Power Station Schwarze Pumpe with integration into the already existing infrastructure of the industrial area Schwarze Pumpe (steam, coal, ash, water, gypsum)

This forms part of Vattenfall's programme to develop and commercialise oxy-fuel technology and is viewed as a crucial stage in scaling up the technology for a 250–350 MW near-zero emission demonstration. The main objectives of the Schwarze Pumpe project include validation of engineering techniques, improved understanding of oxy-fuel combustion dynamics, and a demonstration of the capture technology. The programme will focus predominantly on the optimisation of oxyfuel technology within the plant's major components.

The pilot incorporates the complete process chain, as required for a full-scale power generation plant. This includes steam generator, ASU, ESP, FGD, flue gas clean-up system, and CO_2 treatment plant. This approach allows the testing of each component of the full capture chain and the interaction of the different components in terms of start-up, shut-down, load change behaviour, and switch from air to oxy-fuel combustion. As already well-established technology, no steam turbine is used. The plant's steam generator produces ~40 t/h of steam at 330°C and 25 MPa; this requires 5.2 t/h of pulverised lignite and 10 t/h of oxygen. At full load, ~9 t/h of liquefied CO2 is produced. Alstom supplied the plant's steam generator and ESP. Air Products supplied the CO2 handling equipment and the ASU was supplied by Linde. During the course of the programme, a range of lignites and hard coals will be tested.

Other factors to be addressed include coal moisture content, variation of excess oxygen content (1–5%), variation of flue gas recirculation rate, and variation of different oxygen content at different burner registers. CO2 captured from the plant (90% capture target) will be transported by truck to the Altmark natural gas field in Northern Germany, Europe's largest on-shore field. During a three-year trial, CO2 will be injected into depleted gas reservoirs to determine if the field's lifetime can be extended, once a permit for storage operations has been obtained. There are plans to inject a total of 100 kt of CO2, although the formation has an estimated storage capacity of 600 Mt.

The basic purpose of the plant is to provide operating information to make it possible to scale-up the technology to a 400–600 MW demonstration power plant. The plant operates with a complete process of coal input and oxygen production up to separation of CO2. It is possible to operate on full load both in air firing mode and oxy-fuel mode. The present plant is designed to operate on lignite and in a second phase on bituminous coal.

The plant had operated using lignite for over 3000 hours with slightly more than half of this time in the oxy-fuel mode. 1400 tonnes of CO2 had been captured. **It is possible to change from air firing to oxyfuel firing in 20 minutes**. Good flame stability has been obtained at oxygen concentrations above 21 wt% but different burner swirls are necessary for air and oxy-fuel operation. Some combustion tests still to be carried out include

- Variation of coal quality (moisture, sulphur content, particle size)
- Different burners with integrated ignition burner
- Material tests for demonstration plants and 700ºC technology under an oxyfuel atmosphere
- Co-firing biomass and bituminous coal
- deNOx tests.

The burner operates in premixed mode in a stable and reliable way with an oxygen concentration of 28 vol%. Limits for emissions are kept easily for the oxy-fuel mode of operation. Indeed, primary measures for NOx reduction were not required, typical emissions being <700 mg/m3 (dry). Burnout was good with low unburnt carbon in the fly ash and slag.

2. CO2 Sink – Ketzin, Germany:

The team visited Ketzin site on 8th February, 2012. Ketzin again is the very unique facility where intensive research on storage challenges of CO2 are studied with various IT models and rigorous testing schedules. This is the first ever Indian team to visit this pioneering site and the team greatly appreciated the opportunities provided for this by the project. Dr Fabian Moller from Zentrum for CO2 – Speicherung Operation Engineering interacted with the team. The project aims to develop the basis for the underground storage technology by injecting CO2 into a saline aquifer near the town of Ketzin west of Berlin. At Ketzin, geological data are available from previous exploration in connection to underground storage of natural gas. In addition to older observations complementary investigations has provided new valuable geological information from the site. A test storage system is established in a sandstone reservoir at depths below 600 metres and injection of CO2 has been carried out.

