POWER GENERATION TECHNOLOGICAL DETERMINANTS FOR FUEL SCENARIO OUTLOOK

by

Miro R. Susta and Peter Luby

IMTE AG

Switzerland

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ABSTRACT

Concentration of power market revolutionary changes within the relatively narrow time frame of the last decade will continue for at least another decade.

Too many dynamic factors have been seen in the research & development of new power generation technology as well as commercial realisation.

Too many impulses have been also seen in the independent power market arena. New legislation framework, new financing tools, deregulation, privatisation and liberalisation trends have become typical with many emerging-economy countries but also with countries having highly developed infrastructure supported by stabilised legislation & political system.

All these factors have favoured natural gas (NG) as first-priority option wherever this was possible. Gas turbines (GT) based technologies **have dominated in the new capacity demand saturation. GT technologies will also dominate further on. However, this does not mean that NG will retain the first choice for ever. NG market saturation may appear approximately about 2010-2015.** Huge reserves of coal together with appropriate coal-based technologies like IGCC (Integrated Gasification Combined Cycle) or PFBC (Pressurised Fluidised Bed Combustion) will cause subsequent decline from NG towards other fossil fuel commodities.

Reasons for such scenario are given in our analysis.

INTRODUCTION

In the last decade power generation industry has been subject to the pressure of power machinery market forces more intensively then ever before. Complexity of uncodified business rules which are not to be defined easily caused imbalance especially in fuel prices. This market is not mature yet. This market has not acquired its traditional features which are as strict, rigid and transparent like e.g. in the world's crude oil processing business.

Let us consider e.g. price level of NG. This most noble fuel whose proven reserves are estimated for no more but half century is underestimated by the world-average figure swinging about the value of 3.5 USD/GJ.

Our intention is not to analyse why this is so. Neither shall we discuss whether this market imbalance is good or not for further industry development. We are just restricting our deductions to the statement that GT machinery has achieved scientific & engineering technical status which otherwise would hardly have been possible under less favourable NG price circumstances.

And this was important. In the frame of historical, economical, ecological and technical progress we have to deal with GT as the crucial market driving element of private power industry. This element deserves our primary attention for all of the positive (but also controversy) features which have identified GT as the revolutionising driving force in the new competitive power industry[1].

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

It is intensive enough to deserve attention of the present paper.

FUEL COMMODITY OUTLOOK

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

How far away is the horizon of NG price dominance?

Before replying these questions we shall briefly review forecasts presented by some reputed institutions like e.g. Utility Data Institute (UDI), Forecast International and/or Energy Information Administration. Neglecting several percentage differences among them we are taking note of the following figures:

1. Forecasts for decade 1996-2005

1.1 Global growth in power generation capacity is expected to be about 650 GW. More than 50% of this capacity (340 GW) will be ordered from Asia and 170 GW out of this capacity will come to China. Out of the 170 GW China's added capacity 75% (125 GW) will be coal-fired.

1.2 Share of various power generating components will be as follows: 36% GT, 47% ST (steam turbines) and 17% hydroturbines.

1.3 Share of independent power producers (IPP) will be 30% from the global growth of the world's power generating capacity.

1.4 Share of the growth in power generating capacity by technology will be as follows: 95 GW OCGT (Open Cycle Gas Turbine), 212 GW CCGT (Combined Cycle Gas Turbine), 215 GW direct fired ST (mainly coal fuelled), 20 GW nuclear ST, 108 GW hydropower.

1.5 Consumption of electricity will increase from 1300 GWY level of 1995 to 1700 GWY in 2005.

2. Forecasts for decade 2006-2015

2.1 Global growth in power generation capacity is expected to be about 900 GW. 45% of this capacity

(400 GW) will be ordered from China and 300 GW out of China's added capacity will be coal-fired.

2.5 Consumption of electricity will increase from 1700 GWY level of 2006 to 2300 GWY level in 2015.

3. Fuel scenario in double-decade 1996-2015 is shown in the following table in which % of fuel commodities is listed together with absolute consumptions in GWY (gigawatt-years); (1GWY = 0.7 MTOE = 31.5 x 10^6 GJ):

Fuel	1995 (%)	1995 (GWY)	2015 (%)	2015 (GWY)	Growth + (GWY) %
NG	16	210	23	540	+330 **33%**
Coal	37	480	36	820	+340 **34%**
Nuclear	17	215	10	240	+ 25 **2.5%**
Hydro	21	275	22	500	+225 **22.5%**
Oil	9	120	9	200	+ 80 **8%**
Total	**100%**	**1300**	**100%**	**2300**	+1000 **100%**

As is obvious from the above listed figures, considerable increase from 16% to 23% NG is counter-balanced by nuclear drop from 17% to 10%. The remaining fuels will retain their percentage share. Coal will retain its dominant position with 820 GWY (36%).

