RESEARCH ARTICLE OPEN ACCESS

Prospect of Coal Based IGCC to Meet the Clean Energy Challenge

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ABSTRACT
The development of a country is nearly proportional to the average per person energy consumption rate, which is very low in our country. However, the rate of average energy consumption is increasing day by day throughout the world. With increasing the production of energy, the problem of environment pollution from the power generation sources and energy efficiency becomes more imperative. Coal is the major source of primary energy of the world, however, the energy efficiency of coal based power plant is low, and also it significantly polluted the environment. Therefore, to improve the energy efficiency and reduce the pollution from coal based power plant is an important issue to discuss. In this paper, the primary reserves of energy throughout the world are discussed. Integrated gasification combined cycle (IGCC) is a latest technology used to improve the performance of coal based power plant. The process of IGCC and the present condition of IGCC throughout the world is discussed. Finally the advantages of IGCC and necessity of moving towards IGCC from convention coal based power plant is discussed in terms of cost, efficiency and environmental issues.

***Keywords* -** Energy, Coal Gasification, IGCC, Clean Coal Technology, CCS

I. INTRODUCTION

With increasing population and development, the rate of consumption of energy is also increasing day by day. According to International Energy Agency(IEA), the world energy consumption increased by 39% from 1990 to 2008, and according to the projection of International Energy Outlook 2013 (IEO2013), world energy consumption will increase by around 56 percent from 2010 to 2040 [1]. Efficiency of energy conversion is an important issue to utilize the limited energy properly. Also the environmental pollution from power generation sources is an important issue. IGCC is a latest technology used to improve the performance of coal based power plant. Although the cost of IGCC is high as compared to conventional coal based power plant, it significantly increases the energy efficiency and reduces the environmental pollution. In this paper, the primary reserves of energy, the process of IGCC and the present condition of IGCC throughout the world is discussed. The advantages of IGCC and necessity of moving towards IGCC from convention coal based power plant in terms of cost, efficiency and environmental issues is also discussed.

II. WORLD ENERGY SCENARIO

The reserve of primary energy sources of world top ten high reserve countries are given in Table I. The world fossil fuel (coal, gas and oil) proved reserve is 7,163 billion barrels oil equivalent [2] [3]. The US holds the largest individual coal reserves, followed by Russia and China. According to British Petroleum Statistical Review of World Energy of June 2013, the largest primary energy consumer USA consume 2735.16 million tonnes oil equivalent primary energy where 68.5% energy comes from coal and 2nd highest source is oil by 17.7%. Natural gas contributes just 4.7% of total energy consumption of USA [2]. The total reserve of primary sources in terms of oil equivalent is given in Table II. It is clear that coal is the main sources of energy of the world. Now, nearly 41.5% of electricity is generated from coal [4].

III. ULTIMATE FUEL FOR FUTURE

It has been estimated that there are over 861 billion tonnes of proven coal reserves worldwide. This means that there is enough coal to last us around 112 years at current rates of production [5]. Table-1 illustrates the world fossil fuel proved reserved in top 10 countries and Table-2 compare with oil equivalent energy and proved that, coal is the ultimate fuel for near future.

TABLE 1: World Fossil Fuel (Coal, Gas and Oil) Proved Reserve By Country [2]

	Coal			**Oil**			**Natural Gas**		
	Country	**Million Tonnes**	**Share of total**	**Country**	**Billion Barrels**	**Share of total**	**Country**	**Trillion Cubic Feet**	**Share of total**
Top 10 Counties	USA	237295	27.6%	Venezuela	297.6	17.8%	Iran	1187.3	18.0%
	Russian	157010	18.2%	KSA	265.9	15.9%	Russian	1162.5	17.6%
	China	114500	13.3%	Canada	173.9	10.4%	Qatar	885.1	13.4%
	Australia	76400	8.9%	Iran	157.0	9.4%	Turkmenistan	618.1	9.3%
	India	60600	7.0%	Iraq	150.0	9.0%	USA	300.0	4.5%
	Germany	40699	4.7%	Kuwait	101.5	6.1%	Saudi Arabia	290.8	4.4%
	Ukraine	33873	3.9%	UAE	97.8	5.9%	UAE	215.1	3.3%
	Kazakhstan	33600	3.9%	Russian	87.2	5.2%	Venezuela	196.4	3.0%
	South Africa	30156	3.5%	Libya	48.0	2.9%	Nigeria	182.0	2.8%
	Oth. Europe & Eurasia	22175	2.6%	Nigeria	37.2	2.2%	Algeria	159.1	2.4%
	Pakistan	2070	0.2%	China	17.3	1.0%	India	47.0	0.7%
	Bangladesh	2083	0.2%	India	5.7	0.3%	Bangladesh	6.5	0.1%
	Total – 860938 Million Tonnes			Total - 1668.9 Billion Barrels			Total – 6614 Trillion Cubic Feet		