Vattenfall is one of the partners involved in the project, which is coordinated by GFZ, the German Research Centre of Geosciences. The project started in 2004 and in 2008 the first CO2 was injected into previously examined geological formations. Approximately 30000 tons of CO2 have been stored underground.

- ***Company/Alliance:*** Lead: GFZ German Research Centre for Geosciences and Ketzin partners
- ***Size:*** 0.06 MT/Yr
- ***CO_2 Source:*** Hydrogen production and oxy-fuel pilot plant (Schwarze Pumpe)
- ***Storage:*** Sandstone reservoir (630 m)
- ***Motivation/Economics:*** Monitoring CO2 in the subsurface and feasibility of sequestration. To provide information for future policy making in EU.

There are four central objectives for the CO2MAN research project undertaken in the site:

- Monitoring the migration behaviour of the injected CO2,
    - Determining the sensitivity of individual monitoring methods
    - Developing geophysical monitoring concepts for CO2 storage
- Characterizing and quantifying the CO2-induced interactions between fluids, rock and the microbial community in the storage system
- Validating the tools for statistic modeling and dynamic simulation at the real-life storage site in Ketzin
- Transferring knowledge to the public and to interest groups, policy-makers and approval agencies

Focal points of the work:

- Monitoring and securely carrying out the injection operations
- Planning and carrying out measurement campaigns
- Drilling of additional wells

From June till August 2011, an observation well was drilled ending at the top of the cap rock of the storage formation. In 2012, another observation well will lead into the storage reservoir, which already contains CO2 in order to investigate the storage conditions in light of the ongoing CO2 injection since 2008.

3. Staudinger Post Combustion Pilot Plant, Siemens, Germany:

The team visited Siemens Energy Sector Fossil Division - New Technologies Carbon Capture and Sequestration on 9th February, 2012. This is the first post combustion facility visited by the team and unique in many respects. Dr.Ruediger Schneider, Head R&D and Mr. Gernot Schneider, Director Marketing and Sales interacted with the team on the carbon capture technologies developed by Seimens.

Existing coal-based IGCC power plants with Siemens technology includes 298 MW Puertollano, Spain plant and 253 MW Buggenum, Netherlands plant. Siemens offers several gasifier frame sizes: SFG-200; SFG-500; SFG-850; SFG-1200. Gasification is able to meet the strictest environmental regulations: Low emission of particulate matter, organic compounds and easy disposal of sulphur and Possibility of capturing and storing or sequestering CO2. Various projects were executed by Seimens on IGCC with polygeneration of chemicals which includes Summit Texas Clean Energy Project and Ningxia Coal to Polypropylene project.

Siemens Post-Combustion Carbon Capture for Fossil Fuel fired Power Plants is based on amino acid salt formulation for the capture of CO2 from flue gas. CO2 Absorption, Desorption is a proven technology in chemical processing, oil and gas industry. The project aims at “Scalable” market introduction, retrofitable to existing power plants, introducing preferred solution for CCS demonstration projects and mastering Scale up from pilot to demonstration plant. The amino acid salts developed have no vapour pressure. Therefore the solvent slip can be completely eliminated. The flue gas is sent into an absorption tower where amino acid salts absorb CO2 in the flue gas. The salts are regenerated using Low Pressure steam at 90-105 deg C. 2.7 GJ energy is required for regenerating solvent per tonne absorption of CO_2, which is equivalent to 40% LP steam. The amino acid salts have very low O_2 degradation rate. The efficiency is < 6 %-pts, lower than the hard-coal fired power plant, without CO2 compression. To compensate for the Solvent deactivation due to degradation(thermal, O2 , NOx ,SOx , etc...), Siemens have developed a proprietary reclaimer technology which reduces solvent consumption, waste disposal and operating cost. Various future projects and prospects for the technology were also discussed.

A visit was made to the pilot scale test facility for capturing 1 tonne per day of CO2 from a slip stream of flue gas generated by 4 x 500 MW hard coal fired power plant.

