EUROPEAN UNION

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Report on

Benchmarking learning tour to Modern Power Plants and Research Organizations in Netherlands, Germany and France

6th to 13th October, 2013

Under the Project

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

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Summary:

IPCC 2013 report has clearly confirmed that rise in average global temperature is positively correlated to rise in concentration of anthropogenic CO_2 in atmosphere and due to this the polar ice cap and most of glaciers are retreating which will significantly affect our livelihood and our very existence in earth. So, it is an immediate requirement to act to mitigate this rising trend of CO_2.

In line with this, to learn and understand the new technology developments in efficiency improvements and CO2 emission reduction in the coal fired power plants, under the EU supported project on **'Developing cluster for Clean Coal Technology (CCT) and Carbon Capture and Storage (CCS) for the Indian Thermal Power Sector'**, eight executives with a mix of both senior power plant professionals and young clean coal research and development professionals undertook a benchmarking learning tour to the most modern coal based power plants in Europe during 6th to 13th October, 2013. The study tour team has visited two modern power plants in Netherlands, two modern power plants in Germany and also had meetings with International Energy Agency (IEA) in Paris. This technical report will provide details of the learnings from the study tour on the recent advancement made in CCT and CCS in Europe.

Key features of power plants visited by the study tour team:

- Amer power plant in Geertruidenberg in the Netherlands, visited on 7th October, 2013 is the largest biomass co-fired power plant of gross capacity of 1245 MW(electrical) using 35% biomass co- firing and wood gas.
- Ultra-Modern Power Plant at Maasvlakte near Rotterdam- MPP3, Netherlands, visited on 8th October, 2013 of unit capacity 1100MW has an advanced supercritical tower type boiler made of T24 material.
- Trianel coal-fired power plant Lünen GmbH & Co. KG, Germany, visited on 9th October, 2013, is a coal fired power plant of unit capacity-750 MW, once through tower type vertical wall opposite wall fire type boiler of height of 110mtr.
- Datteln power plant, Germany, visited on 10th October,2013 is a coal fired power plant of unit capacity-1100 MW, which has once through two pass type spiral wall direct opposite wall type boiler. Chimney is inside the cooling tower of height 180mtr.

The team visited IEA, Paris on 11th October, 2013. Key points discussed in two meetings with Dr. Jean Francois Gagne, Head of Energy Technology Policy Division and Dr. Juho Lipponen, Head, CCS Group, IEA Paris on 11th October, 2013 are as follows:

- TREC-STEP and BHEL's partnership project on Developing a Cluster for CCT and CCS was presented to IEA team
- Role of BHEL in power sector in India and BHEL's initiatives on CCT and CCS (development of IGCC, AUSC technology and Oxy fuel combustion and Biomass co-firing demonstration) was presented to IEA team
- IEA's emission model of 2DS and 6DS was presented
- Current status of global average rate of emission of CO_2 from a coal fired power plant (1000 gm of CO_2/kWh).
- To achieve IEA's vision of 2DS by 2050, the average emission from a power plant must be less than 200gm of CO_2/kWh
- To achieve the target of 2DS by 2050, IEA has proposed to replace all low efficient power plants with high efficiency and low emission technologies HELE (AUSC CFBC boiler and PC boiler, IGCC with 1700˚C class gas turbine) coupled with CCS and also emphasized to reduce the dependency of coal in power generation incorporating more renewables.IEA expects India should build capability to store 1 Gt of CO_2 by 2030 and 11.6 Gt of CO_2 by 2050.

Study tour benefits:

- **Establishment of knowledge network with experts** for future co-operation and collaboration in the field of CCT and CCS.
- Learning from the EU's experiences related to **biomass co-firing and initiating implementation of biomass co-firing in PC boilers (supercritical as well as subcritical) up to 35% (of biomass) using the Indian coal.**
- Development of **wood gasification technology, as an alternative clean fuel for boilers**.
- Use of advanced materials for reducing weight and **improving market competitiveness for Advanced Ultra Supercritical boiler**.
- Development of **Oxy-fuel combustion technology for CCS and retrofitting it in existing boilers**.
- Learning from the **safety practices in the power plants in Europe** and adapting them to Indian conditions

The study tour has been of immense benefit to the study tour team in building strong knowledge networks and in understanding in-depth various technologies implemented in reducing CO2 emission in the coal based power plants.

Visit to Ultra Modern Power Plants in The Netherlands:

The team has visited two modern power plants in Netherlands as below:

1. **Amer power plant in Geertruidenberg on 7th October,2013.**
   Contact person: Dr. Wim Willeboer, Manager, Process Technology
2. **Ultra Modern Power Plant at Maasvlakte near Rotterdam- MPP3 on 8th October,2013**
   Contact person: Dr. Aris Blankenspoor, General Project Manager

The study tour team had good discussions with the power plant team and was also able visit both the power plants. The study tour team made presentations of the EU CCT CCS Cluster Project and on BHEL CCT CCS initiatives to the visited institutions. The power plant team has also made eloborate presentations on the salient features of the power plant during the meeting, which has been a very good learning for the Indian study tour team. It has been clear from the discussions, that the Netherlands government policy is to reconsider coal as an important,reliable, sustainable energy source for Netherlands. With the deployment of High Eefficency Low Emission technologies and renewable energy sources,their government expects to mitigate the CO_2 emission.

1. Amer power plant in Geertruidenberg:

First plant the team has visited is Amer power plant in Geertruidenberg on 7th October, 2013. The study tour team had an extensive discussion with the team of executives from Amer Power Plant headed by Dr. Wim Willeboer, Manager, Process Technology.

Amer Power Plant is one of RWE's largest power generation sites and the largest bio-mass co-fired (35% by weight) power plant not only in Netherlands but also in Europe.

