Technological Determinants for Asian Power Generation Fuel Scenario Outlook

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1. INTRODUCTION

World net electricity consumption is expected nearly double over the next two decades, according to the *International Energy Outlook 2004 (IEO2004)* reference case forecast.

Worldwide total demand for electricity is projected to increase on average by 2.3% per year, from 13'290 TWh[1] in 2001 to 23'072 TWh in 2025. According to the same forecast, the electricity consumption in developing Asia[2] is projected to increase on average by 3.7% per year, from 3'000 TWh in 2004 to 6'275 TWh in 2025.

In Asia, the power generation industry is a diverse and complex patchwork of utilities, governmental agencies, and independent and captive power producers. Regional differences in industry composition and structure as well as fuel resources are in large part attributable to patterns in population, climate, economic activities and history of electrification in each region.

Regional differences in generation reserve margin, load growth, fuel mix and generation technology are very important factors in encouraging or discouraging the participation of power generators in competitive regional markets.

Many dynamic factors have been also seen in the Research & Development of new power generation technology and its commercial realization. Gas turbine (GT) machinery has achieved scientific and engineering technical status which otherwise would hardly have been possible under less favorable natural gas (NG) price circumstances.

Miscellaneous impulses have been seen in the independent power market arena. New legislation frameworks, financing tools, deregulation, privatization and liberalization trends have become typical in Asian region.

[1] TWh=1'000GWh

[2] Without Japan & Middle East

At the same time, the strong effect of fuel commodity prices upon engineering progress generates its counter-effect. A feed-back of power generating technology towards the fuel commodity structure does exist. All these factors have favored NG as first-priority fuel option wherever this was possible. GT based technologies have dominated in the new capacity demand saturation and they will also dominate further on. However, this does not mean that NG will retain the first choice for ever; its market saturation may appear by about 2025.

Huge reserves of coal together with appropriate coal-based technologies like Ultra-Supercritical Steam Cycles, Integrated Gasification Combined Cycle or Pressurized Fluidized Bed Combustion will cause subsequent decline from NG towards coal and other fossil fuel commodities.

1. Fuel Scenario Outlook

The mix of primary fuels used for electric power generation[3] has changed a great deal over the past three decades on a worldwide basis.

While the coal has remained the dominant fuel, NG-fired power generation has grown steadily and very rapidly in the 1970s, 1980s and 1990s.

NG has proven to be a very popular and clean choice for power generation worldwide. From 1975 to 1995, worldwide consumption of NG for power generation increased by an average of 6% per year.

On the other side, in conjunction with the post-world war II high oil prices caused by OPEC oil embargo in 1973-1974, the Iranian Revolution in 1979 and the recent crude oil price escalation (refer also to Figure 2); the use of Fuel Oil (FO) for power generation has been slowing since the mid-1970s.

Due to hardly acceptable price and other technical and technological reasons, the role of FO in Asian’s, power generation market is expected to diminish over the next two decades.

In most of the Asian countries the FO is used only as an emergency back-up fuel or for smaller power generation units in remote areas where NG is not available and coal supply is not feasible or expensive.

[3] In the following sections of this paper “Power Generation” without “Electric” will be used.

During the last fifteen years, the Asian power generation industry went through turbulent development, which put an immense pressure on the power machinery market forces more intensively then ever before. During this period the power generation has been changing from a regulated to a competitive industry.

The traditional, state-owned, utilities which have been controlling almost 100% of the power generation capacity started to face strong competition from relatively new, so called Independent and Captive Power Producers (IPP & CPP).

Complexity of un-codified business rules, which are not to be defined easily, caused imbalance especially in NG prices. This market is still not mature yet. It has not acquired its traditional features which are as strict, rigid and transparent like e.g. in the world's crude oil processing or coal business.

Let's consider NG and FO current price level. NG, the most noble fuel whose proven reserves are estimated for no more but half century is underestimated by the world-average price swinging between the values of 3.0 to 6.0USD/GJ[4], depending on region and mode of transportation.

The crude oil has reached 60 USD/barrel price level in this year (2005). This is around 50% higher than 12 months ago.

In the frame of historical, economical, ecological and technical progress we have to deal with NG / FO in conjunction with GT as the crucial market driving element of power industry in Asia, and especially in Southeast Asia.

This element deserves our primary attention for all of the positive (but also controversy) features which have identified GT as the revolutionizing driving force in the new competitive power industry.

At the same time, the strong effect of fuel prices upon engineering progress generates its counter-effect. A feed-back of power generating technology towards the fuel commodity structure does exist.

Two following important questions have to be answered:

- How far away is the horizon of NG price dominance?
- What has to be undertaken before NG supply reaches its crisis level?

[4] =2.84 to 5.69 USD/millions BTU

Before replying both questions a brief review of world electricity consumption projections as presented by some reputed institutions like Utility Data Institute (UDI), Forecast International and/or Energy Information Administration shall be done.