4. RWE Coal Innovation Centre, Niederaussem Power Plant, Germany:

On 10th February, 2012, the team visited Niederaussem Coal Innovation Centre. This provided a very rare and unique opportunity, to see at one go, several generations of technology development in coal based power generation and also a very effective CCS pilot.

Dr. Markus Doll, Head of New Technologies/CCS RWE Power AG briefed the team on various initiatives being taken at RWE for efficiency improvement and CCT.

1000 MW Coal Power plant at RWE

RWE ranks first among electricity generators in Germany and third in Europe with an installed capacity of about 34 GW and generate 165 billion kilowatt hours of electricity per year. Producing some 100 million metric tons a year, RWE Power is the world's largest lignite producer. About 90% of the lignite produced in opencast mines is used to generate electricity. The remaining 10% is processed to briquettes, lignite powder and lignite coke.

The Clean Coal Strategy of RWE Power was explained as below:

- Efficiency increase by replacement: under construction: 6,500 MW - 6.8 Bill. € investment
- Increase in efficiency by dried lignite prototype: first dried lignite power plant with efficiency >50%
- Increase in efficiency by increasing steam parameters: 700°C test facility
- Post combustion capture (PCC)demo plant for CO_2-usage/ conversion and Geological storage
- IGCC demoplant 450 MW IGCC-CCS: On hold due to financial constraint

Efficiency increase through RWE's fluidized-bed drying process with internal waste heat utilization (WTA®)

- Development target: Efficiency increase + 4% points, Dry lignite-fired power plant with >47% efficiency, Commissioned in December 2008
- Recovery of drying energy using WTA® technology (high-efficiency boiler technology)
- Commercial-sized demonstration plant for fluidized-bed drying at the Niederaußem lignite-fired power plant
- Capacity: 110 t/h of dry lignite
- Investment: €50 mill.

Development of high-efficiency CO_2 scrubbing with pilot plant at Niederaußem

- Development target: Applying known gas-scrubbing technologies to power plant flue gas, reducing energy requirements to efficiency losses of <10% points in the power plant and CO_2 capture rate of > 90%
- Project partners: Linde and BASF

- RWE Power budget: €9 mill. 40% funding by the Federal Ministry of Economics and Technology (BMWi)
- In operation since July 2009
- Continuation of development and tests until 2013 supported by the BMWi with an additional €3.5 mill.

Further development of flue gas desulphurization supports CO2 capture and further reduces SO2 emissions. RWE Power testing REAplus high-performance scrubber with AE&E

- Development target: SO2 capture efficiency from flue gas of >99.7%
- Dust collection >95.0%
- In operation since August 2009.
- Preparation for tighter SO2 limits of EU after 2020.
- No further treatment of flue gases necessary for CO2 flue gas scrubbing.

A visit was made to all the three pilot scale facilities.

5. <u>IEA Clean Coal Centre, London:</u>

The team visited IEA Clean Coal Centre, London on 13th February, 2012. A panel of resource persons from IEA Clean Coal Centre CCC and IEA Green House Gas group interacted with the team. Dr. Geoffrey Morrison, Programme Manager, IEA Clean Coal Centre gave a brief overview on the activities of IEA CCC. Various CCC projects which are in progress were discussed. IEA CCC also conducts seminars on various fields of CCC including biomass cofiring and mercury emissions. The sixth international conference on CCT will be held on May 2013 at Greece, on the following topics

- Ash and slag
- Biomass cofiring
- Carbon capture and storage
- Carbon capture solvents
- Carbonate cycling and solid sorbents
- Chemical looping combustion
- Combustion
- Gasification
- IGCC and precombustion carbon capture
- International and regional perspectives
- Mercury and flue gas cleaning
- Oxyfiring

Dr. John Gale, General Manager IEA GHG made a presentation on Overview of IEAGHG Activities. IEA GHG Capture portfolio includes

- Technical studies on key issues
- Post Combustion Conference series
  - Learning's from pilot plants/ lab scale developments
- Oxyfuel Conference series
  - Recent developments and learning's from pilot plants/ lab scale developments
- Solid Looping network
  - Network of researchers on solid looping monitoring development of technology
- What have we learnt from early commercial CCS projects

Various training programmes and conferences organised by IEA GHG were also discussed during the briefing.