A. Coal

The most important part of primary energy sources are the carbon based fossil energy. Coal contributes 61% of total fossil fuel proved reserve in the whole world, where oil by 23% and Natural gas by 16%, following British Petroleum Statistical Review of World Energy [2].

TABLE 2: Fossil Fuel Proved Reserve oil eqv. 2013, [2]

Fossil Fuel	Reserve	Oil Equivalent Billion Barrels	Percentage of Total
Coal	860,938 Million Tonnes	4304	61
Oil	1669 Billion Barrels	1669	23
Natural Gas	6614 Trillion Cubic Ft.	1,190	16
Conversion : WCA standard, [3] 1 Mil. tonnes hard coal = apprx. 5 Million barrels oil equivalent 1 Tri. cubic feet NG = 0.18 Billion barrels oil equivalent			

B. Drawback of Coal as a fuel

We know that the coal is a dirty fuel to burn. The major drawbacks of coal come from the adverse environmental effects that accompany its mining, transport and combustion. The combustion of coal produces higher amount of CO_2 than that of from oil and natural gas for per unit of heat output, as in Fig-1. It also produces sulphur dioxide (SO_2), nitrogen oxides (NO and NO_2), mercury (Hg) compounds, and many other elements that cause acid rain, ash, and climate change. The solid fuel coal is more difficult to burn than liquid or gases and also its physical transport is difficult compare to other. Also Coal mining involves considerable environmental effect.

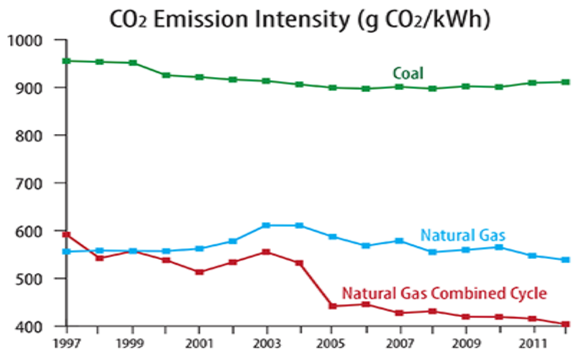

Fig. 1 Emission of CO_2 from traditional coal, natural gas and natural gas combined cycle based power plant [6].

C. Solution, That Add Great Advantage

A promising solution comes with coal gasification. The bad impact of burning of coal can be reducing by the clean-coal-technology which is a collection of technologies being developed to mitigate the environmental impact of coal energy generation. When coal is used as a fuel source, the gaseous emissions generated by the thermal decomposition of the coal include SO_2, NO_2, CO_2, and other chemical by-products that vary depending on the type of the coal being used. Clean coal technologies are being developed to remove or reduce pollutant emissions to the atmosphere. Some of the techniques that would be used to accomplish this include chemically washing minerals and impurities from the coal are as follows:

1. Gasification (IGCC), treating the flue gases with steam to remove sulfur dioxide.

2. Carbon capture and storage technologies to capture the carbon dioxide from the flue gas.

3. Dewatering lower rank coals (brown coals) to improve the calorific value.

IV. GASIFICATION PROCESS

Gasification is a process that converts organic or fossil based carbonaceous materials into syngas. One of the major environmental opportunities of this technology is the fact that impurities can be almost entirely filtered out when feedstock is transformed from a solid into a gas. Although there are various types of gasifers (gasification reactors), different in design and operational characteristics, there are three main gasifier classifications into which most of the commercially available gasifier fall. These categories are as follows:

(a) Fixed (moving) bed gasifier,
(b) Entrained-flow gasifier
(c)Fluidized-bed gasifier

Commercial gasifier of "GE Energy", "ConocoPhillips E-Gas™ " and "Shell SCGP" are examples of entrained-flow types. Fixed-or moving-bed gasifier includes that of "Lurgi" and "British Gas Lurgi (BGL)". Gasification is well experienced in different types of industry worldwide. More than 144 industries are using this process worldwide. National Energy Technology Laboratory, listed the number of proposed worldwide gasification projects having commercial potential, there are 35 IGCC (Integrated Gasification Combined Cycle), 12 SNG (Synthetic Natural Gas), 25 CTL(Coal-to-Liquids), 9 CTC (Coal to Chemicals), 8 BTL (Biomass to Liquids), 3 WTE (Waste-to-Energy), 1 WTEth (Waste-to-Ethanol), 1CBTL (Coal-Biomass-to-Liquids), 3 GTL (Gas-to-Liquids), 1 PTL (Petcoke-to-Liquids) and 1 BTG (Biomass to Gas) industries have proposed [7].

A. Coal Gasification Process

Gasification is one of the best ways to clean pollutants out of coal. The coal is fed into a high-temperature pressurized container (gasifier) and combined with hot steam and controlled amounts of air or oxygen under high temperatures (up to 2600 °F) and high pressures (up to 1200 psig) to generate synthetic gas or 'syngas'. The composition of the syngas can vary depending upon the conditions in the gasifier and the coal that is used, but typically it is a mixture of carbon dioxide, hydrogen, methane, and nitrogen and carbon monoxide. In a gasifier, the carbonaceous material undergoes several different processes, as in Fig-2:

1. The dehydration or Drying process occurs at around 100°C. Typically the resulting steam is mixed into the gas flow and may be involved with subsequent chemical reactions, notably the water-gas reaction if the temperature is sufficiently high enough.

2. The Pyrolysis process occurs at around 200-300°C. Volatiles are released and char is produced, resulting in up to 70% weight loss for coal. The process is dependent on the properties of the carbonaceous material and determines the structure and composition of the char, which will then undergo gasification reactions.

3. The Combustion process occurs as the volatile products and some of the char reacts with oxygen to primarily form carbon dioxide and small amounts of carbon monoxide, which provides heat for the subsequent gasification reactions, $C+O_2 \rightarrow CO_2$

4. The Gasification process occurs as the char reacts with carbon and steam to produce carbon monoxide and hydrogen, via the reaction $C+H_2O \rightarrow H_2+CO$

5. In addition, the reversible gas phase water-gas shift reaction reaches equilibrium very fast at the temperatures in a gasifier. This balances the concentrations of carbon monoxide, steam, carbon dioxide and hydrogen. $CO+H_2O \leftrightarrow H_2+CO_2$

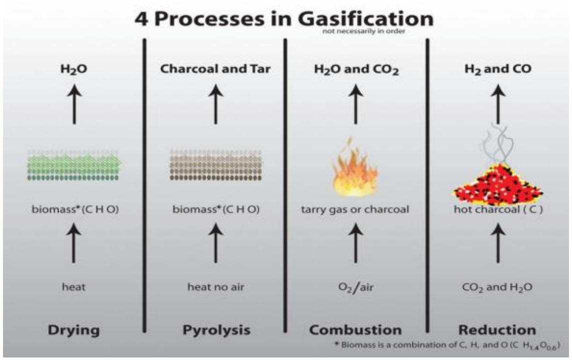

Fig. 2 : Basic 4 step process occurring in the time of coal gasification [8].