EQUILIBRIUM BETWEEN NG AND COAL

The end of double-decade 1996-2015 is indicated as the starting point in which an interesting inversion between the two main fuel commodities may happen. By our opinion, year 2015 may represent the inflex point with starting decline of NG accompanied with ever increasing share of coal and other solid fuels in fossil-fuelled generation future.

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 tripled by 2015.

Today, the world price differential between coal price 1.6 USD/GJ and NG price 3.5 USD/GJ is too small to make coal competitive enough in territories where both these fuels are available. The dramatic increase in CCGT & OCGT systems implementation in private sector 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 4-5 USD/GJ to be replaced by coal. This may, however, come true 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 new technology scenario such switch-over between NG and coal will be accompanied with massive expansion of GT into the domain of solid fuel commodity. As we have already outlined, this solid fuel and technology convergence will be the main topic of our paper and role of GT as the crucial element will be justified as being contributor and carrier of highest possible thermodynamic efficiency.

EXPANSION OF GT IN SOLID FUEL SEGMENT

Two promising technologies for solid fuelled power generation have started to achieve commercial status, namely IGCC and PFBC. Out of these two technologies we shall be devoting special attention to IGCC because GT contributes to power output by 60%-65%, while PFBC only by 20%-23%.

IGCC has already achieved a strong pre-commercial basis and first commercial applications have already been implemented, as is shown in Tabs. 1 and 2. In Tab.1 description of four most important IGCC projects based on **fixed-bed** technology (positions 1 and 3) and **fluidised-bed** technology (positions 2 and 4) is given.

In Tab.2 description of another five projects based on **entrained-flow** technologies (positions 5 - 9) is given.

The successful demonstration stage which all of these technologies have overcome has been accelerated by favourable incentives of the last decade, especially by environmental imperatives. If the predicted growth in coal-fuelled power generation continued without widely applied pollution-suppressing technologies emissions level would increase by 350% within the next double-decade and by 1000% by the year 2035. Such estimates have been issued by the World Bank.

Most of these projects, however, would not have been economically viable, unless subsidised 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 EC. Their strategic vision consists in the assumption what happens when the availability and continuing low level of NG is over. Some sources are confident that even in 2000 the production costs difference between NG and gasified coal shall disappear. 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.

Over the next decade, China and India will contribute by 50% to the world's increase in anthropogenic greenhouse emissions. These two countries will continue to be dependent on coal-based power production. Successful commercialisation of IGCC may become hot urgent for them.

In China alone, which will be the biggest market for coal-fired stations, more than 54 billion of USD is estimated to be spent within the next five years only to prevent pollution. In this country 70% of smoke and dust in the air and 90% of the country's SO2 are generated from burning coal used for industry and residential heating.

In the USA, which have 55% of their huge 900 GW power generation capacity based on coal will be the second biggest market for coal-fired technologies. At the same time 60% of this obsolete capacity is older than 30 years, some of them suffering anxiety to cope with 1992 Clean Air Act Amendments (CAAA). Highly advanced deregulation process which is being underway now, requires however, that stranded cost investment is solved first, so that IPPs' "wait and see" attitude is overcome and trust of capital sources is renewed.

EXPANSION OF GT IN REFINERY RESIDUE SEGMENT

Probably the most optimistic results in IGCC technology have been achieved in heavy oil residues pressurised gasification which have already assumed commercial success without any subsidisation backup. This has, however, been possible by the synergetic co-production effect of producing other gasification products valuable for refineries, like e.g. hydrogen, pressurised air, steam, as well as free option of power to be either sold over-fence, or utilised for own purposes. Three projects of this kind are realised in Italy (Falconara, Sarlux and Priolio) with several hundred MW capacity each and another three projects world-wide (El Dorado 35 MW in the USA, Puertollano 318 MW in Spain and Pernis 127 MW in the Netherlands) are introduced in Fig. 1 together with projects which we have already introduced via Tabs. 1 & 2. This niche of IGCC application is however, discussed in detail in another paper of ours and therefore is out of the scope of present paper.