Dr. Robert M Davidson, Manager for Carbon capture and coal science gave presentation on the report published on Overview of capture of CO2 in pulverised coal power plants

6. British Geological Survey and National Centre for Carbon Capture & Storage (NCCCS), Nottingham, UK

British Geological Survey BGS and National Centre for Carbon Capture and Storage NCCCS were visited by the team visited on 14th February, 2012. Prof. M H Stephenson, Head of Science (Energy), British Geological Survey gave a summary of the research done at BGS on Carbon Capture. This includes the static modelling of UK storage capacity, Surface monitoring at In Salah, Long term process monitoring studies using cap rock structures in simulated conditions and regional storage studies for CO2 storage

A technical study on the Regional Assessment of the potential for CO2 storage in the Indian Subcontinent was done by BGS. Details of potential storage sites in India were collected from CEA database and classified into Good, average and poor sites. According to the studies, 0.3 billion tonnes of CO_2 storage space is available in coal fields alone. Under 800m, CO2 undergoes phase change from gas to supercritical liquid and occupies less space. These regions are classified as good storage sites. A software database is developed incorporating all information on Indian Power Plants and the CO_2 emission rates from the power plants.

The team also visited various lab facilities at BGS such as Transport Properties Research Laboratory, Geomicrobiology Laboratory, Hydrothermal Laboratory, Computer Controlled Scanning Electron Microscopy, Mineralogy and Petrology and Biostratigraphy Laboratories.

Transport Properties Research Laboratory:

This provides key quantitative science in support of CCS, defining the temporal evolution of system parameters necessary for the safe, long-term geological storage of CO2. The lab excels in characterisation of low permeability materials such as reservoir seals, well bore cements and reservoir traps (e.g. fault bounded formations). Laboratory experiments are performed under simulated in situ conditions of stress, pore pressure, temperature and chemical environment. Experiments are aimed at the provision of quantitative data for mathematical modelling of leakage and migration, together with an understanding of the principal transport processes. The main emphasis of the laboratory's output has been on multi-phase flow in ultra-low permeability materials and their associated hydro-mechanical (deformation) behaviour. Studies have focussed on various reservoirs cap-rock materials (for CCS studies and reservoir over-pressuring), both lithified and unlilthified clays (as potential host-rocks for waste disposal), pre-compacted bentonite seals and clay liner seals (engineered barriers). A new dedicated capability is under construction to initially examine the temporal evolution of permeability within cement.

Geomicrobiology Laboratory:

Detailed work to understand the biological processes involved in the safe long-term storage of CO2 is carried out in this laboratory. The lab has wide experience in the understanding of biological processes involved in the transport of contaminants in a variety of rock types using the developed Biological Flow Apparatus (BFA) and is the first centre in Europe to be able to provide quantitative information in realistic conditions. Work is currently underway to examine the biological effects on transport properties in reservoir rocks.

Hydrothermal Laboratory:

This lab is used to study fluid-rock interactions and processes over a range of temperatures and pressures typical of the upper few kilometres of the Earth's crust. The laboratory has been used for CO_2-water-rock reaction studies for over 15 years, and is one of the leading centres in Europe for these types of studies. The laboratory contains a variety of equipment capable of maintaining controlled conditions for timescales of up to several years. Reactions are followed by various means, including: visual observations, monitoring fluid chemical changes over time, and detailed mineralogical analysis of the reaction products. Full analytical support (e.g. mineralogical and fluid chemical), is provided by other laboratories at the BGS. Various arrangements of reactors are available, and include: Batch reactors (various pressure/temperature capabilities, with or without fluid sampling facilities); High pressure, windowed reactors for optical studies; High pressure/temperature direct sampling batch reactors (Dickson-type autoclaves); High pressure column reactors for flow-through studies; and Simple, high pressure core flood reactors for flow-through studies. Many items of equipment in the Hydrothermal Laboratory have been manufactured within the BGS workshops.

