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Clean coal technology to improve environmental quality and energy efficiency

Coal is the world's most abundant and widely distributed fossil fuel source. It is a major source of commercial energy in the present scenario. Coal currently supplies over one third of the world's electricity and 23% of global primary energy needs. Conventional power generation system, though one of the cheapest means of production of electricity in the world, have energy efficiency only 30-35%. However, it has enormous environmental impact which includes emission of large amount of gases like CO_2, SO_2, NO_x, and Hg, particulate matter which primarily includes fly ash. This is responsible for global warming and air and water pollution. To reduce this environmental impact due to emissions from thermal power plant and to meet the quality requirements of the coal consumers, it is imperative to adopt clean coal technologies. "Clean coal" is a term used in the promotion of the use of coal as an energy source by emphasizing methods being developed to reduce its environmental impact.

This paper addresses advanced power generation systems like integrated gasification combined cycle (IGCC) system and underground coal gasification (UCG) which claim to have energy efficiency in the range of 45-50%. Carbon capture and storage (CCS) technology for capturing emitted CO_2 and storing it in geological formation appears to be one of the efficient means to reduce CO_2 in the atmosphere. This technology has also been enumerated in this paper. An account for global and Indian initiatives for clean coal technology is given. Clean coal mining operation along with coal preparation technology practiced in India is also discussed in brief.

Introduction

Coal is the world's most abundant and widely distributed fossil fuel source. It is a major source of commercial energy in the present scenario. Coal currently supplies over one third of the world's electricity and 23% of global primary energy needs. Over two third of steel production is dependent on it and it is widely used as a source of energy in the production of cement. Coal-fired electricity drives the economies of the two most populous and fastest growing countries in the world today – China and India – as well as a number of key industrial economies, such as the USA and Germany. Around 77% of China's electricity comes from coal. About 93% of the country's electricity in South Africa is generated from the coal (Catelin, 2005; IEA, 2002; IEA 2007; WCI, 2004).

India is expected to be among the leading markets for basic material by 2015 due to rapid demand growth. As per estimates, the demand for steel in India will reach to 80-100 mt by 2015 and India will then be the fifth largest market in the world. India will become the fourth largest market for the coal by 2015 with demand estimated to reach 790 mt. At present, India is the third largest producer of the coal in world (http://www.coal.nic.in/abtcoal.htm).

Coal is one of the largest producers of the greenhouse gases. The pollutants produced with mining to burning of coal are not only damaging the earth surface to atmosphere and hydraulic regime to bio-diversity but also threatening the very survival of the human being due to global warming. Burning coal produces about 9 billion tonnes of CO_2 each year which is released to the atmosphere, about 70% of this being from power generation. Other estimates put CO_2 emissions from power generation at one third of the world total of over 25 billion tonnes of CO_2 emissions (http://en.wikipedia.org/wiki/carbon_dioxide). Globally, coal related CO_2 generation increased by 31% between 1990 and 2004 (coming_clean.pdf).

However, energy generation from the coal on the other hand is essential for the industrialization, employment generation and quality improvement of human life. There comes the need for clean coal technology. This paper deals with the very concept of clean coal technology, scope of application of this technology in different stages of coal production and use, technology to improve energy efficiency and environmental quality and finally institutional mechanism in global and national level to ensure effective implementation of clean coal technology.

Clean coal technology (CCT)

"Clean coal" is a term used in the promotion of the use of coal as an energy source by emphasizing methods being developed

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to reduce its environmental impact. These efforts include chemically washing minerals and impurities from the coal, gasification, treating the flue gases with steam to remove sulfur dioxide, and carbon capture and storage technologies to capture carbon dioxide from the flue gas. These methods and the technology used are described as clean coal technology (http://en.wikipedia.org/wiki/Clean_coal_technology). The coal industry uses the term "clean coal technology" to describe technologies designed to enhance both the efficiency and the environmental acceptability of coal extraction, preparation and use, with no specific quantitative limits on any emissions, particularly carbon dioxide.

CCT represents a continuously developing range of options to suit different coal types, different environmental problems, and different levels of economic development (WCI, 2003). There are two primary ways of reducing CO_2 emissions from coal use – (a) the greatest potential is offered by carbon capture and storage (CCS) which can reduce CO_2 emissions to the atmosphere by 80%-90%; and (b) improving efficiencies at coal-fired power stations – meaning lower emissions per unit of energy output (WCI, 2007).