Neglecting several percentage differences among them, attention shall be paid to the figures presented in the following Table 1:

Pos	Region	Actual	Projections				Annual Change
	Electricity Consumption in 1000 GWh	2004	2010	2015	2020	2025	%
1	North America a)	4’430	4’840	5’300	5’790	6’310	1.9
2	South & Central America	740	860	1’000	1’195	1’425	3.2
3	Europe b)	4’250	4’670	5’100	5’545	5’970	1.7
4	Africa	420	500	600	715	810	3.1
5	Middle East	550	635	725	820	925	2.8
6	Asia c)	3’000	3’725	4’510	5’340	6’275	3.7
7	Japan	820	870	920	965	1’010	1.0
8	Australia & Pacific d)	230	260	290	315	340	1.8
9	World	15’140	16’360	18’445	20’685	23’065	2.45

a) Including USA (with Hawaii), Canada & Mexico
b) Including Eastern Europe & former Soviet Union Countries
c) Excluding Japan & Middle East
d) Including New Zealand & Pacific Islands

Table 1 World Electricity Consumption

What is the status of Asian present and future power market scenario? Last year (Table 1, Year 2004, Pos 6) the electricity consumption in Asia was 3 millions GWh. Transferring this figure into MWel[5], with an average PLF[6] of 80%, we get around 340 GW of power generation capacity in Asia[7].

Percentage of NG and coal utilization for power generation in Asia is shown in Figure 1.

According forecasts made by miscellaneous reputable international organizations the NG contribution shall steadily increase until year 2020 - 2025, when a break-point shall be reached.

[5] Electrical power output
[6] Power Load Factor
[7] without Japan and Middle East

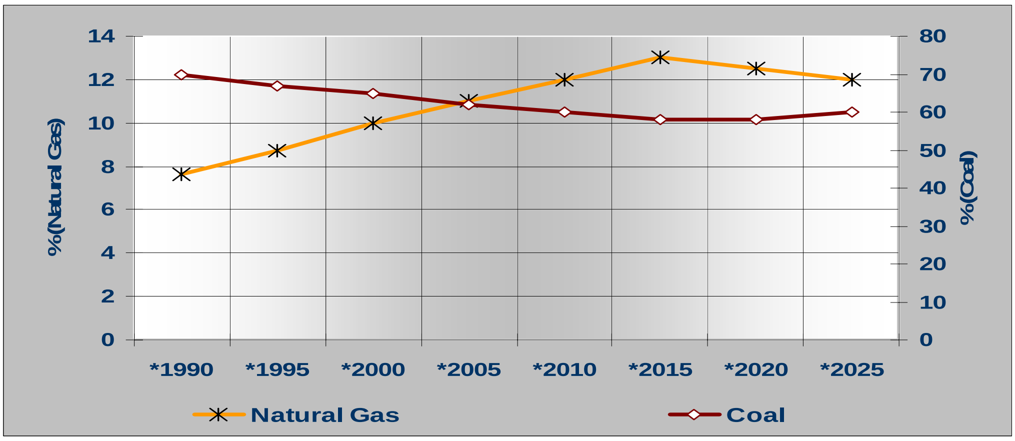

Figure 1 Natural Gas vs. Coal for Power Generation in Asia

It is to be expected that the NG will soon or later follow, most probably not so steep and unexpected, the oil price trend. However any current projection may not prove right few years later. Just for reference and comparison, last year (2004) the IEO World Oil Price Projections have shown a slight oil price reduction by around 2USD per barrel for the year 2005 (from 26.9 to 24.7 USD/barrel).

But actual world market crude oil prices have not followed this prediction. Actually we are facing an immense oil price increase by 30 USD/ barrel (a jump from 27 to 57[8] USD/barrel level) during past two years and 49%[9] price increase during past 12 months months, as shown in Figure 2.