Computer Controlled Scanning Electron Microscopy:

Here, the mineral and surface chemistry analysis of the cap rocks are studied using variable pressure computer controlled scanning electron microscope. Samples with moisture can be studied in this system. Samples from hydrothermal laboratories and microbiology laboratory are tested here to analyse the change in structure and composition of the cap rocks during the CO_2absorption process.

Mineralogy, Petrology & Biostratigraphy Laboratories:

Here, the mineralogical and petrographical characters of rock reservoir and seal are studied, and in the Hydrates Laboratory experiments under the high pressure/low temperature conditions found on the bed of deep oceans or under permafrost are conducted. Most of the focus of the laboratory over recent years has been the investigation of how CO_2 hydrate behaves within sediments and the impact the hydrate has on the physical properties of the sediments. This has been directed towards understanding processes that might exist if CO_2 were to be stored in cool, deep-water sediments – an alternative and somewhat novel approach to underground CO_2 storage.

The team also visited the lab facilities at Nottingham University. Dr. Mercedes Maroto-Valer explained various works done on mercury specification and CO_2 absorption studies.

An analytical setup is developed to study the forms of mercury released from coal in power plants at different temperatures. Various studies are also being done for analysing the Hg forms released in flue gas. A new project on photo catalytic reduction of CO_2 is also being undertaken at the university. Synthetic catalyst like titanium dioxide is being used for converting CO_2 to O_2 and other carbon compounds. This project is in the initial stage and yet to be tested in the lab scale.

On 15th February, 2012, the team met and interacted with Dr. Sam Holloway, Geologist at BGS.

7. **Post Combustion Carbon capture Pilot Plant, Ferry bridgeDoosan Power Station, UK:**

The team visited carbon capture pilot plant at Ferrybridge Power Station in West Yorkshire by Doosan Babcock on 15th February, 2012. Ms. Rebecca A Gardiner, CEng MIChemE, Senior Engineer, R&D interacted with the team.

Doosan Power Systems, in collaboration with SSE (Scottish and Southern Energy) and Vattenfall, has developed a 100 tonne carbon capture pilot plant. The £21 million project will capture 100 tonnes of CO2 from five megawatts (MW) of coal-fired power a day. The plant was commissioned in December 2010 and trial runs have just started. The significance of this project lies both in its scale, and its ability to demonstrate the operational characteristics of a carbon capture facility on an actual power station as well as the performance of the amine compound on real flue gas.

The system consists of an absorber 2.5 m diameter and 40 m high and stripper 1 m diameter and 31 meter high. Flue gas enters absorber at 35 deg C. The absorber has structured packing for reducing pressure drop. Stripper is randomly packed with SS. 2.5 bar saturated steam is used for regenerating the amine in the stripper.

CO_2 and O_2 in the in the flue gas are measured online. Other parameters like conductivity of condensed water, amine in the flue gas are measured at the laboratory. Initial testing will be done using MEA to establish the process. Collaborative research is being done with University of Regina for development of new solvent called RS2 which is a mixture of different amines. Various experiments will be done by changing temperature and steam parameters.

8. Renfrew test facility, Doosan Power systems, Glasgow, UK:

Oxyfuel test facility of Doosan Power systems, Renfrew was visited by the team on 16th February, 2012. Dr. Bryant Mark, Head, Plant Group Product Development briefed the team about the company profile and the Post Combustion CO_2 capture facility at Doosan systems. The team visited the post combustion facility which simulates the entire process of modern coal-fired power generation.

The post combustion facility simulates the entire process of modern coal-fired power generation. It will burn real coals and biomass, and includes a range of gas clean-up systems, before carbon dioxide capture takes place.

The facility uses Solvent Scrubbing Technology to capture CO2 from coal-fired flue gases, through a process of absorption and regeneration. Doosan Power Systems has been developing and will continue to develop this technology in partnership with the Canada based HTC Purenergy and the University of Regina.

Originally constructed to test primary NOx reduction measures, the facility was subsequently adapted and upgraded to test secondary NOx reduction measures.