Technology pathway of CCT may be considered to take place in three stages (WCI, 2003; WCI, 2007), such as:

- *Increased use of existing commercial technologies for lower emissions* – Eliminating emissions of pollutants such as particulate matter and oxides of sulphur and nitrogen. This has largely been achieved and the issue now is the application of 'off-the-shelf' technology.
- *Deployment of new, state-of-the-art technologies of coal combustion* – Increasing thermal efficiency to reduce CO_2 and other emissions per unit of electricity generated. Major gains have already been achieved and further potential can be realized.
- *Development and commercialisation of the next generation of technologies for ultra low emissions* – Eliminating CO_2 emissions. The development of 'zero emissions technologies' has commenced and is accelerating rapidly.

This CCT can be implemented in different stages of coal life cycle. Implementation of CCT at different stages is enumerated below.

Coal mining

"Clean coal mining" is defined as extraction of coal in environment-friendly manner so as to have minimum dilution in coal and minimum impact to environment. Following steps are taken to reduce adverse impact on environment in case of underground coal mining (Singh and Singh, 1999):

- Regular practice of hydraulic sand stowing of voids to minimize land subsidence.
- Filling of old quarries and plantation of quarried area.
- Avoiding movement of coal at surface in open dumpers. This can be accomplished by a network of belt conveyor through underground roadways that will transport coal directly to the washery.
- Mine water may be directly used for stowing purposes. Treatment of mine water by water treatment plant makes it potable.
- High capacity main fans may be installed to give clean air to workers inside the mines and to render the mine gases harmless by adequate dilution before these are discharged into the atmosphere.

The mining process underground requires working clean coal section in a way to keep clean of band, weak fragile roof or floor rock. Following options are possible for improving the quality of coal during mining (Singh, 1999).

- Maintain horizon in mechanized mining, shearing or continuous mining
- Stabilize weak roof against caving in and mixing to the coal mass
- Mining in sections, maintaining the band as roof or floor of different sections
- Picking band or intrusions and discarding in the goaf or underground voids
- Control over soft floor cutting and mixing with coal
- Control over erratic floor blasting particularly in case of dipping seams
- Selective mining of clean coal section

Coal preparation

Coal preparation refers to the treatment of raw coal to enhance its suitability for particular end-uses. Effective preparation of coal prior to combustion yields the following advantages:

- upgrades the quality of the coal in terms of heat value
- improves the economics of transportation of coal by removing most of the non-combustible material, thereby produces less ash for disposal at the power plant
- improves the homogeneity of coal supplied
- improves utilistation efficiency of coal
- reduces emissions of oxides of sulphur from coal

In early days the coal preparation was carried out through following processes:

- Hand picking of stone, shale pieces on the face in the tubs or conveyors
- Selective mining leaving band in the roof, floor or in the goaf
- Segregation of stone in the dumping yards during loading in wagons or trucks
- Sizing and screening

The practices became uncommon with the nationalization of coal industry. Coal washery came into existence for using high ash content coking coal in the steel industry way back in 1951-52. Washing of coal involves crushing it to suitable size and use of heavy media (HM) bath to separate out different specific gravity fractions as clean coal, middling and rejects. Magnetite, having specific gravity in the range of 4.8 to 5.4 used in washery for washing process, is ground to -325 mesh and mixed with water to maintain the desired gravity in HM bath or HM cyclone for separation of coal from its impurities (Singh and Singh, 1999). There are over 23 washeries in coking coal sector with raw coal input capacity of 41.9 million tonne per annum (mtpa). The coal washery products on average constitute 50% clean coal and 20% middling. Tata Steel washeries have a better yield of 76-80% clean coal (Singh, 1999). India's non-coking coal accounts for nearly 92% of total coal production. Hardly any effort was made to clean non-coking coal as the mining remain selective with ash content below 30-35%. Environmental threat and unfavourable economics of long distance transport of high ash coal to power plants forced cleaning of even power grade coal.

One of the recommendations of a conference held on "clean coal for green power" on 29.05.08 at India Habitat centre, New Delhi, was that coal washing should be made an integral part of all major coal projects. In this conference Coal India Ltd. proposed to set up 18 coal washeries in different coalfields for washing 100 mtpa of coal (Recommendations of Conference on Clean Coal for Green Power, 2008).