B. Integrated Gasification Combined Cycle (IGCC)

An integrated gasification combined cycle (IGCC) is a technology that uses a gasifier to turn coal into synthesis gas (syngas). It then removes impurities from the syngas before it is combusted. Some of these pollutants, such as sulfur, can be turned into re-usable by-products. This results in lower emissions of sulfur dioxide, particulates, and mercury. With additional process equipment, the carbon in the syngas can be shifted to hydrogen via the water-gas shift reaction, resulting in nearly carbon free fuel. The resulting carbon dioxide from the shift reaction can be compressed and stored. Excess heat from the primary combustion and syngas fired generation is then passed to a steam cycle, similar to a combined cycle gas turbine. These results in improved efficiency compared to conventional pulverized coal. Fig-3 shows, the basic difference of process step which makes the IGCC more efficient.

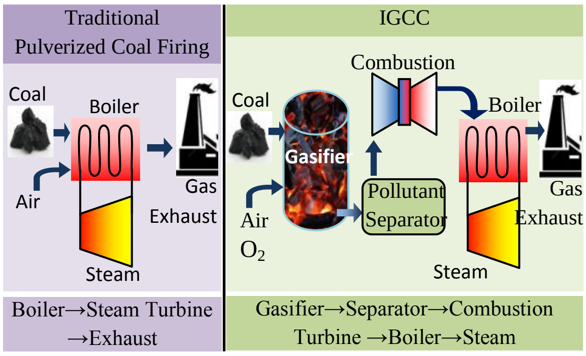

Fig. 3 Comparative process-step between traditional Pulverized Coal Firing and IGCC.

Separating and capturing carbon dioxide is easier and less expensive when oxygen is used in the gasifier (rather than air), and it does more than lessen the amount of greenhouse gases that are emitted into our atmosphere. Carbon dioxide can actually be useful. It can be pumped deep underground and stored in a storage field. From there, the carbon dioxide can then be piped to older oilfields to help recover oil that was previously left unused. Fig-4 illustrates the whole process of IGCC power plant.

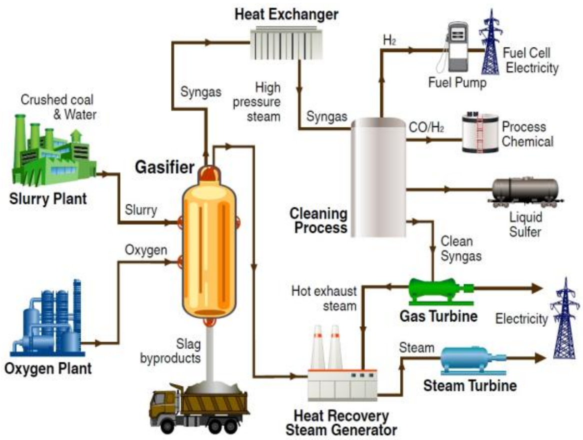

Fig. 4 Process flow of the IGCC Power plant [8].

C. Present Scenario of IGCC

As far as IGCC power generation is concerned, there are only six coal based units in the world, shown in Table 3. However, a small number of new projects have been initiated worldwide, each at some stage of planning or construction. According to National Energy Technology Laboratory, already 35 projects have proposed in worldwide to generate 20,730MW electricity by IGCC plant where the US proposed the maximum individual IGCC plant (11,775MW by 20 projects), followed by UK (2,540MW by 4 projects), Saudi Arabia (2,400MW by 1 project) and China (1,0505MW by 2 projects) [7].

D. IGCC Environmental Performance

An inherent advantage of the IGCC process is the potential for low emissions by using fuel gas clean up - instead of flue gas clean up. Because of the high partial pressures, impurities can be removed more effectively and economically compared to conventional clean up of the large volume flow of the combustion flue gas. Table-4 shows the emission profile of IGCC compared to conventional steam power plants.

Table 4: Comparison between Emission of Conventional Pulverized Coal Power Plant and IGCC Power Plant [10].

Pollutant	Adv. PC	IGCC	Change
SO2 (lb/MMBtu)	0.1	0.025	Decrease 75 %
NOX (lb/MMBtu)	0.06	0.0075	Decrease 87.5 %
CO2 (kg/kWh)	7.66	6.64	Decrease 13.3 %

Commercial processes such as MDEA and Selexol can remove more than 97 % of the sulfur so that the clean syngas has a concentration of sulfur compounds < 20 ppmv [11]. The more expensive Rectisol process can similarly achieve a concentration of < 0.1 ppmv [5]. SO_2 emissions of 0.15 lb/MWh has been demonstrated at the ELCOGAS plant in Puertollano, Spain [12]. The commercial technology for mercury removal is available, 99.9% Hg removal from syngas has been demonstrated [12].

