Contribution of IGCC & PFBC to Global Fuel Consumption Trends

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Fuel consumption trends in power generation industry have been clear and transparent in the last decade. Hegemony of natural gas (NG) and combined cycle power plant (CCPP) projects was obvious in those territories in which natural gas was accessible.

Superior parameters in thermal efficiency, operating costs, and environmental benefits were criteria which have simplified the decision-making process for those project developers who were having access to NG.

Their dilemma was not “what kind of power plant to built” any more. Their problem has become reduced to the question “what kind of combined cycle power plant to built”.

Statistics compilators therefore have easier life today than their colleagues from forecasting institutions. Really, if we want to predict anything today we have to face more counter-effecting influences than before.

One of them is the increasing share of the independent power generators world-wide. Their aggressive business philosophy prefers short-time investment return periods. These are guaranteed by the natural gas (NG) technologies.

The other is the ever-increasing pressure of environmental legislation in most countries. This also favors natural gas as the dominant choice in green-field projects.

There are more of them, but there is one which has materialistic and therefore ultimate force: Worldwide deposits of NG are restricted. NG resources are enough for half century, while deposits of coal are enough for another 235.

If we suppose a half century limit for NG it means that the tension in the market will become much earlier. Deposits of NG exploitation will be ever deeper and more remote.

Costs of the NG distribution infrastructure investment and maintenance will be growing. Although similar trend is inevitable with coal exploitation and distribution infrastructure this will be delayed. This effect is time- spread over a century dimension and therefore moderated within two-decade outlook for coal.

On the other side, competitive power of NG may further be reduced by its possible conversion as the feedstock in the hydrocarbon processing industry. Almost three quarters of NG resources are situated in countries with not very high political stability, like Middle East and FSU.

This is not the case for deposits of coal. New exploitation technologies, like underground gasification will amplify competitive power of this fuel.

Even more realistic is the "coal by wire strategy", predicted for China and other countries with under developed power transmission infrastructure.

If we accept that this decade has belonged to NG we are admitting that this decade has belonged to gas turbine (GT) at the same time.

GT as the crucial power generation element has become the important component shaping the technological background for the competitive choice between gas and coal in those regions where both these fuels are available.

All this was possible because of very agreeable NG prices. They are underestimated today. GT machinery has achieved scientific & engineering technical status which otherwise would hardly have been possible under less favorable NG price circumstances.

Dynamism of the future switch-over from NG to coal, which we already declared as inevitable, depends on how quickly GT technology incorporates into the coal-based power generation machinery arsenal.

In this paper, before outlining some predictions we wish to present a compilation of technologies which, by our meaning, may substantially affect the equilibrium shift between NG and solid fuels in the future. Our paper is primarily devoted to those of them which comprise GT as the main machinery element like IGCC (Integrated Gasification Combined Cycle) and PFBC (Pressurized Fluidized Bed Combustion).

Nevertheless, other non-GT based technologies are also important fuel market shapers, because they may affect the fuel market structure in the medium-term outlook. These are FBC (Fluidized Bed Combustion) and supercritical steam generating processes.

A real benchmark in the CFB (Circulated Fluidized Bed) technology is the 250MW CFB project Provence/Gardanne.

EDF is the main shareholder. It started its commercial operation in April 1996. Its emission parameters are 97% for SO2 capture with the Ca/S ratio less than 3.

Dust emissions are under 50 mg/Nm3. NOX emissions are less than 250 mg/Nm3, which is well below European limit 650 mg/Nm3. It is the biggest atmospheric CFB plant in the world.

As such, it is considered as the forerunner for a family of very large 500 MW CFB projects. As soon as 500 MW capacity scale is achieved, this technology will probably become fully recognized and accepted by the power generation sector worldwide.

Another step in the CFB advanced development has been successfully demonstrated by the first practical application of the Babcock & Wilcox IR-CFB in Carbondale, Illinois, USA.

This Coal-fired CFB boiler with internal recirculation particle separation system has provided promising initial operating experience by now.