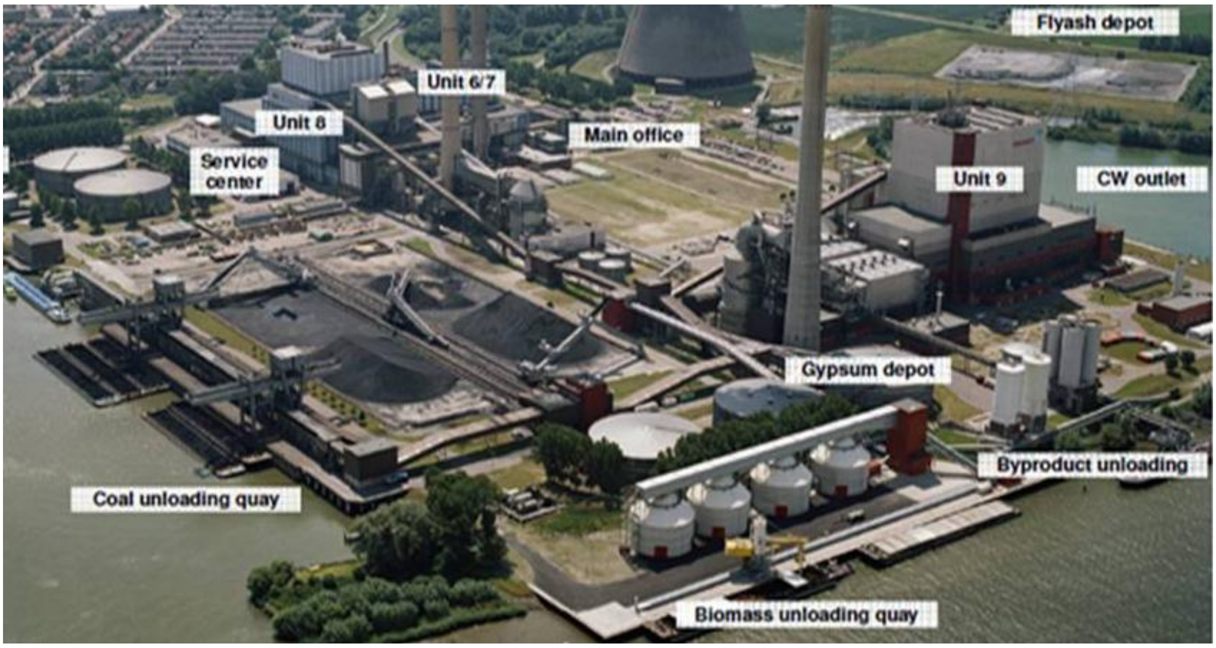


Fig 1: view of Amer Power Station

The Amer power station consists of four power generating units (unit 6,7,8 and 9), 150KV switchyard, coal unloading quay and storage area, biomass unloading quay and storage area, cooling water inlet and outlet area, cooling tower, chimney, ash disposal area both fly ash and bottom ash and main office. The older 5 units which were in operation since 1952 have been demolished and newer units with higher efficiency have been established. The gas fired unit 6 and unit 7 established in 1980 are meant for supporting the peak demands whereas unit 8 (established in 1980) and unit 9 (established in 1993) are meant for sustainable generation of electricity. Total electric capacity of unit 8 and unit 9 is 1250MW net with additional 600MW district heating. Basic features of unit 8 and unit 9 are as following-

Table 1: key features of unit 8 and unit 9

Specifications	Unit 8	Unit 9
Commissioned	1980	1993
Supplier	Combustion engineering	Sulzar
Capacity	610MWe net/250MW_{th} (heating)	640MWe net/350MW_{th} (heating)
Type of boiler	Subcritical	Supercritical
Steam parameters	175 bar/540˚C(reheat 540˚C)	250 bar/540˚C(reheat 568˚C)
Efficiency	38%(LHV)	42%(LHV)
Fuel	Coal, biomass, natural gas	Coal, biomass, natural gas, syn gas(wood gas)

Types of Biomass Used:

They import 90% of their biomass demand from America (Georgia state) and Canada. Local vendors only act as a supportive source when they are out of stock and cannot be refilled immediately by importing biomass. Amer plant experimented with different types of biomass for Unit-8 and unit-9 and ultimately they decided to co-fire following biomass with coal:

- Wood pellets
- Citrus pellets
- Palm kernel chips
- Olive residue
- Coffee husk

Technical challenges of using Biomass:

Biomass is quite different from coal both in physical and chemical properties. Biomass is more fibrous than coal and also lower in density. It has low ash content and low sulphur content. It has got high volatile matter and oxygen content. Also alkali content in the coal is also high which reduces ash melting point. These lead to some problems when firing biomass with coal in boilers.

Storage and Transportation of Biomass: Biomass storage and transportation is a major issue in any power plant. Biomass is hygroscopic material. So if it is left open it will absorb more moisture. Further it has got high volatile matter content. So it is susceptible to catch fire.

Fig 2: biomass unloading area of Amer power station.

In Amer power station the team has observed that they use closed Silos to store biomass as shown in figure-2. They unload biomass from the burger as it can be seen in the figure-2 by means of vacuum unloader which sucks the biomass and transport through completely enclosed pneumatic conveyor to the silos. From the silos it is fed to the pulveriser again through closed pneumatic conveyors.

Problems with pulverisers: Biomass is more fibrous than coal. This leads to some problems during milling. Initially they tried to mix it with coal and pulverize it in the roller mill. The supplied wood pellets are of higher size. So they found that the particle size after milling is much higher than that of coal. Typical particle size distribution is shown in the table-2.

Table 2: Particle Size Distribution PSD of biomass and coal used in Amer Power station

Biomass PSD

R > 4000 µm	0.4 %
R > 2000 µm	7.3 %
R > 1000 µm	44.8 %
R > 500 µm	76.7 %
R > 213 µm	93.7 %

Coal PSD

R > 200 µm	0.1 %
R > 90 µm	12.0 %

From table-2, it is clear that the 0.1% of coal fed has a particle size greater than 200 µm where in case of biomass it is more than 93.7%. So biomass has higher particle size after pulverisation. This difference in PSD between biomass and coal leads to a number problems when tried to blend biomass and coal.

When blended biomass with coal and subject it to pulverization in bowl mill, large amount of biomass gets shifted outwards due to their higher particle size than coal. So ultimately, different mixture of coal and biomass were got at mill outlet.

In order to prevent this incident, modifications to the existing coal mill were made. A ring has been inserted in the mill as shown in the figure-3 to prevent larger biomass particle to move outward and put it again into the grinding zone. With this modification biomass is retained in the mill for longer time for pulverization. Apart from this the roller angle has been changed and also most of the openings in the mill are closed as shown in figure-3.

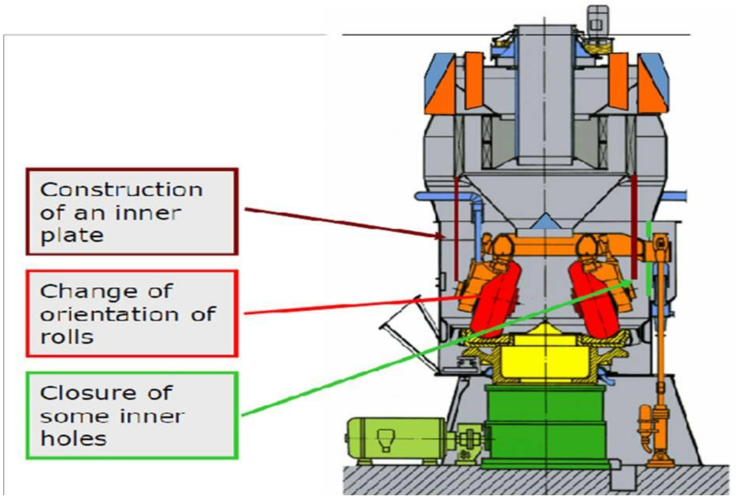


Fig 3: coal mill for biomass after modification

Problems were faced because of fire during pulverisation, due to its high volatile matter content. So biomass and coal is pulverized in an inert atmosphere by injecting flue gas into the pulveriser.

The team shared that even with all these precautions there were still problems in combustion when they blend biomass with coal. So co-firing was practised instead of blending and two separate mills were dedicated for biomass and coal. The bowl mill was also replaced with hammer mill for pulverising biomass.

Problems were faced during combustion of biomass blended with coal. The biomass they are using has high char burnout time and also biomass suffers early volatisation. Due to this incomplete combustion takes place in boiler. The problem is further compounded by the fact that particle size is higher in case of biomass. As we can see in their CFD analysis oxygen concentration still varies even after firing zone while comparing with typical Indian coal fired-boiler.