Table 3 : Existing Coal Based IGCC Power Plant In Operation Worldwide [9]

Coal based IGCC Plant	1 Willem-Alexander	2 Wabash River	3 Tampa	4 Puertollano	5 Vresova	6 Nakoso
Location	Buggenum, Netherland	Indiana, USA	Florida, USA	Ciudad Real, Spain	Czech Republic	Fukushima, Japan
Commission yr.	1994	1995	1996	1998	1996	2004
Capacity	253MW	262MW	250MW	300MW	430MW	250MW
Feed Fuel	Black coal + Biomass	Black coal + Petroleum coke	Black coal	Black coal + Petroleum coke	Lignite	Black coal
Gasifier Type	O_2-blown Dry-feed Prenflo	O_2-blown Dry-feed E-Gas	O_2-blown Slurry-feed GE	O_2-blown Slurry-feed Shell	O_2-blown Dry-feed GSP	Air-blown Dry-feed HMI
Coal Consumption	2000 TPD	2500 TPD	2600 TPD	2500 TPD	2000 TPD	1700 TPD
Net efficiency	43%	39%	41%	42%	44%	42%

The cost of Mercury removal has been estimated to $ 3,412/ lb for IGCC vs. $ 37,800/ lb for Pulverized Coal plants. Also the IGCC plant uses 20 % to 50 % less cooling water than conventional coal plants [12], and water losses during operation are about 32–36% less than other coal-based technologies. This is a major issue in many countries -including the United States; where water supplies have already reached critical levels in certain regions. IGCC produces about half the amount compared to conventional PC plants. The solid waste is also less likely to leach toxic metals which are encased in the solidified slag. The slag is a useful by-product with a value.

E. IGCC Efficiency Performance

Compared to pulverized coal power plants, IGCC power plants have significantly higher efficiency. According to World Coal Association (WCA) London, the average global efficiency of traditional coal-fired plants is currently 33% compared to 45% for the most efficient plants like IGCC, due to the coupling of the gas and steam turbine process to the generation can be achieved. From the practical experience, average net efficiency of six existing IGCC plant is 41.8% with the maximum efficiency in 430MW Vresova IGCC plant by 44% and the minimum efficiency found in 262MW Wabash River IGCC plant, Indiana USA by 39%, as shown in Table 3. In IGCC power plant, efficiencies of over 55% can be achieved in the future. Compare to other advanced power plant processes, IGCC technology exhibits the highest efficiency and thus the lowest specific CO_2 accrual.

F. IGCC Cost Performance

One of the major disadvantages of coal gasification is the cost to set up and maintain the necessary facilities. The problem being that based purely on cost of electricity (COE), IGCC is not competitive with traditional pulverized coal or natural gas. As additional emissions restrictions are imposed on electricity generators, IGCC is expected to become the lowest cost solution especially if carbon capture and sequestration is required. Other sides, gasification byproducts (sulfur and slag) are readily marketable. For example, sulfur can be used in fertilizer production and slag can be used in roadbed construction and roofing materials. U.S. Energy Information Administration (EIA) summarizes the updated cost estimates for generic utility-scale generating plants, including seven powered by coal, illustrated in Fig-5.