Innovative principle of this improvement consists in the fact that with the IR-CFB all particles collected by the U-beam impact separator are recirculated directly back to the furnace without the use of L-valve return legs.

Another technology, which does not belong to the category of GT related systems, is coal fired supercritical system. Newest indication that the last word has not been said either here came from Denmark last year.

Elsam Production, which is a joint venture of six Jutland-Funen utilities have launched the project of to convoy plants - Nordjyllandsvaerket and Skaerbaekvaerket Unit 3, both 412 MW.

Both are very similar in parameters, with the difference that, Nordjyllandsvaerket will be fired by coal while Skaerbaekvaerket by gas with oil backup. Record breaking thermal efficiencies 47% for Nordjyllandsvaerket and 49% for Skaerbaekvaerket have been expected. Advanced double reheat cycle 580°C / 580°C / 580°C has been applied.

Steam turbines supplied by MAN Energie / GEC Alsthom have 5 pressure levels design from 285 bar down to 23.5 mbar in condenser. Advanced materials had to be used both for steam turbines and heat generators. For example super clean 3.5% Ni rotor to withstand the steam inlet temperatures. HP/IP rotor is made of 10% chromium material, etc.

Once-through Benson type boiler with spiral water walls is designed with 13CrMo4 4 for the helical wound and upper pass of the boiler. Austenitic alloys were used for superheater tubes. A fine-grained version of the SA213-TP347H-type steel was selected.

However, the main attention of our paper is focused to GT-related clean-coal technologies, like IGCC & PFBC.

Before undertaking this analysis we shall outline a brief review of published forecasts for the power generation sector. Some recognized forecasting institutions predict the following figures for the following two decades:

1. Forecasts for decade 1996-2005
   - 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.
   - Share of various power generating components will be as follows: 36% GT, 47% ST (steam turbines) and 17% hydro turbines.
   - Share of independent power producers (IPP) will be 30% from the global growth of the world's power generating capacity.
   - 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.
   - Consumption of electricity will increase from 1300 GWY level of 1995 to 1700 GWY (gigawatt-years); (1GWY = 0.7 MTOE = 31.5 x 10^6 GJ) in 2005.
2. Forecasts for decade 2006-2015
   - 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.
   - 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
   This is outlined in the following table in which % of fuel commodities are listed together with absolute consumptions in GWY:

Fuel/Year	1995 %	1995 GWY	2015 %	2015 GWY	Growth GWY / %
NG	16	210	23	540	+ 330/ 33.0
Coal	37	480	36	820	+ 340/ 34.0
Nuclear	17	215	10	240	+ 25/ 2.5
Hydro	21	275	22	500	+ 225/ 22.5

Oil	9	120	9	200	+ 80/ 8.0
Total	100	1300	100	2300	+1000/100.0

As is obvious from the above listed figures, the considerable increase from 16% to 23% NG is counter-balanced by the 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 the 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 point at which the decline of NG, accompanied with an ever increasing share of coal and other solid fuels in fossil-fuelled generation, starts.

In a new technology scenario such switch-over between NG and coal will be accompanied with massive expansion of GTs into the domain of solid fuel commodity.

EXPANSION OF GAS TURBINES IN SOLID FUEL SEGMENT

IGCC and PFBC have started to achieve commercial status as the new promising technologies for solid fuelled power generation. Both these technologies are incorporating GT as the prime mover. GT reliance is, however stronger with IGCC because GT contributes to power output by 60%-65%, while with PFBC only by 20%-23%.

Research and development status of IGCC is adequate to the design experiences which has this technology traditionally achieved in its industrial applications. Power generation application has therefore achieved a strong pre-commercial basis. First commercial applications have already been implemented, as indicated in Tables 1 and 2.

In Table 1.a. descriptions of the four most important IGCC projects based on **fixed-bed** technology (projects 1 and 3) and **fluidized-bed** technology (projects 2 and 4) are given.

In Table 1.b. descriptions of another five projects based on **entrained-flow** technologies (projects 5 - 9) are given.