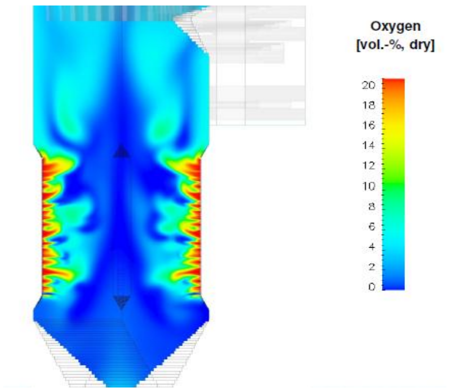


Fig 4: CFD analysis of Amer power station

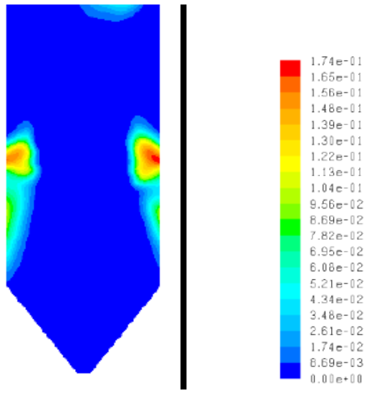


Fig 5: CFD analysis of typical Indian coal fired boiler

This incomplete combustion not only reduces efficiency but considerable amount of carbon monoxide is formed during the combustion and this leads to corrosion of boiler. The situation becomes more acute with larger particle size of biomass delivered by the mill even after modifying the coal mill. Near the arch, the biomass being a heavier mass is unable to follow trajectory of the flue gas and thus gets accumulated near the arch zone of the boiler and the concentration of carbon monoxide is high in arch area as shown their CFD studies (figure 6). To ensure the complete combustion they change the air-fuel ratio and they increases excess air percentage.

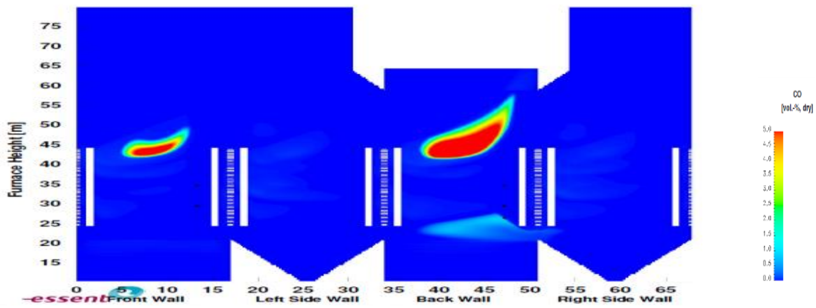


Fig 6: CFD analysis for CO measurement in boiler of Amer power station

Biomass has high alkali content (8-9%). So, slagging and fouling becomes major issue while going for higher percentage of biomass co-firing as well as blending. Amer power plant has optimised and recommends maximum 35% biomass by weight for co-firing with coal.

Wood Gasification Technology:

Unit 9 of Amer power station uses wood gas along with coal, biomass and natural gas. Wood gasification technology is a known one, but deploying wood gas as an alternative fuel for boiler is a new concept. It took the team almost 7 to 8 years for developing and augmenting the technology to the current capacity.

The team had detailed discussion on the Wood Gasification Process, various problems surmounted during various phases of the development of technology, modifications made in each stages of the technology development, etc. These interactions have been useful for the study tour team.

Problems faced in the initial phases:

- Because of high alkali contents the gas cooler suffers fouling
- The path of gas in the gas cooler frequently gets blocked by the solid particles
- Filter gets damaged at regular period.
- During the startup and shut down condition in the filter the syngas and the fly ash catches fire due to presence of hot char
- Excessive wear in wet scrubber
- Agglomeration tendency of bed material
- Safe guarding system is very complex

Solutions to the problems:

- Replaced filter by cyclone to separate the fly ash from the syn gas. Cyclone are used since there is no need for high purity of syn gas. So this completely solved two problems regarding frequent replacement of filters and also catching of fire during start up and shut down process.
- To prevent excessive wear the wet scrubber was replaced and was found that this replacement does not affect the whole process.
- Increase the outlet temperature of the gas cooler. This prevented the fouling and chocking problems in gas cooler.
- Since agglomeration of bed materials and firing of system still existed, Start up burner is placed outside the main combustor. The bed material of main combustor is heated only by the hot flue gas generated by another combustor. Further they went for higher particle of material without affecting the fluidization characteristics. This solved the problems regarding the agglomeration of bed materials.
- Since it is difficult to remove the unburnt biomass completely from the syn gas by means of cyclone, it was decided to go for oxygen free operation. Started operation under stoichiometric ratio condition for heating up of main combustor and found that the system parameters were not affected. Once the steady state is reached the steam was used instead of flue gas for continuation of generation. These minimize the oxygen content during start up and thus preventing any incident of fire.
- It was identified that oxygen concentration and temperature at different point are the main parameters for controlling the whole process. So all irrelevant parameters were excluded and developed simpler safeguarding controlling system which focus on oxygen concentration and temperatures at different points.

The present schematic of the Amer Power plant after making all necessary above modifications is shared to the study tour team as below:

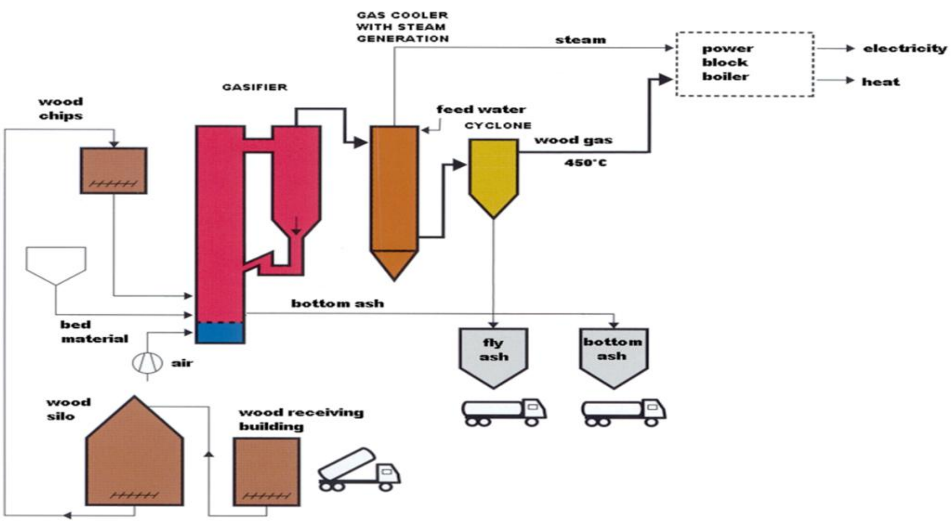


Fig 7: scheme of the plant after modification

Part of the study tour team members at the Amer Power Station, Netherlands

2. **Ultra-Modern Power Plant at Maasvlakte near Rotterdam- MPP3**:

The study tour team has visited MPP3 plant on 8th October, 2013. At MPP3, the team had very intersting interactions with Dr. Aris Blankenspoor, Head of Operations and his team. A visit to the MPP3 plant and also the CCS pilot plant was also organized.