Advanced power generation system

The advanced power generation system primarily consists of coal gasification which is a process that converts coal into carbon monoxide and hydrogen by reacting it (coal) at high temperatures with a controlled amount of oxygen and/or steam. The resulting gas mixture is called synthesis gas or syngas and is itself a fuel. The two most widely used systems are integrated gasification combined cycle systems (IGCC) and underground coal gasification (UCG). These two systems are described below.

Integrated gasification combined cycle systems

In IGCC systems, coal or other fossil fuel is fed to a gasifier at elevated pressure, where it reacts with oxygen or air and steam, to produce a raw fuel gas. This raw gas is cleaned to remove particulate materials and other gaseous pollutants before being fired in a gas turbine. Hot gas from the gas turbine exhaust is passed through a waste heat recovery system and the steam produced is used to drive a conventional steam turbine. Hence, electricity is produced from both the gas and steam turbines (Sage and Mills, 1996). A typical IGCC flow diagram is shown in Fig.1. During gasification fuel gas consisting of mainly CO, CO_2, H_2, CH_4, N_2 and H_2S are produced. This mixture of CO, CH_4 and H_2 produced through gasification is burnt after it passes through a hot gas cleanup unit and the very hot exhaust is routed through a gas turbine to generate electricity. Afterwards, the residual heat in the exhaust gas is used to boil water for a conventional steam-turbine generator via a heat recovery steam generator thus producing more electricity (Ben-Slimane and Hepworth, 1994b).

IGCC offers energy efficiencies of up to 50%, with a potential of 56% in the future, thereby significantly improving environmental performance. An IGCC plant needs 10 to 20% less fuel than a large-scale standard coal-fired power plant and up to 35% less than a small-scale industrial coal-fired power plant. Emissions are greatly reduced, even compared to advanced conventional technologies, with 33% reduction in nitrous oxides, 75% less sulfur dioxide and almost zero particulate emissions. This system needs 30-40% less water than a conventional thermal power plant. However, cost of setting up of an IGCC plant is a bit more than that of conventional power plant. It is estimated that an IGCC plant is 10 to 20% more expensive to build than a conventional power plant.

Underground coal gasification (UCG)

Underground coal gasification (UCG) is a physico-chemical process of conversion of coal into gaseous energy source at the place of its occurrence. It is carried out in non-mined coal seams using a network of injection and production wells drilled from the surface. The process is flexible in operation and is capable of producing commercial quantities of gas to be used as a chemical feedstock or as fuel for power generation. The technique can be applied to resources that are otherwise not economical to extract and also offers an alternative to conventional coal mining methods for some resources (Underground coal gasification - Wikipedia, the free encyclopedia.htm).