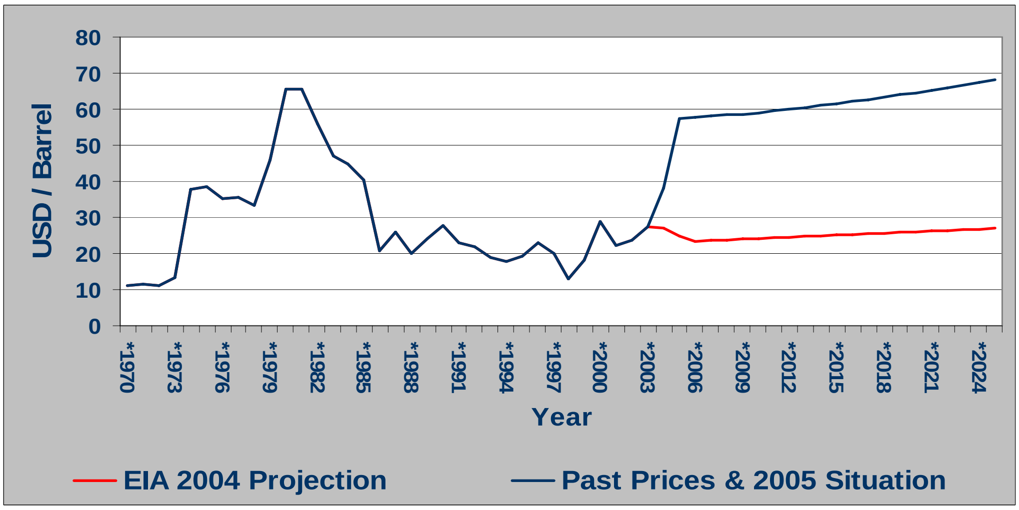

Figure 2 World Oil Prices 1970 - 2025

8 International Crude Oil Price on 15th June 2005 (Conference Paper Closing Date)

9 EIA projection for 2004 was 26.9 USD/barrel, but actual price by middle of July 2004 was 38.2 USD/barrel

With increasing demand for NG, the market price of this fuel commodity will increase as well. The question is only how fast and to which level?

On the other side as the most abundant non-renewable energy source available, coal has traditionally played a major role in ensuring energy security worldwide.

Even with huge abundance of coal, its use very often suffers the classic ills of inefficiency and high pollution. Some of the more significant reasons include coal variability (which prevents boilers from operating at optimum efficiency), antiquated designs, and poor maintenance.

With reserves geographically diversified across Asia, major exporters and importers in Asian countries as well as healthy, transparent and highly competitive and expanding international market, the coal prices have had a strong track record of stability, especially in comparison with NG.

However, future coal use in Asia now faces major challenges. The liberalization of the power sector and the prosperous NG market, coal's main competitor, have brought some uncertainties into the coal market during last two decades.

Even-though that NG is still maintaining its strong position in power generation market, the absolute figures show, that the Asian demand for coal for power generation continues to grow steadily and much faster then NG, as shown in Figure 3.

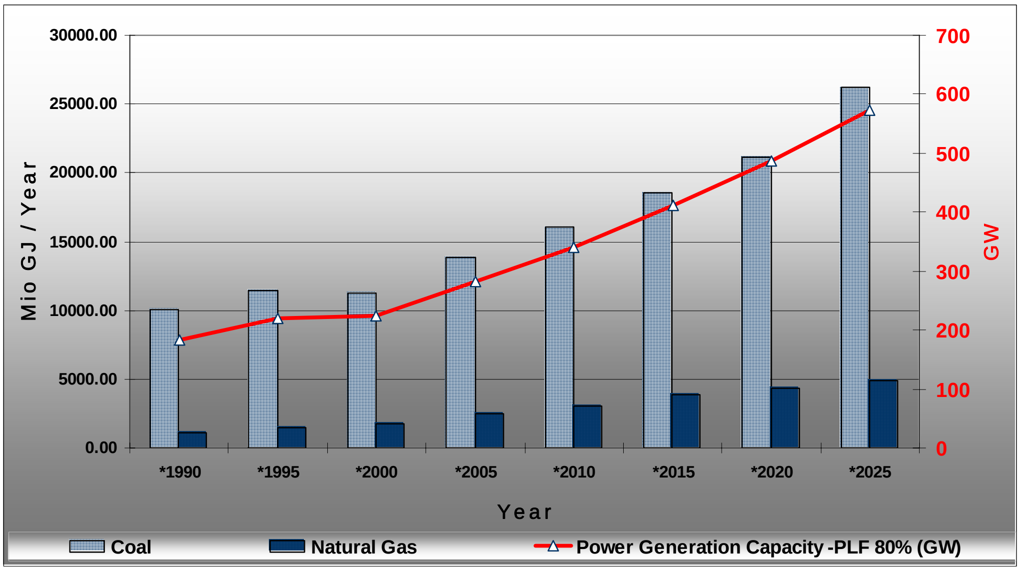

Figure 3 **Natural Gas & Coal Utilization for Power Generation in Asia**

Currently about 62% of the Asian region power generation sector is fueled with coal, followed by hydro & renewable (14%), NG (11%), nuclear (7%), FO (5%) and geothermal (<1%), Figure 4.

21st Century Business Herald reported that China's annual coal demand is expected to reach 2.5 billons metric tons by 2010 and 2.9 billions metric tons by 2020.

China Coal Industry Development Research Center (CCIDRC) predicted that coal consumption by power producers in China will reach 1.1 billions Metric tons in 2005, 1.5 billions metric tons by 2010 and 1.9 billions metric tons by 2020.

Over the projection period, NG and renewable are expected to gain shares of the power generation fuels mix, displacing mostly nuclear, oil, hydropower and slightly also coal (Figure 5).