- Upgraded for oxyfuel operation as part of the OxyCoal-UK: Phase 1 project –a collaborative project sponsored by the UK government with industrial and academic participation.

Emissions Reduction Test Facility

Doosan Power Systems is currently retrofitting a PCC pilot to its 160 kWt Emissions Reduction Test Facility (ERTF), located at its R&D center. This pilot, sized to capture approximately 1 metric tonne per day (tpd) of CO2, will expand upon earlier testing conducted by HTC where they validated the long-term performance of their proprietary RS-2TM solvent and TKOTM advanced process flow scheme.

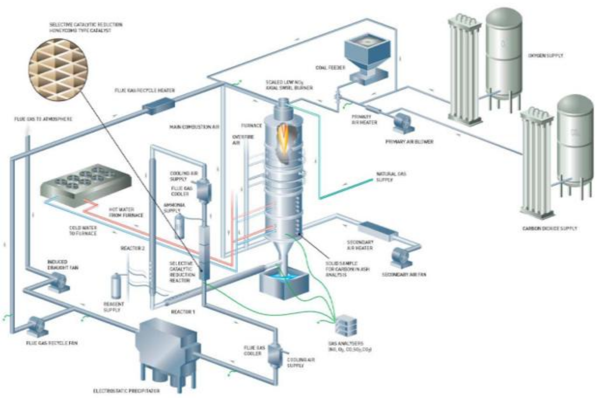


Figure ERTF Schematic with post combustion capture   ERTF with PCC

The Emissions Reduction Test Facility (ERTF) was originally designed for the investigation of primary in-furnace NOx control technologies. It has since been modified to allow investigation of Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) post combustion NOx reduction processes.

A schematic diagram of the ERTF and the main equipment associated with it is shown in Figure. The facility is capable of oxyfuel operation as well as conventional combustion. The furnace is 16.0 ft long and 20 inches in diameter, arranged vertically. The burner (a residence-time scaled-down version of a 42 MWt commercial low-NOx axial swirl burner) is located at the top of the furnace and fires vertically downwards. The furnace is lined with castable refractory (96% alumina), backed by insulating board to control the thermal environment. A water jacket removes heat to a forced draught air-cooled heat exchanger.

The facility can operate at 160kWt on either natural gas or coal or can fire at higher rates by using a combination of both fuels. Pulverized coal is supplied pre-ground with a typical size distribution of 80% less than 75 micron. The coal is manually loaded into a hopper and is fed at a controlled rate by a loss-in-weight feeder.

Primary air is supplied by a blower and is pre-heated electrically to give a delivery temperature of around 140 to 160°F at the burner. Secondary air is supplied by a forced draught fan and is heated electrically to around 450°F. The secondary air can be split into two separately metered streams - main combustion air to the burner and over fire air to the furnace. Overfire air injection ports are located at 14 levels with 3 ports at each elevation. These allow the injection of combustion air to the furnace downstream of the burner so that global air staging can be investigated. A total of 28 sampling ports are located along the length of the furnace which may also be used for re-burn fuel injection if required.

Control of the ERTF is broadly manual but data logging is automated, by means of a Eurotherm 2500 data logging series modules system using proprietary software iTools, direct to a PC. Analysis of the data (averaging and consistency checking) is carried out "just off line" during the set-up period for the following test. Spurious data are quickly identified allowing repeat tests to be undertaken as appropriate.