The successful demonstration stage, which all of these technologies have overcome, has been accelerated by favorable 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 levels 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 subsidized under various supporting national & international programmes like the Clean Coal Technology Programme sponsored by the US Department of Energy or other programmes like Thermie sponsored by EC.

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 commercialization of IGCC may become 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).

EXPANSION OF GAS TURBINES IN REFINERY RESIDUE SEGMENT

Probably the most optimistic results in IGCC technology have been achieved in heavy oil residues pressurized gasification which have already assumed commercial success without any subsidization backup.

This has, however, been possible by the synergetic co-production effect of producing other gasification products valuable for refineries and chemical industry (e.g., hydrogen, ammonia, Fischer Tropsch liquids, methanol, acetic anhydride but also pressurized air, steam, as well as free option of power to be either sold over-fence, or utilized for own purposes).

General experience with IGCC economy confirms that economical viability is guaranteed only with the above mentioned more highly added value products that energy itself.

Future prospects, however seem optimistic, especially with higher output units 500MW plus, about 1200 USD per kW. Moreover, compare to traditional coal combustion IGCC with 99 percent of sulphur removal and emissions less than 20 ppm are superior.

Syngas performance, which contains high percentage of hydrogen (about 60 percent) has a more agreeable performance with GT. Thermal efficiencies in demo plants achieved 43 per cent. Application of the next generation of advanced GT may push this edge up to 50%, provided that also air separation cryogenic units are substituted by ion-transport membranes.

COMPATIBILITY OF GT WITH ENVIRONMENTAL RESTRICTIONS

The trend towards tighter legislation restrictions related to ground level ozone will hardly be reduced in foreseeable future, like e.g. the next decade. In the USA, for example, emission regulations require new installation to meet NOX emission levels of between 5 and 25 ppm depending on the location and size of the installation. In southern California, in Japan, NOX requirements are below 10ppm.

The USA Environmental Protection Agency is currently revising the existing ozone national ambient air quality standards and proposes even tougher limits. Simiar trends may be expected also in other OECD countries.

There is a question whether GT technology development will be able to cope with such requirements. Fortunately, optimistic outlook for this question is justified.

Apart of traditional current advanced technologies like SCR, DLN there have been successful experiments executed with flameless combustion technology which uses a combustor with a catalyst so that lower combustion temperatures with better uniformity of the temperature field can be achieved.

Possibility of commercial success for this R/D results has been confirmed in June 1997 when company Genxon signed a MoM with GE for the application of their Xonon flameless catalytical combustion system. The deal, if successful, may be applied to the GE's worldwide installed GT fleet.

REVIEW OF IGCC TECHNOLOGIES

Solid fuel gasification is not a new technology. It has widely been used in chemical and fuel conversion industry. It was an atmospheric technology. SASOL process operating in Sasolburgand Secunda, South Africa where more than 90 Lurgi gasifiers consume 30 mil. t/a of sub bituminous coal is commercially the most important application world-wide.

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, but is developed for large-scale commercial basis. Trials were carried out in the USSR in thirties and recently in the USA.

The principal difference for adequate gasification 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 pressurized regime and the other is the Gas Cleanup System (GCS). Conventional GCS, so-called CGCS (Cold CGS) operates at a mild temperature regime. The more progressive technology called HCGS (Hot GCS) operates under elevated temperatures.

Each IGCC plant consists of three parts. Two of them, namely GT Power Plant and ST Power Plant are analogical to the standard CCGT system. Chemical technology part - Gasification Island in the main technology segment. One of the possible technological schemes for this part is shown in Figure 1 (Texaco process).

The gasifier can be blown either by oxygen or air. Steam injection may be also applied for moderation purposes. The gasifier works under elevated operating pressure, 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.

Energy saving effect is based on chemical energy transfer. In this manner, syngas medium is utilized with highly effective exergy balance, rather than sensitive heat of flue gas. Efficiencies approaching about 50%, normally impracticable with any other solid fuel fired technology, are potentially possible if gas turbines of advanced generation are applied (Susta & Luby, 1997).