Fig 1: Ultra-Modern Power Plant at Maasvlakte near Rotterdam- MPP3

E. ON is building this new power station based on coal fired technology with supercritical steam parameter. Currently this generating method is the only technology with proven reliability that can be applied on an industrial scale in contrast with coal gasification which is still at experimental stage. The new power station's energy return will be 46% which is 20% higher than current Dutch power stations. As with the current operation, E. ON will use biomass as fuel in the new power station. Alongside studies into the maximum percentage of biomass that can be used, E.ON is also researching further reduction of CO_2 emissions by supplying heat to market gardeners and other industrial clients. This will provide some seven percent of Holland's electricity requirements. Investment in the project exceeds € 1.2 billion.
The Key features of the MPP3 Plant is as below:

Table 1:Key features of MPP3

Key features	Key data
Unit capacity	**1100MW**
Steam conditions	**285 bar/ 620 degree C**
Efficiency	**47%**
Type of boiler	**Once through ultra-super critical tower type**

Turn down ratio	**30%**
Firing type in the boiler	**Direct wall opposed firing**
Firing elevation	**5**
Burner per elevation	**6**
Turbine	**1 HPT, 1 IPT, 3 LPT double flow**
Net electrical output	**1069 MWe**
Generator limit capacity	**1155 MWe**
ID fan size limit	**800 MWe**
Fuel used	**Hard coal, biomass**

Suppliers of Power plant equipment: Engineering and plant layout design has been done by E ON. The power plants equipment suppliers are as shown in the table 2.

Table 2: suppliers of packages for MPP3[3]

Packages	Supplier
Steam generator	**Hitachi power**
Turbine and generator	**Alstom Power Generation**
Control system	**ABB**
Civil works	**EMBM**
Piping	**E ON**
FGD	**Fisia**
ESP	**TOM**

Boiler materials: E ON installed once through ultra-super critical tower type boiler supplied by Hitachi Power. Main feature of this boiler is the utilization of advanced material to withstand the steam parameters and as well as to reduce the weight of the boiler. The materials for super heaters and reheater are shown in figure-2

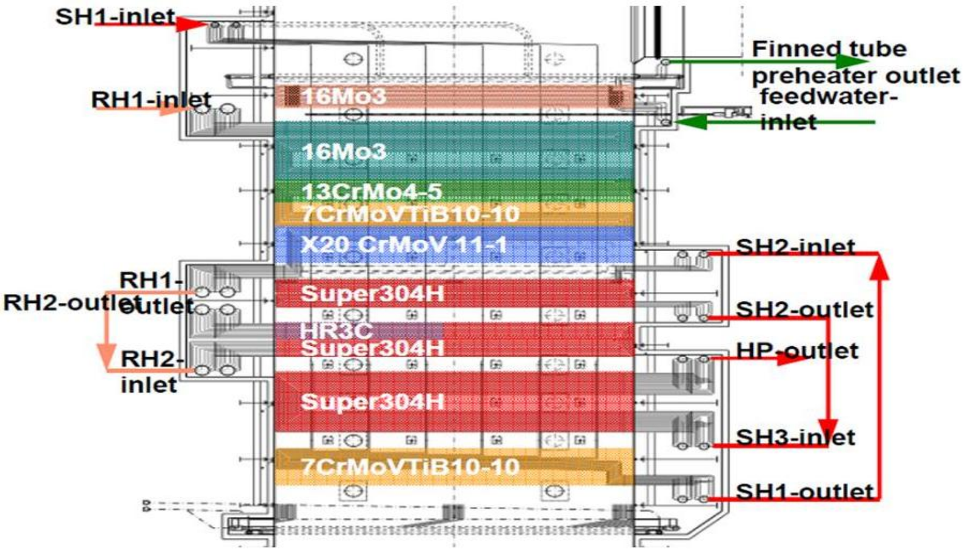


Fig 2: materials used in different SH and RH regions[3]

Further they went for T24 material developed by German companies for membrane water wall panels which reduces the weight of water wall and also material requirement.

Benefits of usage of T24 :

Construction of high efficiency power plants requires obtaining materials with improved high temperature strength, superior resistance to oxidation and resistance to high temperature corrosion. With the increase of pressure, not only the final super heater tubes, but all steel tubes including the economizer tubes and membrane water wall (MWW) tubes must provide improved high temperature strength.

The necessary increase in the temperature would entail a changeover from the time-independent to the time-dependent design stress. Bainitic-ferritic steels, such as 10CrMo4-5 (T12) and 11CrMo9-10 (T22), which have been used so far, do not have adequate creep rupture strengths for use in waterwalls under the conditions of advanced power plants. These facts have led to development of new perspective low alloyed steel for membrane walls T24 (7CrMoVTiB7-7).

Table 3: material composition of T22 and T24

material	C	Si	Mn	Al	Cu	Cr	Ni	Mo	W	Ti	V	Nb	B	N
T22	0.08 - 0.15	0.15 -0.4	0.3-0.7	max 0.04		2.00 - 2.50		0.9-1.20						
T24	0.05 -0.1	0.15 - 0.45	0.3-0.7	max 0.02		2.20 - 2.60		0.90 - 1.10		0.05 -0.1	0.2-0.3		0.0015-.007	max 0.01

Currently numbers of ultra-supercritical power plants in Europe are using T24 material for constructing MWW tubes.

CCS initiatives:

E ON has taken up a joint project with Dutch government in developing CCS technology. Netherlands empty gas fields have a good potential for storage of CO2. EON's multi partner project CATO and CATO-2 has commissioned a post-combustion capture pilot plant at the Maasvlakte power plant in Rotterdam. The capture plant can process up to 1500 Nm^3/h flue gas and capture 250 kg/h carbon dioxide (CO_2). The flue gas flow is equivalent to 0.3 MWe power output of a coal-fired power plant. An overview of the capture pilot plant is given in Figure 3.

Fig 3: The TNO pilot capture plant at the EOn site at the Maasvlakte (Rotterdam, the Netherlands)

The design of the capture pilot plant is based on a standard amine-based (MEA) CO_2 capture process. The processed flue gas is a slipstream taken downstream the Flue gas desulphurization (FGD) unit of the power plant. The pilot plant consists of the following consecutive process units:

- knock out drum
- caustic scrubber
- blower

- absorber tower with washing section
- lean-rich heat exchanger
- stripping tower with reboiler
- condenser

A simplified Process Flow Diagram (PFD) of the capture pilot plant is given in Figure 4.