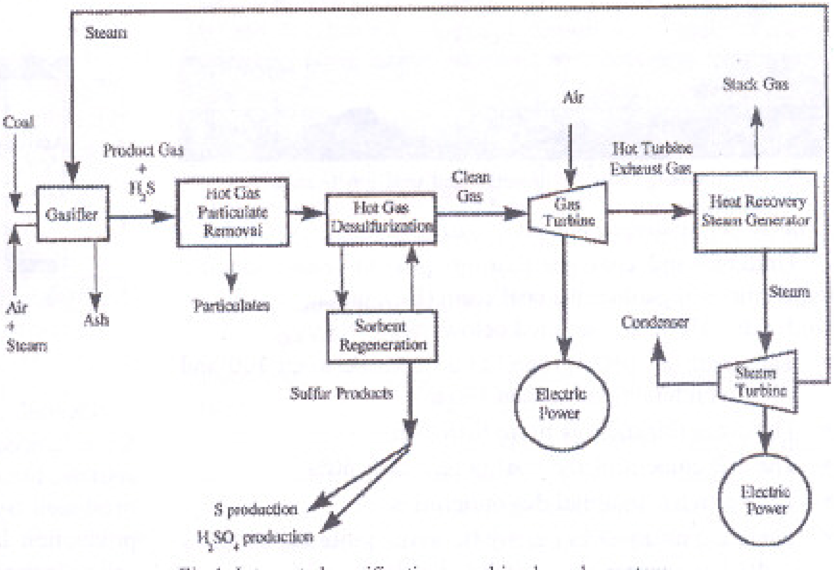

Fig.1 Integrated gasification combined cycle system

Coal is gasified underground by drilling boreholes from the surface into the coal seam, creating a linkage through the coal seam between the injection and production wells and injecting air (or oxygen) and water (or steam) into the underground reaction zone (Fig.2). In the process, coal is partially oxidized, producing low and medium Btu gas. If only air is injected, the produced gases contain a high percentage of nitrogen and have a heating value roughly one-tenth of natural gas. It is named as low-Btu gas. Injecting oxygen rather than air reduces the nitrogen content and raises the heating value of the produced gas to the 'medium-Btu' gas range – of heating value roughly one-fourth of natural gas. If the goal is high-Btu gas (also called as substitute natural gas or SNG), the percentage of methane in the produced gases needs to be boosted. For methane formation in UCG, two additional steps are required. First, some of the CO made in the gasification process is reacted with steam to form additional hydrogen. This step, called shift conversion, sets up the proper ratio of gases for the next step called methanation. The hot gas thus produced is allowed to pass through the coal seam and finally come out through the production boreholes and is carried to the surface where it is cleaned and upgraded for use (DTI Report, 2004).

Shift conversion: $CO + H_2O = CO_2 + H_2$
Methanation: $CO + 3H_2 = CH_4 + H_2O$

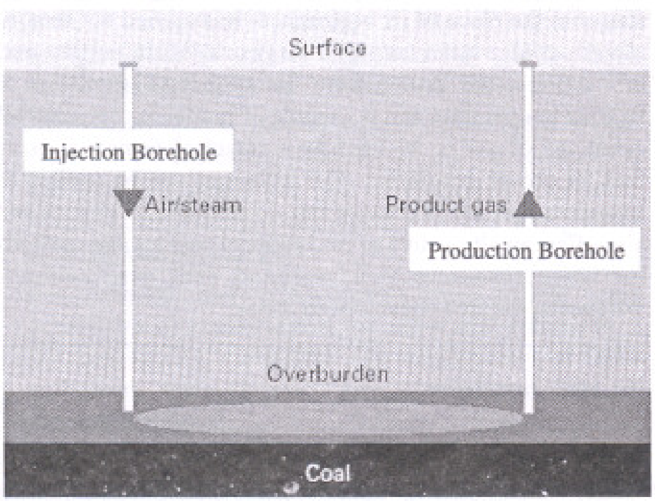

Fig.2 Basic configuration of underground coal gasification process

Criteria for underground coal gasification

Underground coal gasification projects have specific requirements regarding the coal seam (Best practices in UCG-Draft.pdf). These are outlined below:

- The seam lies underground at a depth between 100 and 600 m (preferably more than 300 m)
- The seam thickness is more than 5 m
- The ash content of the coal is less than 60%
- The seam has minimal discontinuities
- There are no aquifers nearby (to avoid polluting supplies of drinking water)

Carbon capture and storage (CCS)

Carbon capture and storage (CCS) technologies allow emissions of CO_2 to be captured and stored, preventing them from entering the atmosphere. CO_2 capture is possible from power stations or potentially other large CO_2 sources, such as chemical, steel or cement industries or natural gas production. CO_2 can be stored in geological formations such as aquifers or expired oil and gas reservoirs, deep un-mineable coal seams, deep unused saline water-saturated reservoir rocks etc.

The world's first industrial-scale CO_2 storage was at Norway's Sleipner gas field in the North Sea, where about one million tonnes per year of compressed liquid CO_2 separated from methane is injected into a deep reservoir (saline aquifer) about a kilometre below the sea bed and remains safely in place. Another scheme separating CO_2 and using it for enhanced oil recovery is located at In Salah, Algeria (http://en.wikipedia.org/wiki/carbon _dioxide). Capture of CO_2 from coal gasification is already achieved at low marginal cost in some plants. One is the Great Plains Synfuels Plant in North Dakota, USA where 6 million tonnes of lignite is gasified each year to produce clean synthetic natural gas and piping its captured CO_2 to oil fields in Canada for years.

Although some components of CCS technology have been proven on a commercial scale, a fully integrated CCS system operating in conjunction with a coal-fired power plant has not yet been demonstrated. The first large-scale demonstration coal-fired power stations with CCS include FutureGen in the United States, due for completion in 2012, and a recently announced "zero emission" plant in Queensland, Australia, to be completed in 2010. These projects aim to demonstrate commercial and technical feasibility of coal-fired power stations with integrated CCS. Fig.3 shows UCG operation with pre-combustion CO_2 separation and its sequestration.