Gasification is carried out under oxygen-deficit reaction environment. 20% to 40% of stochiometric amount of O2 related to a complete combustion enters the reaction, what is enough to cover the saturation energy necessary for a complete gasification.

Reaction temperatures are much higher compare to a general combustion process. Under such temperatures increased extend of devolatilization is made possible. High concentrations of CO2 and increased concentrations of H2O are produced through.

<u>Physical state of ash</u>:

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 H2S and COS. Compare to SO2 and CO2 which arise with conventional combustion processes H2S and COS are more easily removed. Unlike to NOx common to conventional combustion processes NH3 and HCN arise.

TECHNOLOGICAL ITEMS YET TO BE SOLVED

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

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

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

Removal of alkali metals which are corrosive to gas turbine expander metallurgy still remains to be solved as one of the most difficult problems.

The Sierra Pacific, Pinon Pine IGCC project (Table.1a), 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 recognize as milestones in the solid fuel gasification engineering progress. They are listed in Tables 1a and 1b.

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

Wabash River (Table 1b, project 8) is the biggest single-train IGCC plant in commercial operation in the world. 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.

The first stage of gasifier operates at 1426 deg C and 27 bar. 95% oxygen is generated by the crygenic unit. Output of GT (MS7001FA) is 192MW, ST 104 MW, system auxiliary consumption is 34MW, resulting in total plant capacity 262 MW. Practical operational experiences confirmed that candle filters are sensitive elements (Chambers, 1998).

Hürth (KoBra) (Schippers at al. 1993) (Table 1a, project 4), (KoBra= Coal Brown). Well-proven Siemens V94.3 gas turbines are implemented as prime movers. Performance parameters are as follows: GT=212MWe, ST=155MWe.

Another 27 MW is generated by combustion of the gasification residue coke (bottom product + filter dust) in the fluid-bed-boilers. In water scrubber gas is cooled to 140°C. Desulphurization and sulphur recovery: In the gasifier most sulphur is converted to gas phase as H2S & COS. COS is catalytically converted to H2S.

Sierra Pacific, Reno, and Pinon-Pine (Newby, 1997) (Table 1a, project 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 ferrite sorbent is used to remove the remaining sulphur.

Schwarze Pumpe (MPS Supplement, 1996) (Table 1a, project 3). Mixture of brown coal and palletized refuse are the gasifier feedstock. The generated syngas will serve as feedstock to methanol production. In the second phase these gasifiers will be replaced by BGL slagging fixed bed gasifiers with counter-current flow.

Buggenum (Chambers, 1997) (Table 1b, project 5). This is currently the largest IGCC plant in Europe. Commercial operation is scheduled to start at the beginning of year 1998.

Tampa Electric (Table 1b, project 9) (Chambers, 1998). This project has the merit of demonstrating commercial feasibility of the two parallel HGCU systems. Total project capital costs were 510 USD m, with specific figure almost USD 2000 per kW, which, however, comprises reclamation costs for its permitted 1150 MW capacity and inclusive sulphuric acid plant. Syngas LHV equals 7.5 kJ per m3. Its Air Separation Unit consumes 50 MW.

REVIEW OF IGCC PROJECTS PROCESSING HEAVY OIL REFINERY RESIDUES

IGCC systems processing refinery residues are also subject of our interest. In Table 2. selection of six most important IGCC projects of this kind is introduced. All of them are based on entrainment flow gasification technology either by Texaco (position 1-4), by PRENFLO (position 5) or by Shell (positions 6). A simplified block diagram of a general Texaco IGCC process is shown in Figure 1.

Sarlux, Refinery of Saras, Italy (Table 2, position 3) is the largest IGCC under construction today (Chambers, 1997). When ready, it will be double the size of Wabash River IGCC (Indiana, USA) which is the largest IGCC currently in operation. Sarlux is the 1st non-recourse, third Party financed IPP project of this kind. At the same time, it is the largest IPP in Italy.

Coproduction character of this technology is an attractive selling point for any plant like this. Electricity, steam and hydrogen may be generated for refinery purposes while power can be sold over-fence, if appropriate. Texaco quench gasifier is applied. Thermal efficiency expected is 50%.