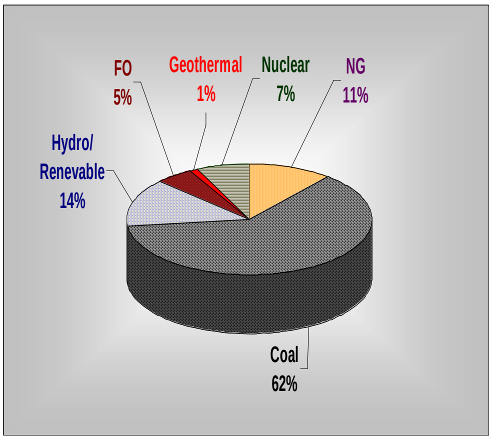

Figure 4
Fuel Mix in Asian Power Market 2005

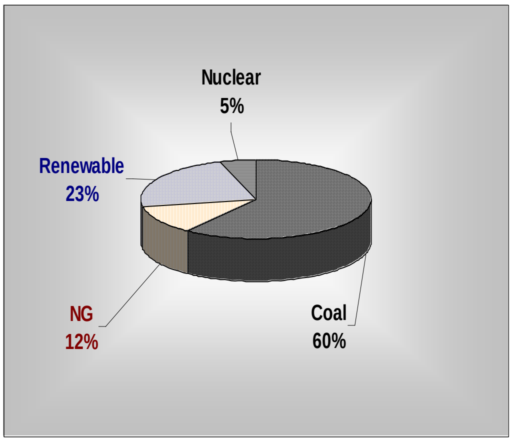

Figure 5
Fuel Mix in Asian Power Market 2025

Now we can suggest the answer to the following question:

- How far away is the horizon of NG price dominance?

Break-point (equilibrium), maximum / minimum (NG / coal contribution for power generation) is expected by the year 2025 as shown in Figure 2.

2. Equilibrium between NG and Coal

During mid of 70's many of the world's well recognized projections have given NG no more than 30-35 years life time span. Present situation? All proven NG reserves worldwide are not lower than 30 years ago.

But this trend will not last for ever. However, the starting point at which the inversion between the two main fuel commodities, NG and coal, might happen has to be moved to a later date.

By our opinion, the year 2025 may bring the culmination point, where NG will start to decline accompanied with ever increasing share of coal in fossil-fuelled generation future (Figure 1 & 3). Traditionally, coal has never been internationally traded on a large scale. Indigenous character of this primary source has always been prevailing.

The new trend of becoming a world trade commodity is dated by 1973. Since then the international coal trade has doubled and it will probably be additionally quadrupled by 2025.

Around 85 - 90% of coal production is consumed in the country of origin, primarily for the power generation. Although only about 10 - 20% of world coal production makes its way into export markets, international trade in coal has grown substantially in last decade.

The present world's price differential between the coal (1.5 – 3.0USD/GJ) and NG (3.0 – 6.0USD/GJ) is too small to make coal competitive enough in territories where both fuels are available.

The dramatic increase in NG fuelled Combined Cycle Gas Turbine (CCGT) power generation technology implementation in private sector (mainly IPP, CPP & MPP[10]) has been the result of cheap and easily available NG supplies.

NG, with all of it excellent attributes in CCGT construction- and ecology preferences, would have to cost at least 3.0 USD/GJ more than the coal, to be replaced by this fossil fuel commodity.

This may become a reality only with growing expenses for NG exploitation from ever less accessible resources, deeper wells and increasing costs for NG distribution network and related infrastructure bottleneck restriction.

In the new, future, technology scenario such switch-over between NG and coal will be accompanied with massive GT technology penetration and expansion into the coal domain.

[10] Merchant Power Producers

The growing economies of the Asia region especially, are looking to increased coal use for power generation, however, on the other side the coal is also under strong attack.

One reason is its contribution to increasing atmospheric concentrations of CO_2, argued to be a cause of potentially adverse climate change.

Coal use is seen to pose local and regional environmental threats. These threats come not from the use of coal itself, but in the failure to employ modern combustion and emission control technologies in several Asian countries, now widely adopted in the power generation industry worldwide.

Even though that the current NG fired CCGT power plants market share is still rising, the larger coal reserves and wider availability, the coal based power generation technologies will dominate in future's the long term.

3. Clean Coal Technology – the Solution for the Future?

What has to be undertaken before NG supply reaches its crisis level?

It is important to disseminate the advantages of Clean Coal Technologies for power generation and support implementation of these technologies in Asian region.

Three major coal utilization technologies for cleaner power generation are available for commercial use and partly implemented in various Asian countries:

- Supercritical- & Ultra-supercritical Steam Technology;
- PFBC Technology; and
- IGCC Technology.

Since we have presented and discussed various Clean Coal Technologies in several papers at Powergen and other international conferences and publications in the past (see References), this paper does not deal wit technical details. However, the two most promising coal based power generation technologies, namely the IGCC and PFBC, are highlighted once more in this paper.

Since first installation in 1969, the numbers of IGCC and PFBC plants have been growing, but not rapidly. A few IGCC plants have been set in USA and also in Europe, for instance in Buggenum in the Netherlands and in Puertollano, Spain, as is shown in Table 2.