REVIEW OF IGCC TECHNOLOGIES

Technology of solid fuel gasification is not new. It has widely been used for more than a century in chemical and fuel conversion industry. It was an atmospheric technology. SASOL process operating in Sasolburgand Secunda, South Africa is commercially the most important application world-wide. **The three SASOL plants,** namely SASOL I., II. and III. **produce approximately 90% of the total world production of gas from coal** and they posses a total of more than 90 Lurgi gasifiers consuming 30 mil. t/a of subbituminous coal. **The synthesis gas (syngas) is used as feedstock to produce liquid transportation fuel by Fischer-Tropsch synthesis.**

Worth mentioning are also trials carried out by Underground Gasification Europe (EGU) in partnership of Spain, Belgium and UK, supported by EC via THERMIE Programme. This technology is also not new, yet not developed for large-scale commercial basis. Trials were carried out in the USSR in 30' and recently in the USA.

The principal difference for adequate **technology adopted for power generation purposes consists in two innovative attributes which** both correspond with adaptability to **GT** admission circumstances. **First of** them **is the pressurised regime and the other is the Gas Cleanup System (GCS).** Conventional GCS, so-called CGCS (Cold CGS) **works at mild temperatures. The other technology called HCGS (Hot GCS) is more progressive and works under elevated temperatures.**

Taxonomy of IGCC power generation technologies is based on the classification by the following features:

A. According to the gasifier design:

- Fixed bed gasification,
  applied in processes:
  Lurgi (projects *Lünnen, Schwarze Pumpe)*
  British Gas Lurgi (project *Schwarze Pumpe)*
- Fluid bed gasification,
  applied in processes:
  Kellog-Rust-Westinghouse--KRW (project *Sierra Pacific)*
  High Temperature Winkler-HTW (project *Hürth KoBra)*
- Entrained Flow Gasification,
  applied in processes:
  Shell (project *Buggenum)*
  DOW (project *Plaquemine*)
  Destec (project *Wabash River)*
  Texaco (projects *Cool Water & Tampa Electric)*

B. According to the ash treatment technology:

- Slagging (fixed-bed & fluidised bed processes)
- Non-slagging (entrnd. bed processes)

A general flowsheet of IGCC is shown in Fig. 2. The standard plant integrates three parts. Two of them, namely **GT Power Plant and ST Power Plant are equal to standard CCGT system.**

Gas generation circuit is the main system which can be blown either by oxygen or air and may be moderated by steam injection. The gasifier works under elevated operating pressure. Temperatures are much higher in oxygen blown atmosphere due to the absence of nitrogen diluent effect. The principal energy saving effect is based on the fact that *chemical* energy of the syngas medium is utilised with highly effective exergy balance, rather than sensitive heat of flue gas. Efficiencies 50%-55%, normally impracticable with any other solid fuel fired technology, are potentially possible if gas turbines of advanced generation like G or H series from GE, GT24/26 from ABB, 501G from Westinghouse or the latest .3A series from Siemens are applied[2].

Taking this opportunity, we refer once more to our paragraph dealing with GT expansion to solid fuel segment. *We state that not only progressive power generation technologies make expansion of GT industry possible. Vice-versa statement is even stronger: Advanced GTs may boost IGCC commercial viability even better.*

Reactions:

1. $C + 1/2\ O_2 = CO$ -1110 MJ/kmol
2. $CO + 1/2\ O_2 = CO_2$ -283 MJ/kmol
3. $C + CO_2 = 2CO$ +172 MJ/kmol
4. $C + H_2O = CO + H_2$ +131 MJ/kmol
5. $CO + H_2O = CO_2$ - 41 MJ/kmol

Physical state of ash:

1. For most coals the ash below 1300°K can be removed dry without sintering or slagging.
2. Ash agglomeration, or sticky ash occurs between 1300 and 1500°K.
3. Above 1500°K molten slag arises.

Low-rank coals are usually preferred under non-slagging condition, due to their higher reactivity.

High-rank coals which are less reactive require higher temperatures.

Pollutants: These are H_2S and COS. Compare to SO_2 and CO_2 which arise with conventional combustion processes H_2S and COS are more easily removed. Unlike to NOx common to conventional combustion processes NH_3 and HCN arise.

TECHNOLOGICAL HOT ITEMS YET TO BE SOLVED

HGCS technology represents the R&D threshhold between current project demonstration status and future large-scale commercial finalisation of IGCC.

HGCS is composed from two stages by which solid particles (dust) are to be removed and the other is the desulfurisation stage.

HGCS process temperatures are 350°C-500°C or higher (Conventional CGCS with wet scrubbing works at much lower temperatures, some of the approaching ambient temperatures).

Sulphur removal: A variety of metal & metal-oxides sorbents are thermodynamically capable of capturing sulphur in reduced forms (H_2S, COS, CS_2).

Desulfurisation on zink ferrite or zink titanate seem to have achieved most advanced status.
Some expensive sorbent materials (about 1.8 USD/kg) are more effective at higher temperatures.