Refinery visbreaker residues (bitumen and tar left over from the refinery process Saras) are used as the feedstock. Saras (the 2nd largest refinery in Europe) with 55% shares and Enron with 45% share are owners. GE, Snamproggeti and Turbotecnica are the turnkey contractors. Mid 12/96 group of International banks approved the 1.3 billion USD loan for this project. Commercial operation is scheduled for 2000.

API Energia, Falconara, Italy (Table 2, position 1) will gasify 440 000 t/y of visbreaker tar, which is a heavy oil residue.

El Dorado, Kansas, USA (Table 2, position 4): Hazardous refinery waste streams are used as the feedstock in this project (Chambers, 1997). US Environmental Protection Agency (EPA) granted permission preferentially because hazards were to be removed. In addition, the gasifier will be exempt from the Resource Conservation and Recovery Act.

It means that the Project's refinery wastes will be considered as a fuel for the Gasifier and the Refinery can avoid disposal expenses and possible long-term liabilities for materials which otherwise would be considered hazardous.

All Gasifier feeds have low or negative costs to the Refinery. Additionally, future changes in market or regulatory conditions may allow using gasification technology for production of hydrogen, methanol or other petrochemical feedstocks.

Puertollano, Spain (Table 2, position 5) is the first project to use the PRENFLO gasification process, developed by Krupp-Koppers and Siemens/KWU (Europower, 1997). A mixture of ash-rich petroleum coke from nearby refinery is used.

Pernis, Rotterdam, The Netherlands (Table 2, position 6): PER and Shell Refinery have installed an IGCC unit to generate power, steam and hydrogen (Chambers, 1997). Full operation is scheduled for this year (1997).

Gasification takes place under 65 bar and 1300-1400°C. Raw gas is cooled to 400°C. CHP (Combined Heat and Power) plant comprises 2 x GT MS6541B with capacity 43MWe each and 1 x ST (Steam Turbine) 28MW + 1 x ST 15 MW, total 127 MWe. The whole PP (Power Plant) shall be integrated with process plant in the late summer of 1997.

Superiority of IGCC over traditional refinery residues power generation technologies has firm economical and environmental basis. Conventional heavy-fuel oil fired PPs and FBC (Fluidized Bed Combustion) which are the traditional oil residue based power generation technologies cannot remain the only tools to solve the increasing heavy residue disposal problem.

IGCC is becoming highly competitive because it is fuel-universal. A wide range of feedstock with solid fuel like coal, petroleum coke via slurries to liquid residues of any kind can be processed with highest efficiency (for several examples refer to Table 2, column 3).

Typically, oxygen as gasifying agent moderated by steam is applied. The product sulphur-free syngas is generated which meets high purity requirements for GT admission. High-quality sulphur as the revenue-improving by-product is generated. Nitrogen left after oxygen separation is effectively admixed as GT denitrification inhibitor. In addition to co-production options like hydrogen and steam mentioned before, also methanol as secondary fuel or urea as fertilizer can be produced.

PFBC - CURRENT TECHNICAL STATUS

PFBC is another clean technology which offers an alternative to IGCC. A simplified technological scheme is shown in Figure 2. Three basic components are integrated in one simple cycle:

A fluidized bed boiler suspended in the interior pressure atmosphere of Combustor Vessel, then GT circuit and ST circuit. Typical inlet operating air pressure of 12 bar is generated by the GT compressor. The air is led into the combustion chamber from below, creating thus a fluidized bed with inert ash and the additive sorbent required for sulphur capture.

There is virtually no residual carbon left after combustion has taken place. Power generation has a different heat distribution than IGCC. About 80% power is generated by ST and only 20% by GT. This is caused by the fact that deeper cooling (down to 800-900°C) must be achieved before entering the GT.