Project Location	Gasification Technology	Fuel	Efficiency (%)	Total Power Output (MW)	Start of Commercial Operation	Capital Costs (USD/kW)
SUV / EGT Litvinov, Czech Republic	Lurgi	Lignite	40	350	1997	
Elcogas SA Puertollano, Spain	Prenflo-O_2	Coal & Petcoke	45.0	335	1997	2'660
Tampa Electric Polk City, USA	Texaco	Coal	40	313	1996	2'000
PSI / Destec Wabash River USA[11]	E-GAS	Coal & Petcoke	39.7	260	1995	1'600
W. Alexander Buggenum Netherlands	Shell	Coal	41.3	253	1994	2'110
Lakeland / DOE Lakeland, USA	ACFBCC	Coal	40.6	250	2005	
Steag Kellerman Lunen, Germany	BGL	Coal	31.7	170	1969	
LGTI Plaquemine, USA	E-GAS	Western Coal	36	160	1987	2'140
SCE Cool Water[12],USA	Texaco- O_2	Coal	31.2	100	1984	2'000
Sierra Pacific Pinon Pine, USA	KRW-air	Lignite	38	99	1996	2'300
Schwarze Pumpe Cottbus Germany	Lurgi-O_2/BGL	Coal / Wastes		75	1996	
Vresova Czech Republic	HTW	Lignite		2x200	1996	

Table 2 Selected IGCC power Plants

The utilization of advanced gasification technology, adopted for power generation purposes, consists of two innovative attributes which both correspond with adaptability to GT admission circumstances.

The first attribute is the combination of GT technology with combined cycle power generation employing IGCC and PFBC systems.

IGCC, like PFBC technology, combines both GT and steam turbines (ST) in combined cycle operation. Depending on the level of integration of the various processes, IGCC may in short term achieve 40 to 42% and in long term upto 50% efficiency.

In combination with IGCC, approximately 60-70% of the power comes from the GT, compared with about 20 - 25% in combination with PFBC.

[11] Wabash River is a repowering IGCC

[12] Demonstration project 1984-1989 in Mojave Desert, CA, currently not in operation

Typical simplified diagram of IGCC power plant is shown in the Figure 6.

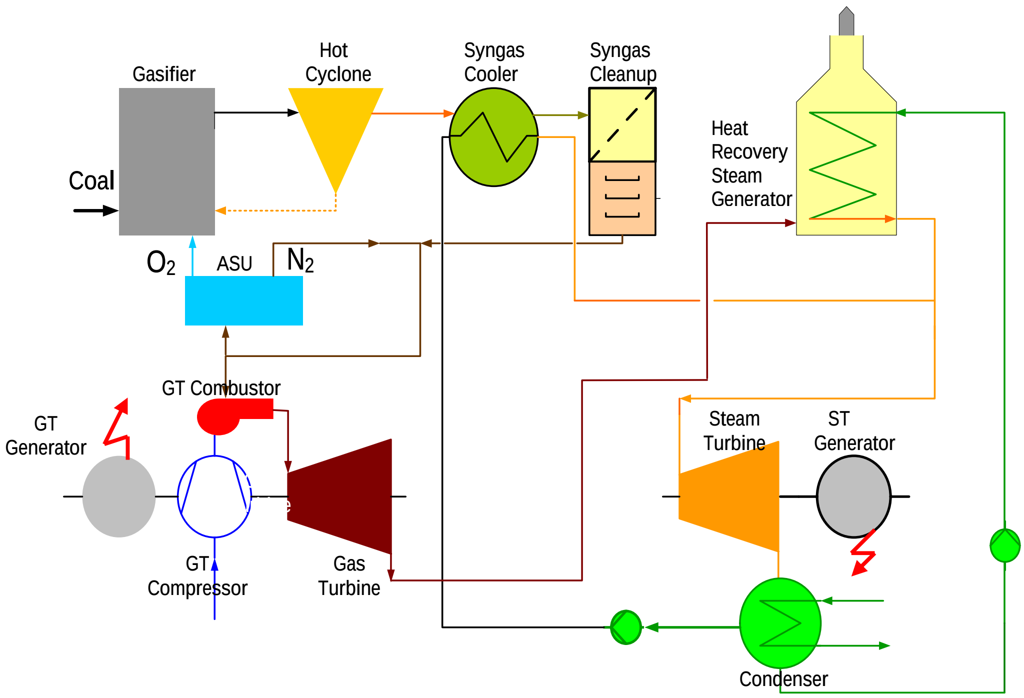

Figure 6 Simplified Diagram of IGCC Power Plant

Each IGCC plant consists of four parts. Two of them, namely GT-Generator and ST-Generator and Heat Recovery Steam Generator (HRSG) are analogical to the standard CCGT system.

Fourth part is the chemical technology part – the Gasification Island – which is the key segment. In the following Figure 7, simplified block diagram of Puertolano IGCC power plant is shown.

The second attribute is the fact that IGCC is one of the world's cleanest, fossil fuel based, power generation technologies.

In average, the IGCC gas cleaning technology removes around 99% of the sulfur in coal, converting it to a commercial product. NO_2 emissions are reduced by more than 90%.

In other words IGCC is one of the most promising technologies in power generation that utilizes low-quality coal as well other solid and liquid fuels and is able to meet the most stringent emissions requirements.