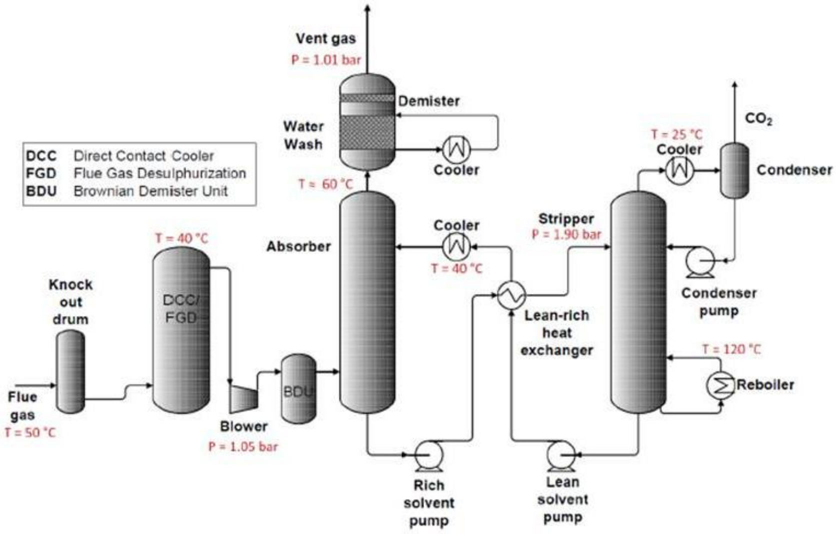


Fig 4: A simplified PFD of the capture pilot plant at the Maasvlakte, Rotterdam

The study Tour team at the MPP3, Netherlands

Visit to Modern Power Plants at Germany

The team has visited two power plants in Germany as below:

1. **Trianel coal-fired power plant Lünen GmbH & Co. KG, Germany on 09th October,2013**
   Contact person: Ms. Heike Mussmann
2. **Datteln power plant, Germany on 10th October,2013:**
   Contact person: Mr. Jorg Schlottmann

(1) Trianel coal-fired power plant Lünen GmbH & Co. KG, Lunen, Germany

The team first visited the Trianel coal fired power plant in Lunen, Germany on 9th October, 2013. The power plant is located on a Greenfield site just outside Lünen. It uses international low sulphur bituminous coal delivered by river barges on the ‘Datteln-Hamm-Kanal’. Siemens, as the EPC consortium leader, was responsible for overall planning, supply of the steam turbine generator set, the mechanical and electrical equipment, including the entire instrumentation and control system, the transformers and switchgear, as well as various auxiliary and supporting systems. Siemens was also responsible for construction, installation and commissioning.

Key features of the Trianel Power plant is as below:

Table 1: key features of Trianel coal-fired power plant Lünen GmbH & Co. KG, Germany.

Net output of the plant	750 megawatts (To classify: this corresponds to the supply of up to 1.6 million households)
Electrical efficiency	greater than 45 percent
Annual operating time	up to 8,000 hours
Annual electricity	up to 6 million megawatt hours
Construction	2008 to 2013
Investment	1.4 billion euros
Height of boiler house	110 m
Cooling tower height	160 m
Height of fly ash silo	70 m
Height coal silo	70 m
Inner diameter coal silo	54 m
	80,000 t
Capacity coal silo	
Cost coal silo	20 million euros
Location	Mute Lünen on dates-Hamm Canal, district Luenen Lippholthausen, Frydagstraße 40
CO_2 per kWh	750g CO_2 per kWh
CO_2 per year at full load (8000 h)	4.5 million tonnes
Full-time jobs with the commissioning in 2013	approximately 470 jobs (economic calculation, 160 in the power plant and in immediate service area)
Separation of CO_2	The power plant is CCS-ready

Plant layout:

General layout planning attached particular importance to a compact and economic design as shown in figure-1. The arrangement of the steam turbine and the boiler, results in short steam lines and a short electrical run to the switchyard. The side arrangement of the cooling tower in relation to the electrostatic precipitator allows efficient routing of the flue-gas exhaust system through the cooling tower, while at the same time optimizing the circulating water system.

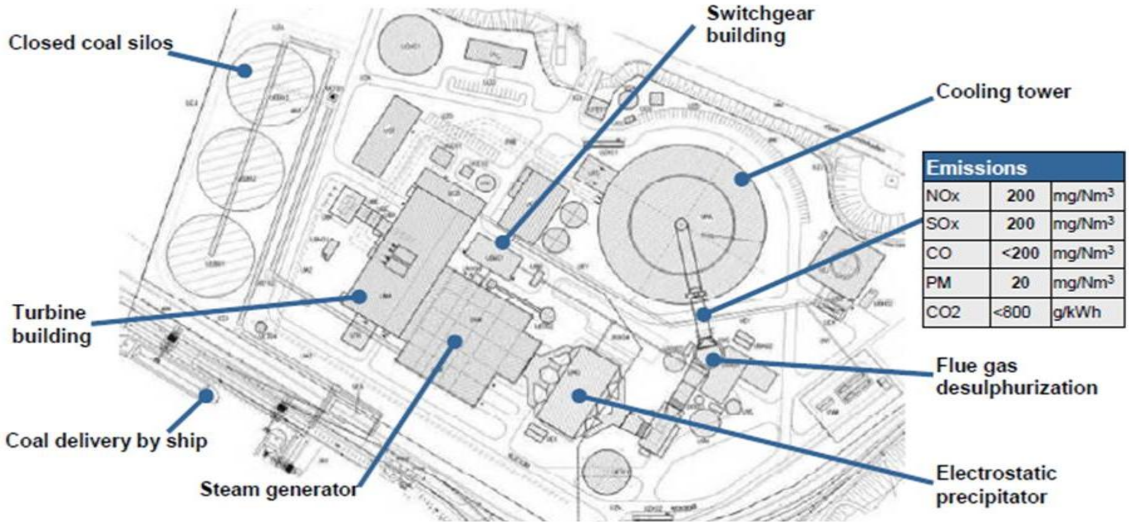


Fig 1: General arrangement drawing

The compact cost-effective plant design in the turbine building also allows for good accessibility during maintenance. Header-type high-pressure feed water heaters and the separate de-superheater are located in front of the high-pressure steam turbine. The main components of the feed water system including the feed water tank, boiler feed pumps and low-pressure feed water heaters are placed in the heater bay, which forms an integral part of the main structure. The central switchgear building is nearby the turbine building and accommodates the central control room.

Steam generator:

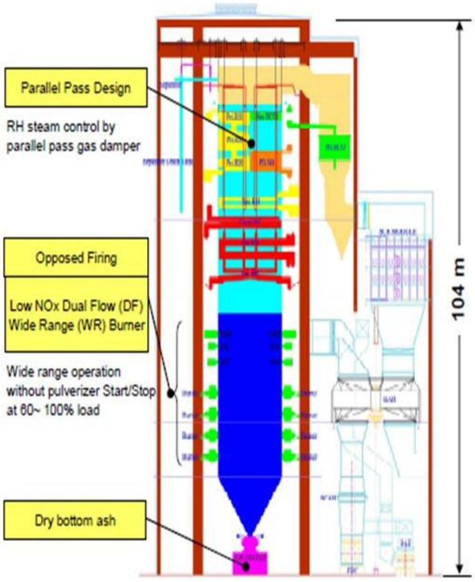
The once-through steam generator manufactured by IHI has a tower design as shown in the figure-2. Key features include:

- low NOx dual flow wide range burner,
- control of the reheat steam temperature by a parallel pass damper,
- a Ljungström-type air preheater,
- dry bottom ash removal.

About 600 kg/s ultra-supercritical main steam (280 bar/600 °C at boiler outlet) are generated. At design conditions, more than 94 per cent of the coal energy (LHV basis) is transferred to the water/steam cycle.