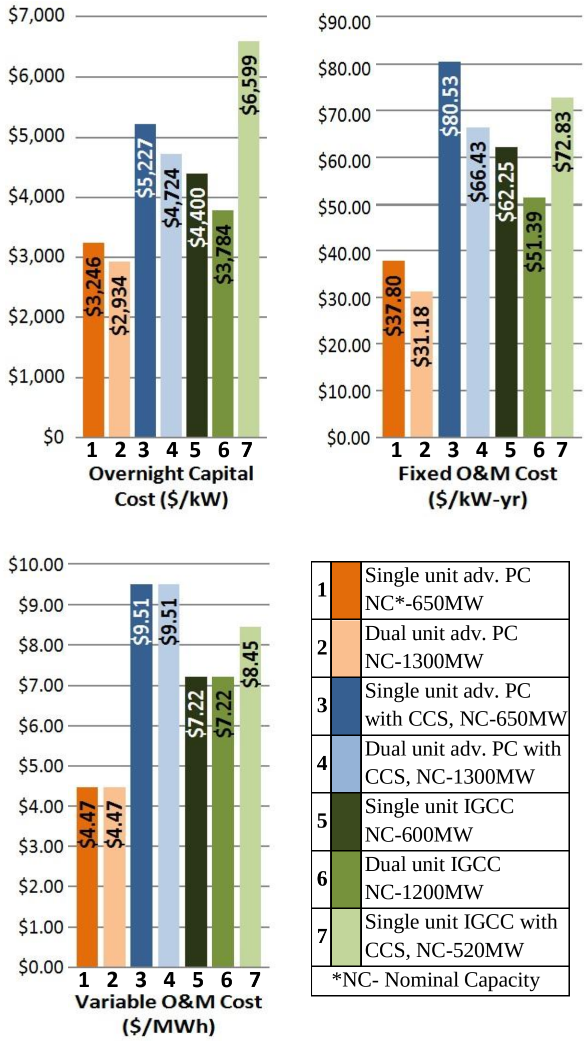

Fig. 5 Comparison of 7 types of coal based power plant by capital, operating & maintenance costs [13].

EIA does not model all of these generating plant types, but included them in the study in order to present consistent cost and performance information for a broad range of generating technologies. Here, a summary base capital cost estimate ("Cost Estimate") was developed for each power plant technology, based on a generic facility of a certain size (capacity) and configuration.

Operation and Maintenance (O&M) cost consist of non-fuel O&M costs, owner's expenses, and fuel-related expenses. It is discussed by two categories: fixed and variable. Fixed O&M expenses are those expenses incurred at a power plant that do not vary significantly with generation and Variable O&M expenses are production-related costs which vary with electrical generation. The analysis shows that, overnight capital cost of "IGCC with CCS" is very high compare to all other coal based power generation process. Other side, both the fixed and variable operation+maintanence cost of "IGCC with CCS" is low compare to "advanced pulverized coal fired with CCS". GE estimates that if super critical pulverized coal were required to achieve the same emissions levels as an IGCC plant, IGCC would achieve cost parity,[14]. However, the real advantage for IGCC comes in when carbon capture and sequestration (CCS) are considered. If emissions including CO_2 were ever subject to externality charges or taxes this would make IGCC a more attractive technology. Several studies have shown that if CO_2 removal from fossil-based power plants is ever required (for subsequent disposal, use or sequestration) it would be much less costly to remove the CO_2 from syngas under pressure prior to combustion rather than removal from the huge volumes of stack gases after combustion at atmospheric pressure. The absorption process is driven by partial pressure and the size of vessels is much reduced under pressure. With carbon capture, the cost of electricity from an IGCC plant would increase approximately 30%. For a natural gas CC, the increase is approximately 33%. For a pulverized coal plant, the increase is approximately 68%. This potential for less expensive carbon capture makes IGCC an attractive choice for keeping low cost coal an available fuel source in a carbon constrained world [15].

A study conducted by MIT shows that the cost per tonne of avoided CO_2 emissions is dramatically lower for IGCC compared to natural gas combined cycle (NGCC) or pulverized coal. However, because of the extremely high efficiency of NGCC and resulting low CO_2 emissions, the actual added cost of electricity for IGCC and NGCC is quite similar. So, it's better to introduce CCS technology with IGCC instead of other coal based power plant. These costs are summarized in the Table-5.

Table 5. Cost of Carbon Capture From Various Generation Technologies, [16].