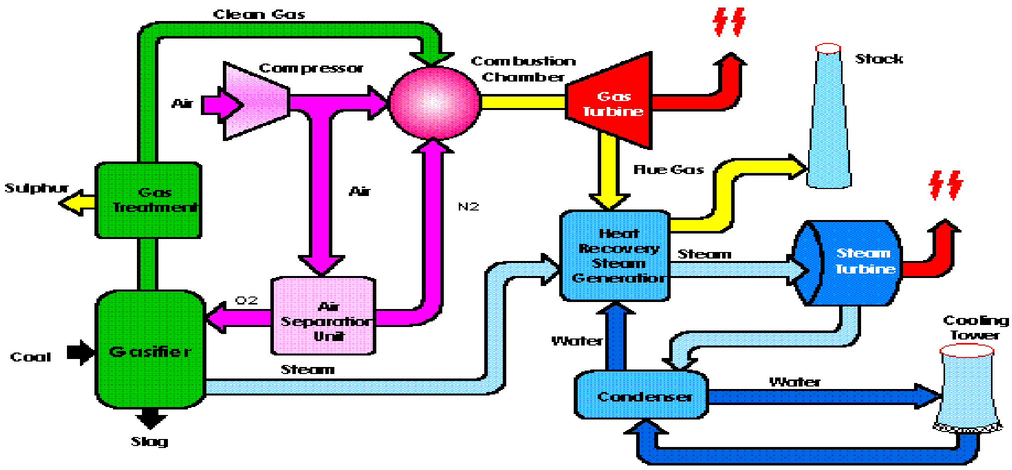

Figure 7 Simplified Block Diagram of Puertollano IGCC Plant

The gasifier can be blown either by oxygen or air. Steam injection may be also applied for moderation purposes.

The modern gasifier works under elevated operating pressure (25-30bar), what is the main difference compare to the classical gasification processes widely applied for more then a century. Temperatures are much higher in the oxygen blown atmosphere due to the absence of nitrogen heat dissipating effect. The gasification process is carried out under oxygen-deficit reaction environment and the reaction temperatures (depending on system between 1'000 - 1650ºC) are much higher compare to a general combustion process. Under such temperatures increased extend of devolatilization is made possible. High concentrations of CO_2 and increased concentrations of H_2O are produced through.

> IGCC systems can be built down to 100-150 MW modules, allowing flexibility in capacity expansion and lower unit costs than onsite fabrication.
>
> Efficiencies approaching 50%, >99% SO_2 removal, and NOx <50ppm, normally impracticable with any other solid fuel fired technology, are potentially possible.

Worldwide largest IGCC is the 335MW Puertollano power plant in Spain (Figure 7).

This demonstration power plant has been designed to use a 50/50 mixture of high ash, medium-low heating value local coal and petroleum coke from a nearby refinery.

The project was selected as Target Project by the European Commission and awarded funding by the THERMIE program focused on the need to take short-term actions to assure reliable clean coal technology for the future power generation. The Puertollano IGCC project has been driven by the demand of energy efficient, environmentally friendly and cost effective coal generation technologies.

The power plant design innovative features focused on three main targets, improved efficiency, reduced emissions and technology full commercialization.

The most distinctive aspect Puertollano IGCC project is that it is an independent power project without a Power Purchase Agreement (PPA).

The structure relied on the cash-flow to be received by virtue of the Stable Legal Framework which is the regulatory system controlled by the Spanish Government to fix the electricity rates, collect and reimburse the utilities.

This was the first occasion on which this regime has been used to support a project financing in the international markets and its use instead of the traditional contractual support from a PPA, is a demonstration of a flexible approach in the market.

Other distinctive aspect to the project is the technological risk. It is the first power project that puts coal gasification technology to commercial use. Pre-construction, technological risk has been offset by a corporate guarantee.

Subsequently, there was a nine month initial support period with various efficiency requirements. The tests ensured that operating costs related to technology did not over-run.

Most of above listed IGCC projects, however, would not have been economically viable, unless subsidized under various supporting national & international programmes like e.g. Clean Coal Technology Programme sponsored by the US Department of Energy or other programmes like Thermie sponsored by EU.

According to recent (Spring 2005) Southern Illinois University report, US DOE will soon choose a site for a 275 MW, near-zero-emissions, IGCC pilot plant that will gasify coal to produce both electricity and surplus hydrogen for uses such as fuel cells.

Illinois and a number of other states are lobbying for this billion-dollar project, but wherever it is sited, it will serve as a major impetus for new clean-coal technologies. Major strategic vision of all Clean Coal projects consists in the assumption what happens when the availability and continuing low price level of NG is over.

Under such circumstances power sector would envisage lack of coal-based technology while NG is no longer economically available. Smooth conversion from NG to clean coal technology has to be ensured. The most important factor and argument for promotion and implementation of IGCC technology is the pollution control. The following Figure 8 shows comparison in specific NO_x emissions from IGCC & PFBC with other selected power generation systems.