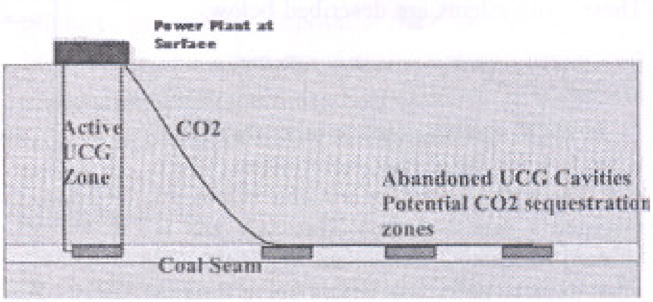

Fig.3 UCG and CO_2 sequestration

Overall in USA, 32 million tonnes of CO_2 is used annually for enhanced oil recovery, 10% of this from anthropogenic sources. Fig.4 shows various alternatives for use of CO_2. CO_2 produced by power station can be utilized for methane production in un-mineable coal seams, injection into deep saline formation and enhanced oil recovery.

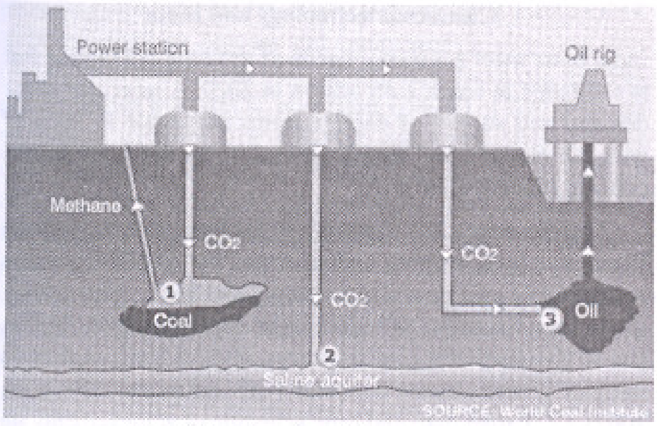

Fig.4 CO_2 alternatives for use or storage

Global initiatives for clean coal technology

USA: FutureGen

The FutureGen project was launched in 2003 to demonstrate a near-zero emission 275 MW coal-fuelled IGCC plus hydrogen production plant, incorporating CO_2 separation together with geological storage. The project is intended to create the world's first zero-emissions fossil fuel plant which, when operational, will be the cleanest fossil fuel-fired power plant in the world (WCI, 2004).

USA/Canada: ZECA

ZECA Corporation is the successor to The Zero Emission Coal Alliance, which was founded in 1999 by The Coal Association of Canada, Los Alamos National Laboratory and 16 other organisations. The ZECA Corporation is undertaking research for the development of the hydro-gasification process. The Corporation is also cooperating with researchers who are looking into mineral carbonation as a route to CO_2 disposal (WCI, 2004).

Canada: Canadian Clean Power Coalition (CCPC)

The CCPC is a public-private partnership that aims to demonstrate CO_2 removal from an existing coal-fired power plant by 2007 and from a new power plant by 2010. CCPC comprises seven founding member companies representing over 90% of Canada's coal-fired electricity generation capacity, together with the Electric Power Research Institute, based in the USA (WCI, 2004).

Canada: CANMET Energy Technology Centre

At the Centre, clean coal R&D focuses on research into oxy-fuel combustion, fluidised bed combustion of steam coals for reduction of acid precursors, and mercury emission reductions from coal-fired power stations (WCI, 2004).

Europe: AD 700 Power Project

The AD 700 power plant involves collaboration between the European Commission and industry and is one of the projects financed by the EU's Fifth Framework Programme. The focus is on establishing ultra supercritical steam conditions, while at the same time developing improved power plant designs to minimise capital investment. The project aims to raise efficiencies to 55%, resulting in lower fuel consumption and reduction in CO_2 emissions of almost 15% (WCI, 2004).

Australia: COAL21 Fund

The Australian coal industry launched the COAL21 Fund in March 2006 to support the financing of near-zero emission coal demonstration projects and associated R&D. The Fund is being raised by an A$0.20 per tonne voluntary levy on coal producers that is expected to raise up to A$1 billion over the next ten years. Through the COAL21 Fund, the Australian coal industry will work with governments, electricity generators and researchers to advance knowledge and commercial-readiness of low emissions energy technology (WCI, 2007).