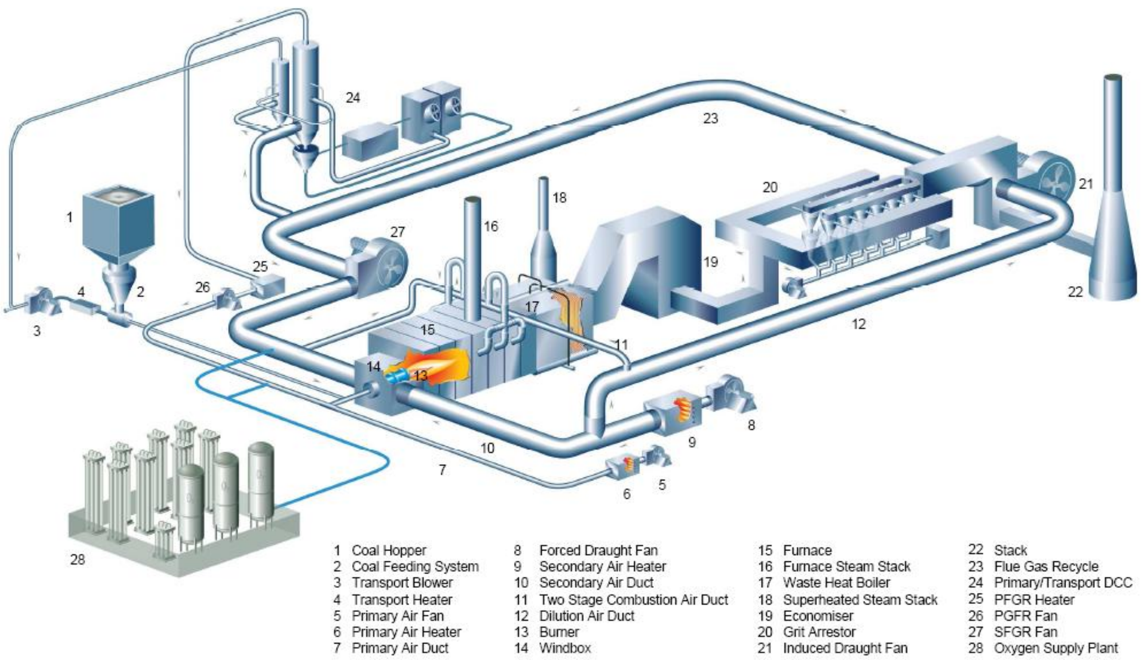
Gas analysis sample points are located at the furnace exit, SCR outlet, and transport duct. Gas analysis is performed utilizing a total of 6 Xentra 4900 Continuous Emissions Analyzers supplied by Servomex. These units are protected by moisture capture systems; all measurements are thus presented on a dry basis. Under typical operation the concentrations of NOx, O2, CO, SO2 and CO2 are analyzed at the furnace exit; NOx and O2 concentrations are analyzed at the SCR outlet or ESP outlet. The test facility was significantly upgraded in 2008 for oxyfuel operation as part of the first phase of the collaborative OxyCoal-UK program.

Clean Combustion Test Facility:

The Clean Combustion Test is one of the largest and most modern single burner test rigs in the world and is designed for development and demonstration of burners firing coal, gas, oil or other fuels upto 90 MW_t capacity.

The 90MW furnace consists of a horizontal water jacketed combustion chamber with an internal length of 17 m from the test burner to the furnace exit plane. The furnace is approximately square in cross section with dimensions of 5.5m wide and 5.5m high. The burner wind box is fitted at the front end of the furnace and is capable of adjustment to accommodate burners of different dimensional size.

The floor, walls and roof of the furnace are formed from a series of interlinked water tanks that operate at near ambient pressure. Furnace cooling is effected by evaporation of water from the tanks which are linked together by special seals that provide both sealing and differential thermal expansion capability between adjacent furnace sections; a total of seven modules make up the furnace length. Internally, the furnace surfaces are partly refractory lined and insulated to provide a thermal environment that is similar to that of the existing commercial utility plant. The burner fires horizontally along the axis of the furnace.



CCTF Schematic – with oxyfuel capability

Single burner for 40 MW Oxyfuel Combustion

Flame video with oxyfuel combustion

VII. Team has interacted with the below list of Experts during the visit:

<table>
<tr><td colspan="2">Schwarze Pumpe power station and Oxy fuel Pilot plant, Spremberg</td></tr>
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<tr><td colspan="2">CO2 Storage Facility, Ketzin</td></tr>
<tr><td colspan="2">Dr. Fabian Moller
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<tr><td colspan="2">Staudinger Post Combustion Pilot Plant, Siemens, Offenbach</td></tr>
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