The results should be compared with caution as differing extents of NO_x mitigation were applied in the studies, as being representative of state-of-the-art technology.

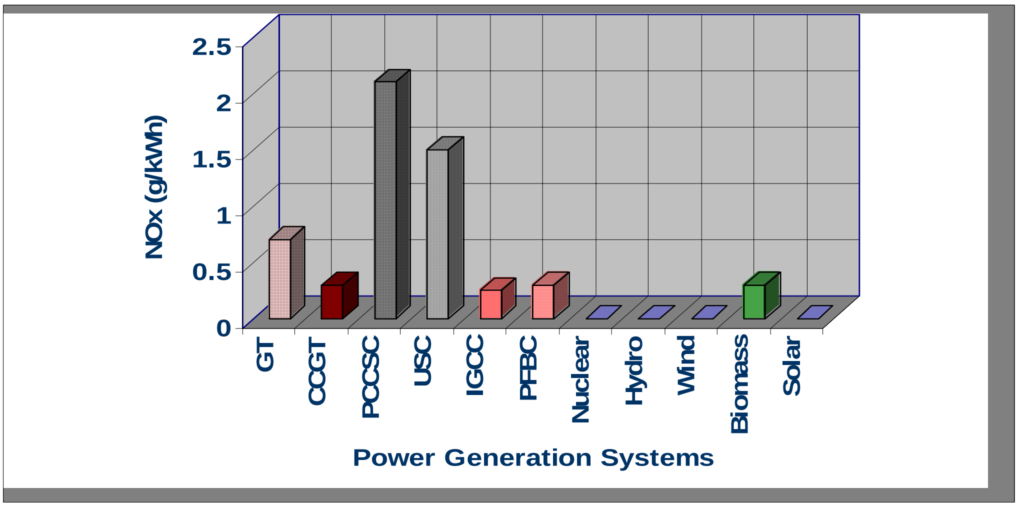

Figure 8 **Specific NO_x Emissions from selected Power Plants**

For the two coal combustion cases [Pulverized Coal Conventional Sub-Critical (PCCSC) & Ultra-Supercritical (USC)], NO_x reduction was limited to the use of low- NO_x burners; the IGCC case assumed injection of nitrogen from the air separation unit (ASU) into the GT to limit NO_x formation; and the GT and CCGT case assumed the use of modern, low dry NO_x burner technology. IGCC technology potential for NO_x reduction is shown in the Figure 9.

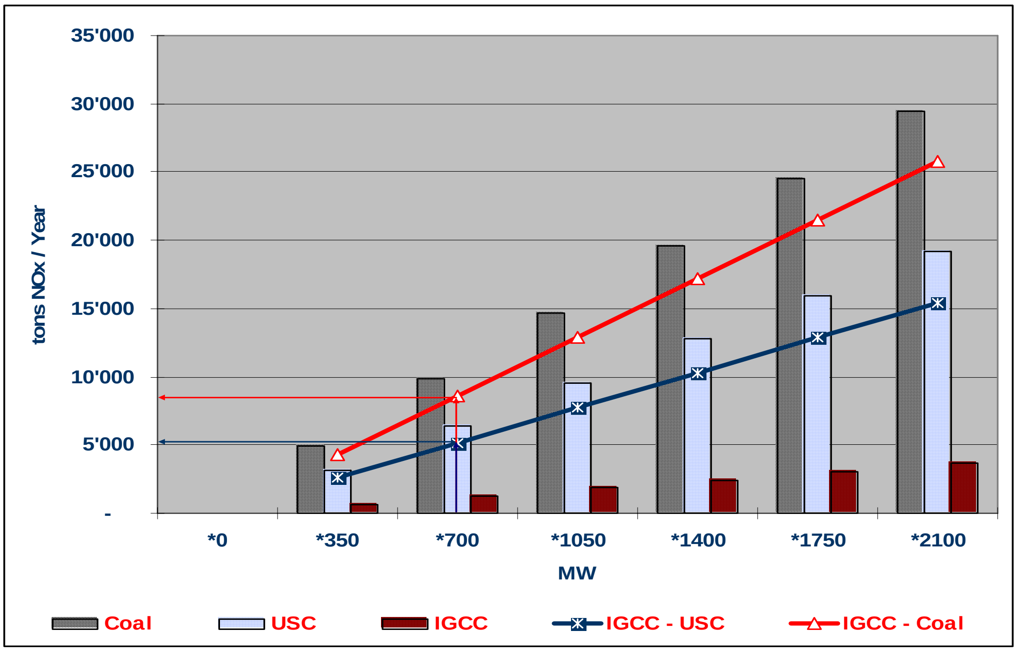

Figure 9 Specific NO_x Emissions from selected Power Plants

One 700MW sub-critical power generation block produces 9'800 tons NO_x per year (PLF=80%) This is 8-times more as IGCC yearly NO_x production, which is around 1'200 tons per year for the power plant of the same size.