With regard to the steam generator, the overall plant efficiency is improved by

- optimizing the heating surface arrangement
- raising the final feedwater temperature to 308 °C
- keeping the excess air coefficient in the firing system less than 1.2
- controlling the reheater outlet temperature without water injection
- reducing the exhaust-gas temperature downstream of the air preheater to 120 °C
- minimizing pressure drops



Boiler Parameter	Value
Boiler Manufacturer	IHI Corporation
Main steam flow	2,160 t/h
Main steam press.	280 bar
Main steam temp.	600 degC
Reheat steam temp.	610 degC
Minimum load (Coal)	Approx. 25%
Accessory of Boiler	**Type**
Mill	IHI-VS Mill x 4
Burner	IHI-DF WR burner X 32
Gas Air Heater	Ljungstrom type x 1
Forced Draft Fan	Axial type x 1
Primary Air Fan	Centrifugal type x 1
Bottom Ash Extractor	Dry type x 1

Fig 2: Characteristic design features of the steam generator in Lünen (source: IHI).

The boiler can be operated in once-through mode in the load range approximately 35 per cent to 100 per cent. Under design conditions, heat transfer to the water/steam cycle reduces the temperature of the flue gases to approximately 350 °C at the outlet of the economizer. Preheating the combustion air decreases the temperature of the exhaust gases even further before they are supplied to the electrostatic precipitators. It should be noted that the values of the process parameters and the boiler efficiency depend on the coal being burnt.

The evaporator in the furnace consists of a spiral pass with smooth tubes and vertical water walls in the upper furnace section. Opposed firing is arranged on four burner levels with low NOx wide range burners. Flame characteristics can be adjusted with respect to the boiler design, load and coal quality. This improves flexibility and enables the operation from 60 per cent to 100 per cent load (at design conditions) without mill start/stop.

A special feature of the boiler design is the control of the reheater outlet temperature without spray water injection in normal operation. This is achieved by a parallel design of reheater 1 and superheater 1/economizer 2 and the use of gas dampers in the upper convective part of the steam generator.

For the given ambient conditions at the power plant site (+9 °C, 80 per cent relative humidity, 18 °C cooling water temperature) the plant concept is designed for a net efficiency of 45.6 per cent based on the lower heating value. Key levers for improving Lünen's overall plant efficiency are high-steam parameters, optimized processes, and highly efficient energy conversion in key plant components.

(2) Datteln power plant Germany

The study tour team has visited the new modern Datteln power plant on 10th October, 2013. Datteln 4 will be setting new benchmarks in terms of efficiency, by optimizing the system technology. The power plant will be able to exhibit an efficiency of over 45%. This represents a substantial increase over the German average. Extracting the district heat increases the efficiency factor of the fuel used to over 60%.

The Key features of Datteln 4 Plants is as follows:

Table 1: key feature of Datteln 4

Key feature	Key data
Electric output	1100 MW gross and 1055 MW net
Electricity for public supply	642 MW(50Hz)

Traction current	413 MW(16.7 Hz)
District heating	380 MW (max)
Net efficiency (electrical)	Greater than 45%
Boiler type	Once through supercritical tower type spiral wall
Firing	Opposed wall firing
Fuel elevation	5
Burner per elevation	6
Steam parameter	285 bar/600˚C
Steam output	2950 tph
fuel	Hard coal
Fuel requirement	360 tph

Coal storage and handling system:

Datteln power plant is situated in Ruhr area in Germany and is well connected to Germany via canals and railways. Barges deliver hard coal via the Dortmund-Ems Canal. Closed conveyor belt facilities transport the fuels to the coal storage (1) or directly into the coal bunker (2)(as shown in fig-1).

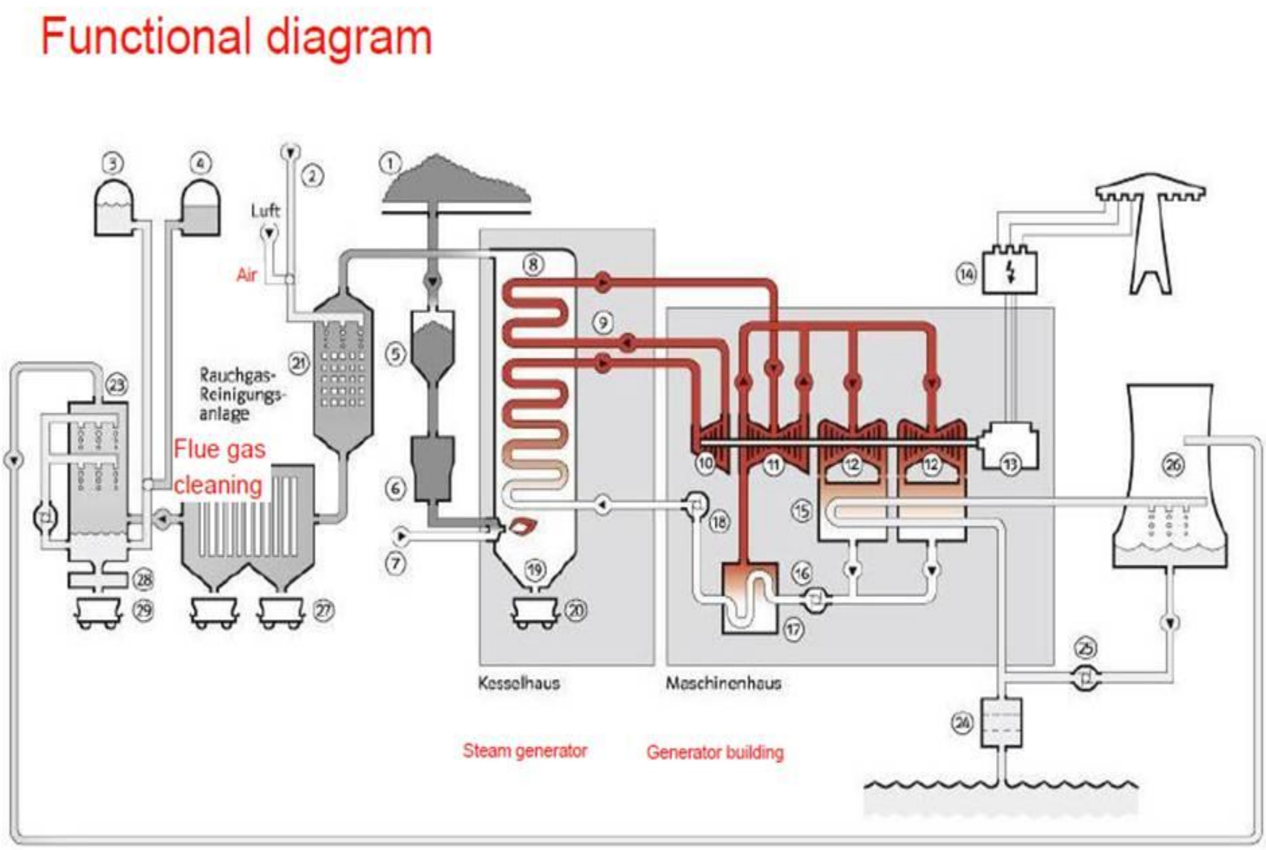


Fig 1: Line diagram of Datteln 4

Five coal pulverizers (3) grind the delivered hard coal to a fine dust. The coal dust is first dried using hot air and then blown into the boiler's combustion chamber. The grinding process results in a far greater coal surface area, leading to optimal combustion.

Steam generator:

The boiler house is where the stream generator (5) is installed . It consists of the combustion chamber (6) and a complex system of pipes (7).