PFBC is therefore thermodynamically less effective than IGCC. However, simplicity of this technology has caused that commercial status is by 5 years ahead of IGCC technology. The following projects (Table 3) which have been- or will be commercially available confirm ABB market hegemony:

Värtan, Stockholm, Sweden (Table 3, position 1) is the first of the array of the initial 5 projects erected according to ABB Carbon technology subsequently within years 1991-1999. The remaining four projects are as follows:

1992 **Escatron, Spain** (Table 3, position 2),

1992 **Tidd, Ohio, USA (**Table 3, position 3),

1993 **Wakamatsu, Japan,** (Table 3, position 4),

1999 **Cottbus, Germany** (Table 3, position 5)

All of these projects have standard parameters given by ABB technology type designation P-200, i.e. power output 70-80 MW, efficiency 42-43%, with all other parameters as listed in Table 3.

ABB hopes to achieve capacity and efficiency upgrading up to 360 MW and 45% respectively, with project:

1998 **Karita, Japan** (Table 3, position 6) which is now being under construction.

PFBC activities in the USA are represented by the 170 MW **Lakeland, USA** project listed in Table 3, position 7.

Attractivity of this technology potentially consists in the following attributes which beat conventional coal-fired systems:

1. Thermodynamic efficiency 42-45% surpasses considerably conventional steam plants parameters, although not in par with the latest IGCC technologies like Sarlux. Good efficiency is guaranteed by favorable kinetic parameters in the fluid bed. A typical reactor of ABB P-200 technology has a 3.5 m fluid bed height, what means that by typical fluid bed velocities of 0.9 m/s sufficiently long contact time exists resulting in very efficient desulphurization conversion.
2. Environmental friendliness is excellent as is also shown in Table 3. Indicated parameters are very well below the tough limits prescribed by most of European governments, particularly the German Federal Emissions Control Act which calls for 400mg/Nm3 limit for SO2 and 200 mg/Nm3 for NOx.
3. Residue from PFBC consists of a mixture of coal ash and partly sulphated limestone or dolomite. It forms a stable end-product which can be safely disposed. It is well self-binding, water-resistant and non-leaching. As such, it is very well suitable as a building material, synthetic gravel, etc.

CONCLUSIONS

In this paper we have presented arguments supporting our firm belief that a smooth, yet visible declination trend from NG in favor 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 GTs turbines in favor of solid fuel reliance will be ever more abundant. IGCC & PFBC technologies are tools which will make such shift viable about year 2015.
- Percent share of NG is projected to be increasing for another 15 years. Yet, this will not be as ample as previously anticipated. Possible bottlenecks in NG world

trade will suppress its growth. Distribution and exploitation difficulties will occur. Further price elevation of NG will reduce its competitive ability vs. solid fuels.

- On the other hand, competitive power of coal will be enhanced by the 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 renaissance in the first decade of the next century.
- The largest 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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Tab. 1a.: IGCC Projects based on Fixed-bed & Fluidized-bed Coal Gasification Technologies

No.	Project	Technology	Parameters	Remark / Attribute	History	Ownership
1	**Lünnen** Germany	**Lurgi** : fixed-bed gasifier, coal-fired, oxygen-blown, dry ash removal, cold gas clean-up system	Output 170 MW	world's first commercial-scale IGCC	Commissioned 1972 Decommissioned after 10,000 hrs of operation	STEAG Germany
2	**Sierra Pacific** Pinon Pine, USA	**Kellog-Rust-Westinghouse:** fluid bed gasifier, coal-fired, air-blown, HGCS with desulphurstn. with zinc/nickel sorbent, particle removal by high temp.ceram.filts.	Output 80 MW	The first integrated hot syngas demonstration of HGCS. Transport reactor system. Full stream high-temperature ceramic barrier filters.	Commissioning 1996	Pacific Power, Nevada, USA
3	**Schwarze Pumpe,** Germany	**Lurgi:** fixed-bed, palletised refuse+lignite, oxygen-blown, dry ash. Project 2nd Phase: **BGL** (British Gas Lurgi) slagging process to be adopted.	Output: 130 MW Syngas as feedtck. for methanol production.	1st operating co-production IGCC with varied power supply option, with full write-off on the gasification plant for methanol production	1st Project Phase with Lurgi dry ash – comm.-ed in 1997. 2nd Project Phase with BGL slagging fixed-bed to be commissioned by end 1998.	Schwarze Pumpe GmbH, Germany
4	**Hürth (KoBra)** Germany	**High Temperature Winkler:** fluidized bed, brown coal, air-blown, ash agglomeration, hot gas partical removal with cold gas desulphurization system	Output 367 MWe	First large-scale HTW IGCC technology Process developer: RWE Energie AG, the largest German utility	Demo plant with HTW gasification to be commissioned in 2000	JV of RWE Energie AG and Rheinbraun AG, both Germany