Japan: EAGLE Project

The New Energy and Industrial Technology Development Organization (NEDO) is undertaking a major project, known as EAGLE (coal energy application for gas, liquid and electricity), to develop coal gassification for use in fuel cells. A pilot plant has been constructed with a coal processing capacity of 150 tonnes/day that aims to develop a coal gassifier suitable for integrated gasification fuel cell (IGFC). The project, which started in 1998 and was due to run until 2006, is part of a broader initiative involving the incorporation of fuel cells within an IGCC (IEA, 2003b).

China

In China, many companies have undertaken bilateral efforts to facilitate access to clean coal technologies. Multilateral institutions, such as development banks and the global environment facility have also been active in this field (Philibert and Podkanski, 2005). China is also emerging as a significant investor in overseas energy projects – the China Development Bank, for example, has assets bigger than the World Bank and Asian Development Bank combined (FT, 2007).

IEA G8 Gleneagles Programme

Under the G8 Gleneagles Plan of Action, the IEA is working with partners around the globe to focus on climate change, clean energy and sustainable development. The IEA's G8 Gleneagles Programme is promoting energy-sector innovation, better practice and use of enhanced technology. This includes programmes focusing on cleaner fossil fuels and CCS (WCI, 2007).

European technology platform on zero emission fossil fuel power plants (ETP ZEP)

The European Commission, European energy industry, research community and NGOs have established an ETPZEP. The platform aims to develop and deploy new competitive options for near-zero emission fossil fuel power plants within the next 15 years (WCI, 2007).

Carbon Sequestration Leadership Forum (CSLF)

CSLF is an international climate change initiative that is focused on the development of cost-effective technologies for CCS. CSLF aims to make these technologies available internationally and to identify and address wider issues relating to CCS. CSLF is currently comprised 22 members, including 21 countries and the European Commission (WCI, 2004; WCI, 2007).

Cooperative Research Centre for greenhouse gas technologies (CO_2CRC)

CO_2CRC is a collaborative research organisation – involving industry, research parties, international collaborators, and government organisations – focused on the development and application of technologies to more effectively capture and geologically store CO_2 (WCI, 2007).

EPRI 66 CoalFleet for tomorrow

The EPRI 66 CoalFleet for tomorrow programme is tackling the technical and economic/institutional challenges to making advanced, near-zero emission coal power plants a good investment option. This industry-led programme provides a vehicle for collaborative RD&D on deployment-related issues for near-term plants (WCI, 2007).

World Bank

The World Bank is working on an investment framework for clean energy and development. This framework will catalyse investments from public and private sources to increase access to energy in developing countries, while using cleaner technologies (WCI, 2007).

Asia-pacific partnership on clean development and climate (AP6)

AP6, consisting of representatives from Australia, China, India, Japan, South Korea and the USA, was announced on 28 July 2005 to work together to develop cleaner, more efficient technologies that will meet climate concerns without negatively effecting economic growth. AP6's Cleaner Fossil Fuels taskforce aims to accelerate the development and deployment of technologies through collaborative research and on-going demonstration in order to reduce costs and facilitate the availability of a range of accessible and affordable low-emission technologies (Morvell, 2006; WCI, 2007).

Clean coal technology and India

India must meet economic needs of growing population that is estimated to reach 1.35 billion in 2020. A large gap in the demand and supply of energy seems inevitable in 2026-27 with the demand and supply of coal to be the most serious concern (Sachdev, 2006).

Therefore the CCT imperatives for India is three-fold: (a) Economic: hydrocarbons and other fuel options are expensive but domestic coal provides a cheaper and better value option, (b) Energy Security: to reduce over dependence on imports and to trap domestic coal resources, and (c) Environment: to mitigate global climate concerns (CO_2 emissions) (Sachdev, 2007). CCT road map and time schedule of achievements are presented in Table 1 and Fig.5.

Indian institutions/organizations working for CCT

National Clean Coal Technology Centre

Establishment of this multi-institutional, multi-disciplinary autonomous and independent institution has been envisaged to identify and pursue (a) coal related R&D programmes, (b) major development and demonstration projects and (c) to cover entire coal chain - coal beneficiation, coal conversion, emissions monitoring and control (Sachdev, 2007).