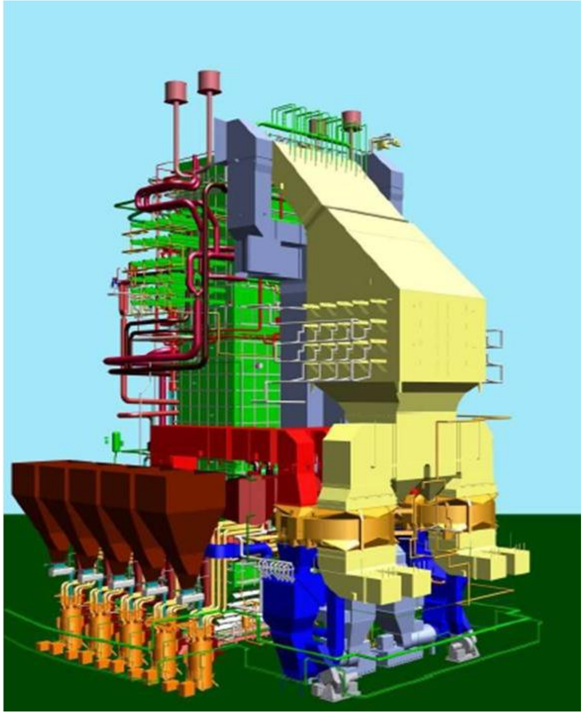


Fig 2: steam generator of Datteln 4

In normal operation the finely ground coal dust is burned at over 1300 degree Celsius in the combustion chamber. The resulting heat brings the water in the lines to a boil. The water is transformed into steam, which is then passed into the turbines at high pressure.

Table 2: steam generator specifications

Technical specifications	data
Supplier	Hitachi Power Europe
Type of steam generator	Once-through-boiler with double front firing
Steam output	2940 tph
Life steam pressure	285 bar
Life steam temperature	600 °C
Steam temperature after heating	620°C
Coal throughput	360 tph
Numbers of burners/level	30 / 5
Number of coal mills	5

Steam turbine:

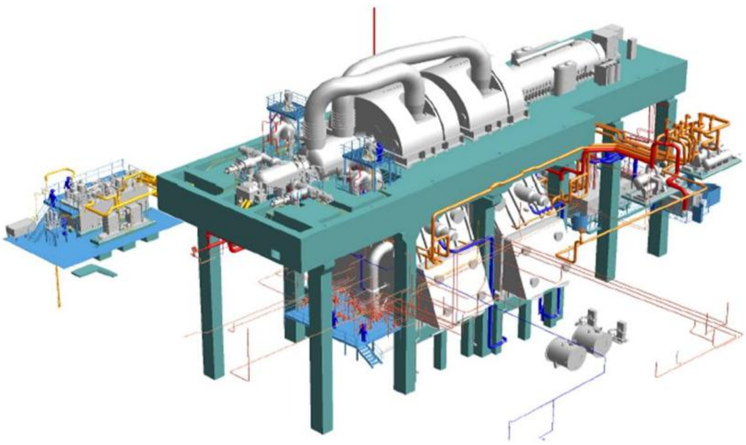


Fig 3: steam turbine

The steam turbine (9) turns at 3000 revolutions per minute. It consists of one high pressure, one medium pressure and two low pressure sections. There, blades transfer the steam's energy onto the shaft. The turbine is linked to a generator (11), which transforms mechanical energy into electrical energy very similar to a dynamo. The generated electricity is supplied into the grid through a transformer (12).

As an inland location, Datteln 4 exhibits a very high degree of efficiency. Over 45% of the energy in the coal is converted into electrical energy, this is high performance technology.

Once the steam has gone through all the turbine stages, it turns back into water in the condenser (13) and begins its journey through the boiler again. This concludes the water-steam cycle.

Cooling water system:

Only the water that evaporates out of the cooling tower is removed from the Dortmund-Ems Canal (14). The cooling tower's height of nearly 180mtrs is needed in order to reach the desired plant efficiency of over 45%. If we use smaller ventilator cooling towers, the plant efficiency would diminish as a function of increased station supply and fuel consumption and CO_2 emissions would rise. This means that an optimal cooling tower height also contributes to climate protection.

Power supply to railway:

A fifth of the electricity used by Deutsche Bahn to run its trains comes from Datteln.

The Study Tour team standing on boiler roof of Datteln 4

Meetings at IEA, France:

The study tour team visited IEA, Paris on 11th October, 2013. Two dedicated meetings were organized with two separate team headed by Dr. Jean Francois GAGNE, Head, Energy Technology Policy Division, Directorate of Sustainable Energy Policy and Technology, IEA and Dr. Juho Lipponen, Head of Unit, Carbon Capture and Storage, IEA.

(1) Interaction with Dr. Jean Francois GAGNE, Head, Energy Technology Policy Division, Directorate of Sustainable Energy Policy and Technology, IEA and his team:

Dr. Keith Burnard, Energy Technology Policy Division, IEA presented on the latest technology development in Coal fired Power Generation. His presentation mainly covered the global trends in the coal markets and also on improving plant efficiency through High Efficiency Low Emission HELE technologies. HELE technologies are those that improve efficiency, reduce specific fuel consumption and reduce specific pollutant emissions.

The presentation covered the major HELE Technologies such as :

1.Ultra-supercritical pulverised coal combustion

2. Advanced ultra-supercritical pulverised coal combustion

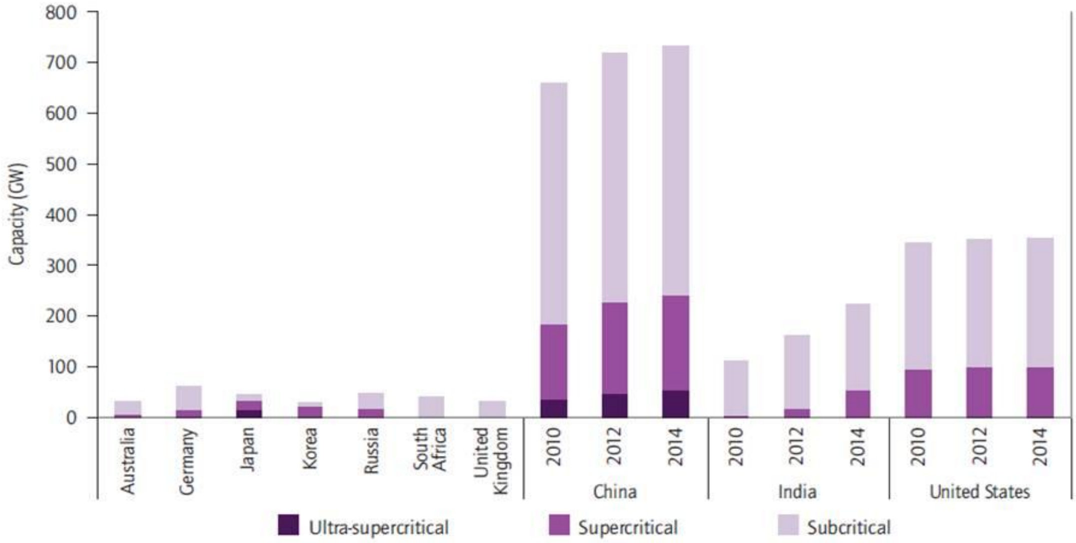
3. Circulating fluidized bed combustion
3. Integrated gasification combined cycle (IGCC)
4.Biomass co-firing
Other advanced technologies for increasing efficiency of coal fired power plants are such as
- Underground coal gasification
- Power generation from low-grade coals

The Technology Roadmap for each of the above technologies were discussed in detail. The IEA Team has also shared the High-Efficiency, Low-Emissions Coal-Fired Power Generation - Technology Roadmap Report with the Study Tour Team.