In an effort to improve IGCC PP efficiency and economics, DOE, Westinghouse and others have been vigorously sponsoring the Development Programme of HGCS technologies. Particle removal technology operating under 900°C will soon be prepared for commercial demonstration. Ceramic Barrier Filter based technology seems to be the leading conception among particle removal systems.

The Sierra Pacific, Pinon Pine IGCC project (Tab.1), using the air-blown, KRW fluid gasifier is believed to be the first integrated hot syngas demonstration.

REVIEW OF DEMONSTRATION & COMMERCIAL IGCC PROJECTS

State-of-the art technological basis is presented by nine IGCC projects which we **recognise as benchmarks in the solid fuel gasification** engineering progress. They are listed in **Tabs. 1** and 2. **Some of them exhibit record-breaking edge in performance parameters, the others contribute by higher stage of innovation, but each one is in a way a milestone in the IGCC research & development process. Historical track of this acquisition is graphically plotted** in Fig. 1 against their MW capacities. Another four refinery gasification projects are also plotted in Fig. 1 for record purposes only.

In view of the identification attributes describing technical, trading, history and ownership data in a condensed and standard format of Tabs.1&2, a few complementary remarks should be added:

Wabash River (Tab.2, position 8) is currently the biggest single-train IGCC plant in full scale operation in the world[3]. This project is part of the US Dept. of Energy's *Clean Coal IV* technology programme. It is the first IGCC project whose power block uses a high-temperature, F-class GT from GE, the MS7001FA. Coal slurry is mixed with oxygen and injected into the first stage of the gasifier. The fluid ash is water-quenched forming a vitreous slag.

Hürth (KoBra)[4] (Tab.1, position 4), (KoBra= Coal Brown). **RWE & Rheinbraun started jointly to plan KoBra demo plant in mid 1990. Siemens V94.3 will be used for KoBra. GT=212MWe, ST=155MWe. Another 27 MW is generated by combustion of the gsf. residue coke** (bottom product + filter dust) **in the fluid-bed-boilers. Dust content of the gas must be reduced to less than 5 mg/m3 in 2 stages: Dust removal & wet scrubbing.** In water scrubber gas is cooled to 140°C. Desulphurization and sulphur recovery: In the gasifier **most S is converted to gas phase as H_2S & COS. COS is catalytically converted to H_2S**.

Sierra Pacific, Reno, Pinon-Pine[5] (Tab.1, position 2). The coal bed is fluidized through special nozzles. Crushed limestone is applied to absorb sulphur and to inhibit conversion of fuel nitrogen into ammonia. The product gas passes through cyclones to remove particulates and recycle fines. A hot-gas cleanup system, a fixed bed of zinc ferite sorbent is used to remove the remaining sulphur.

Schwarze Pumpe[6] (Tab.1, position 3). **Syngas will be generated from a mixture of brown coal and palletised refuse. It will serve as feedstock to methanol production. In the second phase these gasifiers will be replaced by BGL slagging fixed bed gasifiers with couter-current flow. Slag will be discharged as an inert glassy frit suitable as a building material.**

Buggenum[7] (Tab.2, position 5). **Currently the largest IGCC plant in Europe. The plant is undergoing trial operation and has already clocked up more than 5000 operating hours with coal-derived gas. Commercial operation is scheduled to start at the beginning of year 1998.**

CONCLUSIONS

In this paper we have presented a factography review describing the present status of technological progress of IGCC technology. We did so with the intention to support our firm belief that a smooth, yet visible declination trend from NG in favour of solid fuel power generation reliance will take place a little bid earlier than generally anticipated by some prognostic analysis published within the last 2-3 years. Reasons for such conclusions could be assorted in the following four statements.

- Fuel option for gas turbines in favour of solid fuel reliance will be ever more abundant. IGCC technology is one of the technical tools which will make such shift viable somewhat earlier than 2015.
- **Ever-increasing percent share of NG will still continue for at least 15 years.** Yet, this will not be so ample as previously anticipated. **Potential bottlenecks in NG world trade will inhibit its growth by distribution and exploitation difficulties. This factor will cause price elevation impact upon NG and reduce its competitive ability vs. solid fuels.**
- Also **competitive power of coal will be boosted with progress of clean-coal technologies.** Especially low-rank coals with higher sulphur content which so far have hardly had any market chance vs. CCGT NG fired projects will acquire their competitive renesaince in the first decade of the next century.
- Biggest power generation growth is expected with players whose power sector is tightly coal-dependent, e.g. China, India, the USA, Australia.

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