Bharat Heavy Electricals Limited (BHEL)

BHEL is the first and foremost organization to develop IGCC in India. The total IGCC development was executed in three phases. In the first phase, BHEL had set up a pressurized moving bed gassifier of 6.2 MW combined cycle

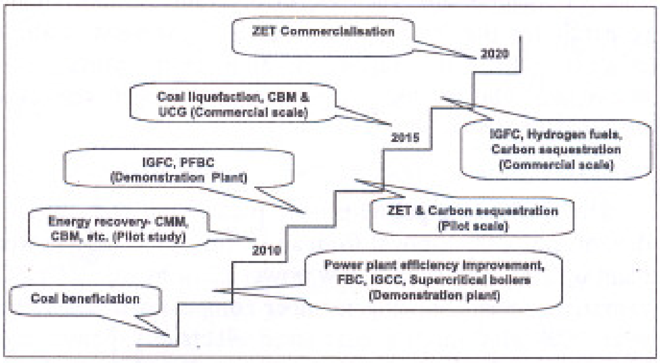

Fig.5 Milestones of Indian CCT road map (Sachdev, 2007)

Table 1: CCT road map for India (Sachdev, 2006)

Ongoing and near term (< 5 yrs)	Medium-scale (5 – 10 yrs)	Long-term (> 15 yrs)
Coal beneficiation, improved recovery, lower cost, rejects disposal	IGCC, PFBC, ultra-supercritical power plants	Zero emission technologies (commercialization)
Economy in coke consumption in steel plants, energy recovery coke ovens	Enhanced energy recovery from coal: CBM, UCG (commercial scale)	Carbon sequestration (commercial scale)
FBC, supercritical power plant boilers, IGCC (demo unit)	Coal liquefaction (commercial scale)	IGFC, Hydrogen fuel from coal
Enhanced energy recovery from coal CBM, CMM (pilot scale)	Zero emission technologies (pilot scale)	
Coal liquefaction (pilot scale)	Carbon sequestration (pilot scale)	

plant for getting the lead in IGCC technology in India. An 18 TPD coal capacity process and equipment development unit (PEDU) was taken up in the second phase. Based on the data and experience from PEDU pilot plant, a PFBG of 168 TPD coal throughput capacity (for 42% ash coal) was designed and retrofitted to the above 6.2 MW IGCC during the third phase of development. Based on the experience from the pilot plant and demo-plant studies, BHEL is planning for setting up a national project of 100 MW IGCC for commercial demonstration. BHEL also has developed hot gas cleanup system (HGCS) using granular bed filter system coupled to a 6 TPD pressurised fluidised bed combustion (PFBC).

Centre for power efficiency and environmental protection

Centre for power efficiency and environmental protection is established under NTPC to work on reduction of CO_2 emissions and improve performance of coal-fired power plant (Sachdev, 2007).

India's commitment to CCT and climate change concerns

India is the first Asian country to join the US Government Steering Committee for FutureGen Initiative. India is also closely associated with international initiatives such as CSLF, Methane to Market Partnership initiative, International Partnership for a Hydrogen Economy and International Thermonuclear Experimental Reactor project. Energy Coordination Committee under the Prime Minister is engaged in identification of actions to be taken to fully meet country's energy needs, and its social, economic and environmental impact and global climate change concerns (Sachdev, 2007).

Conclusion

Coal is an extremely important fuel and will remain so in the foreseeable future. The clean coal technology field is moving very rapidly. This technology has the potential to provide what may be called "zero emissions" - in reality, extremely low emissions of the conventional coal pollutants, and as low-as-engineered carbon dioxide emissions.

Advanced power generation systems have higher efficiency (45-50%) than the conventional power generation system (30-35%). Much of the challenge lies in commercializing the technology so that coal use remains economically competitive despite the cost of achieving "zero emissions".

A review of global initiatives on CCT indicates that several organizations are working in the areas of clean coal. It is expected that more research and funding to such scheme will yield better output leading ultimately to zero emissions and higher energy efficiency. In India, BHEL, Reliance Industries Ltd, ONGC, GAIL, CIL and GIPCL are the leading organizations who are working on clean coal technology. More pilot studies should be taken up by private and governmental organizations to utilize otherwise difficult-to-access coal deposit.

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