Dramatic improvements have been made in IGCC technology capital costs. Coal base plants have been recently bid for less than 1'200USD/kW on a turnkey basis. This capital cost reduction is due to variety of factors, the most influential being:-

- GT performance enhancement;
- Gasification system enhancement;
- IGCC EPC learning curve

Technology improvements, cycle optimization and co-production configurations will continue to drive-down the capital costs of IGCC technology.

In addition, coal-based IGCC power plants will be very competitive alternative in countries with severe environmental restrictions, in countries with abundant cheap low quality coal reserves and also in areas that depend on the use rather expensive fuels for power generation, such as LNG or FO.

The next GT generation, the H-class, is expected to enhance the economic competitiveness of coal-based IGCC power plants to lead this technology to success in the international power market.

4. Conclusions

Coal has been, is being and will be one of most important fuel commodities for power generation. Total world probable reserves of coal are around 12'000 metric Gt[13]. Of this, around 985 metric Gt (more than 25% located in Asia and about 8% in Australia) are considered proven, economically recoverable coal reserves.

The current worldwide coal consumption is 4.4 metric Gt per annum. Even if an average consumption increases 2.5% each year, the probable proven coal reserves are good for 320 years and the proven coal reserves are sufficient to cover coal consumption for next 215 years.

In order to secure safe and reliable power supply in the future, we have to care already now about what would happen when the availability of low priced NG is over.

Under such circumstances power sector would envisage lack of coal-based technology while NG is no longer economically available.

Both, PFBC and IGCC represent a unique partnership between coal gasification and Gas Turbine technology, resulting in high system efficiency at very low emissions production.

As worldwide air emissions standards become stricter, the superior environmental performance of IGCC will take on added economic benefits because the technology can achieve greater emissions reductions at lower cost than less advanced technologies.

There remain few significant barriers to further market penetration of IGCC technology, including:-

- Price, as the technology is around 20-30% (with cost projections 1'000 – 1'300USD/kW based on US & Europe price level) more expensive than competing alternatives;
- The next generation IGCC plants must have an investment cost of less than 1'200 USD/kW and a net efficiency of more than 48%, to be competitive with other clean coal technologies;
- IGCC is projected to be more cost-effective than NG fired CCGT plants when the cost-differential between NG and coal is at least 3.0 USD/GJ; and

[13] Gt=1 Giga Ton=1 Billion Tons

- Technology risk, as many of the existing systems don't have long-term operating histories.

However, even with these barriers we can optimistically conclude that:-

- It is important to evaluate the power generation technologies well in advance;
- IGCC technology it is one of the advanced coal utilization technology with high efficiency and low environmental emissions including NOx, sulphur and CO_2;
- IGCC can use low quality coal or lignite which can be found in many Asian countries such as India, Indonesia and China;
- IGCC in a combination of coal gasification technology with the most advanced, large heavy duty GTs and advanced steam-bottoming cycle with once-through heat recovery steam generator operating under supercritical steam parameters will result in unbeaten coal based power generation efficiency;
- Reusable process media remove sulphur from syngas prior to combustion in the GT. By contrast, plants that employ flue gas desulphurization techniques use limestone, dolomite, or other sulphur sorbents. These substances require disposal;
- With the advent of IGCC systems, coal-fired plants can realistically expect to attain maximum efficiency levels above 50% as early as the year 2015; This means that in less than two decades, IGCC technology promises to raise coal based power generation efficiency levels by more than twice the amount achieved over the last half century;
- IGCC system removes 99% of the coal's sulphur before combustion, NO_x is reduced by over 90%;
- The water required to operate an IGCC plant is less than 50% of the quantity required to run a pulverized coal plant with a flue gas desulphurization system;
- The IGCC process generates a minimum of waste. Moreover, the by-products produced by the process have marketability. Sulphuric acid and elemental sulphur are two primary by-products for which there is market demand. Ash and any trace elements that have melted become an environmentally safe, glass-like slag. This slag is useful to the construction and cement industries;
- In addition to electricity production, the coal gasification process is easily diverted to co-production of such products as methanol, hydrogen, gasoline, urea for fertilizer, and assorted chemicals;
- IGCC technology provides flexibility to power producers because the combined-cycle portion of the process can be fuelled by NG, FO or coal.

A power plant can switch to coal from NG as NG becomes unavailable or unacceptably expensive. In addition, most gasifier systems are easily adapted to different coals;

- Surging crude oil and NG/LNG prices, combined with supply security and environmental concerns, are prompting power generators and industrial firms to further develop coal gasification technologies;
- Coal gasification, the process of breaking down coal into its constituent chemical components prior to combustion, will permit the Asian region to more effectively utilize its enormous, low cost coal reserves.

The Electric Power Research Institute (EPRI), a research organization partly backed by the power industry, announced its Global Coal Initiative five years ago. When it did so, the group predicted that research could make IGCC and PFBC combustion competitive with NG on a cost-of-electricity basis sometime between 2010 and 2020.

It is crucial that today we optimize the development and use of modern clean power generation technologies, which we can apply tomorrow, after tomorrow and in the future, to assure sustainable progress of our planet's healthy development.

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