	IGCC	PCF	NGCC
CO_2 Created (kg/kWh)	6.64	7.66	3.37
Cost of Avoided CO_2 ($/tonne)	18	32	41
Incremental COE(cents / kWh)	1.04	2.16	1.23

V. IGCC POWER PLANT FUTURE

Gasification is a simple and commercially well-proven technology. The gasification database (April 2014) of National Energy Technology Laboratory, USA, shows that total 98 gasification projects worldwide having commercial potential where, 35 IGCC(Integrated Gasification Combined Cycle), 12 SNG(Synthetic Natural Gas), 25 CTL(Coal-to-Liquids), 9 CTC(Coal to Chemicals), 8 BTL(Biomass to Liquids), 3 WTE(Waste-to-Energy), 1 WTEth(Waste-to-Ethanol), 1CBTL(Coal-Biomass-to-Liquids), 3 GTL(Gas-to-Liquids), 1 PTL(Petcoke-to-Liquids) and 1 BTG(Biomass to Gas) [17].

The high cost of IGCC is the biggest obstacle to its integration in the power market; however, most energy executives recognize that carbon regulation is coming soon. However, a small number of new projects have been initiated worldwide, each at some stage of planning or construction. According to National Energy Technology Laboratory, already 35 projects are under construction in worldwide to generate 20,730MW electricity by IGCC plant where the US proposed the maximum individual IGCC plant (11,775MW by 20 projects), followed by UK (2,540MW by 4 projects), Saudi Arabia (2,400MW by 1 project) and China (1,0505MW by 2 projects), [7].

Another source states that, China plans to build 50 coal gasification plants in less populated north-western parts of the country, using the gas produced to generate electricity in the more populated areas, where smog is prevalent, [17]. Future concepts that incorporate a fuel cell or a fuel cell-gas turbine hybrid could achieve efficiencies nearly twice today's typical coal combustion plants. If any of the remaining heat can be channeled into process steam or heat, perhaps for nearby factories or district heating plants, the overall fuel use efficiency of future gasification plants could reach 70 to 80 percent, as in [18].

There are many research agencies and institute worldwide, developing coal gasification technologies to minimize the environmental impact and improve the process efficiency for maximum energy utilization. Some of them are, National Energy Technology Laboratory (NETL)-USA, Commonwealth Scientific and Industrial Research Organization (CSIRO)–Australia, Massachusetts Institute of Technology (MIT)-USA, World Coal Association (WCA)-UK, International Energy Agency- IEA Clean Coal Centre (CCC)-UK, Institute of Clean Coal Technology (ICCT)-China, Canadian Centre for Clean Coal/Carbon and Mineral processing Technologies (C5MPT)-Canada.

Future work on clean electricity generation by coal gasification technology will focus on improving the reliability & performance of the gasifier and finding the best process for Syngas cooling, Water gas shift reaction (WGSR), Acid gas removal (AGR) mechanism, etc. Technical trends, which help gasification, include improving gas turbines and poly-generation. Each increase in combined-cycle efficiency directly reduces the size and cost of the gasification facility required to fire that combined cycle. Advanced intercooled, recuperated, reheat gas turbines have the potential of power-to-cogeneration heat ratio that is an order of magnitude higher than that possible with steam turbines. Poly-generation is unique to gasification and, with deregulation, this concept will develop. Gasification has strategic emission, efficiency, and economic flexibility for the future.

VI. CONCLUSION

Many energy experts predict that coal gasification will be the heart of clean coal technology for the next several decades. Energy efficiency and pollution from energy generation sources is a major concern now a day. This paper discussed the importance of coal as ultimate fuel of future, the drawbacks of conventional coal based power plant and need to move towards Integrated Gasification Combined Cycle (IGCC) power plant. Since coal is the major primary source of energy, improvement of performance of coal based power is a burning issue. IGCC is latest technology used to improve the performance of coal based power plant.

In this paper, the present scenario of IGCC is shortly discussed. The performance of electricity generation by coal gasification technique in terms of efficiency, application, cost and environmental issues as compared conventional coal fired power plant is discussed. Finally the future prospects of coal gasification technology are discussed. Though, some additional cost is involved in IGCC process, however benefits is more significant than this cost. Rich countries can afford this cost and under-developing countries may ask for donation from international organization who donates for health or environmental issues, like World health organization. IGCC technologies increase energy conversion efficiency and provide clean energy from coal which is the ultimate source of primary energy of the world. Bangladesh Government is committed to clean energy and going to use large amount of coal for electricity production, therefore, it is the best time to employ IGCC technology in Bangladesh.

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