Current status of HELE Technologies worldwide:

The IEA team has presented in detail the aging power plant infrastructure in EU, US, India and China. At present, a large number of low-efficiency plants remain in operation: more than half of all operating plant capacity is older than 25 years and of relatively small size (less than 300 MWe). Almost three-quarters of operating plants use subcritical technology. While deployment of SC and USC technologies is increasing, their share of total capacity remains extremely low.

A handful of countries have made it a priority to improve the efficiency of their coal fleets (Figure 1). For example, Japan and Korea, where SC technology was adopted before 2000, have high-performance coal fleets, with average efficiencies in excess of 40% (LHV, net). Since the mid-2000s, China has experienced high growth in coal-fired generation, with the share of SC and USC increasing rapidly. More recently (since 2010), India has seen rapid growth in coal-fired generation, and a growth in the share of SC units.



Note: Refers to capacity in 2010 unless specified otherwise. Definitions of subcritical, supercritical (SC) and ultra-supercritical (USC) technology are described in Box 3.
Source: Platts, 2011.

Fig 1: Capacity of supercritical and ultra-supercritical plant in major countries

The Key recommended actions for the near term, shared by IEA for reducing CO2 emissions are as follows:

- By 2020, CO2 emissions from coal-fired power generation must already have peaked to be consistent with the 2DS.
- Greater efficiencies must be achieved in the power generation sector.
  - Deploying SC and USC technologies, both available now, will be important.
  - Even higher efficiencies to be achieved as A-USC and more advanced IGCC become available.
- Raising efficiency significantly reduces the CO2/kWh emitted.
- Power generation from low-grade coals, such as lignite, can be much more efficient.

- CCS must be developed and demonstrated rapidly if it is to be deployed at a scale sufficient to achieve the 2DS.

(2) Interaction with Dr. Juho Lipponen, Head of Unit, Carbon Capture and Storage, IEA and CCS group team:

Dr. Ellina Levina, Energy Analyst, Carbon Capture and Storage Unit and Dr. Dennis BEST, Cleaner Coal and CCS Programme Officer, Office of Global Energy Policy / DALSA presented on several important areas of the IEA 2013 CCS Roadmap. The presentation covered the current Status of CCS today, Vision for CCS deployment and the required actions for future.

The Key findings of the CCS Roadmap as below were explained elaborately to the study tour team:

- CCS is a **critical component** in a portfolio of low-carbon energy technologies, contributing 14% of the cumulative emissions reductions between 2015 and 2050 compared with business as usual.
- The individual component technologies are generally well understood. **The largest challenge is the integration** of component technologies into large-scale demonstration projects.
- Incentive frameworks are urgently needed to deliver upwards of **30 operating CCS projects by 2020**.
- CCS is not only about electricity generation: 45% of captured CO2 comes from **industrial applications** between 2015 and 2050.
- The largest deployment of CCS will need to occur in **non-OECD countries, 70% by 2050**. China alone accounts for 1/3 of the global total of captured CO2 between 2015 and 2050.
- The urgency of CCS deployment is only increasing. **This decade is critical** in developing favourable conditions for long-term CCS deployment.

The various challenges for CCS deployment interms of Economics, Policy support, Technology development and popular stakeholder views were discussed with the study tour team.

The current progress with large-scale capture projects worldwide has been useful for the study tour team to establish linkages for future needs.

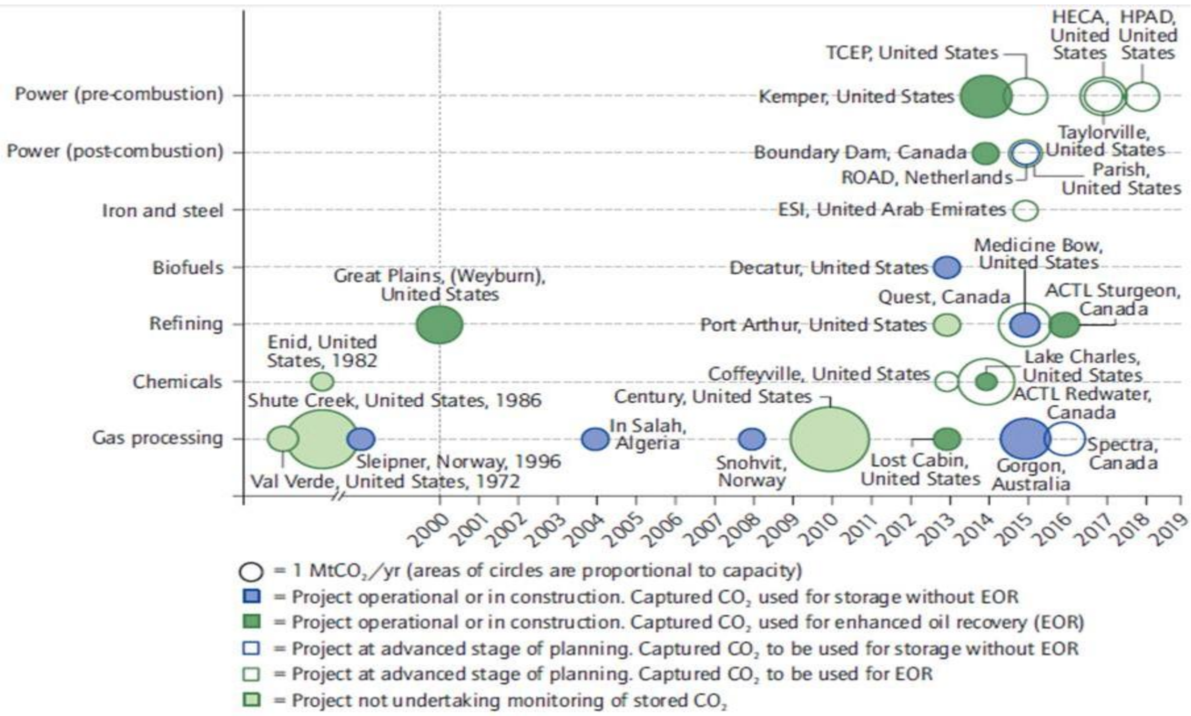


Fig 2: Large-scale CO2 capture projects in operation, under construction or at an advanced stage of planning as of end-2012, by sector, storage type, capture potential and actual or estimated start date

Seven key actions required for next seven years for enabling wide deployment of CCS was discussed in detail with the study tour team:

- Introduce **financial support mechanisms** for demonstration and early deployment.
- Develop laws and regulations that effectively require new-build power capacity to be **CCS-ready**.
- Significantly increase efforts to **improve understanding** among the public and stakeholders of CCS technology.
- Implement policies that **encourage storage** exploration, characterisation and development for CCS projects.
- Reduce the **cost of electricity** from power plants equipped with capture through continued technology development.
- Prove capture systems at pilot scale in **industrial applications**.
- Encourage efficient development of CO_2 **transport infrastructure**.

Meeting with IEA officials