Table 1b.: IGCC Projects based on Entrained-flow Coal Gasification Technologies

No.	Project	Technology	Parameters	Remark / Attribute	History	Ownership
5	**Buggenum** The Netherlands	**Shell:** entrained-flow gasifier, coal-fired, oxygen-blown, ash slagging, hot gas partical removal, cold gas desulphurization	Output 253 MW	In 1994 the largest IGCC plant in the world	Demo plant commissioned 1994 Commercial operation 1998	Demkolec B.V The Netherlands
6	**Cool Water** California, USA	**Texaco:** entrained-flow gasifier, coal-fired, oxygen-blown, ash slagging, cold gas clean-up system	Output 93 MW	Within 1984 - 1986 the largest IGCC plant in the world	Demo plant commissioned 1984 Decommissioned 1989	Texaco and Southern California Edison, both USA
7	**Plaquemine** Louisiana, USA	**DOW:** 2-stage, entrained-flow gasifier, coal-fired, oxygen-blown, ash slagging, cold gas clean-up system	Output 160 MW	Within 1987- 1993 the largest IGCC plant in the world	Demo plant commissioned 1987	Louisiana Gasification Technology Inc., Louisiana, USA
8	**Wabash River,** West Terre Haute, Indiana, USA	**Destec:** 2-stage entrained-flow gasifier, high sulphur bituminous coal, oxygen-blown, continuous slagging, cold gas clean-up	Output 262 MW	Clean Coal Technology Programme of DOE,USA. Within 1995 - 1996 the largest IGCC plant in the world.	Commercial operation started in November 1995	JV of Destec Energy Inc.and PSI Energy Inc., both USA
9	**Tampa Electric Co.** Polk Power Station, Florida, USA	**Texaco:** entrained-flow gasifier, coal fired, oxygen-blown, hot gas cleanup system developed by GE Environmental Services Ic.	Output 260 MW	Partcipation of US Department of Energy, via Round 3 of the Clean CoaL Technology Programme	Commissioned 1996	Tampa Electric, Florida, USA

Tab. 2.: IGCC Projects Based on Refinery Residues Gasification Technologies

No.	Project	Technology	Parameters	Remark / Attribute	History	Ownership
1	**Falconara,** Italy	**Texaco:** entrained-flow gasifier, fired with heavy oil residue visbreaker tar, oxygen-blown, cold gas clean-up system	Output 276 MW Efficiency NA	Consortium of 7 international banks will provide 660 Mil. USD out of the total project budget of 880 mil. USD. The rest provided by Owners.	Financial close in July 1996, construction started early 1996, commissioning scheduled for May 1999	50% by ABB who also is the Contractor and 50% by API Energia (Italy)
2	**ISAB Energy, Priolio**, Italy	**Texaco:** entrained-flow gasifier, fired with residuum oil from supercritical extraction, oxygen-blown, cold gas clean-up system	Output NA Efficiency NA	One of the first large-scale co-production project, processing residual oil components	Financial close achieved in July 1996, construction underway	51% ERG 49% Mission Energy
3	**Sarlux,** Refinery of Saras, Italy	**Texaco:** entrained-flow quench gasifier, fired with bitumen + tar left from refinery, oxygen-blown, cold gas clean-up system	Output 550 MW Efficiency 50%	World´s largest and most efficient IGCC ever built. First non-recourse, 3rd party financing and largest IPP under constrct. in Italy by now.	Mid Dec. 1996 a group of international banks approved 1.3 bn USD loan. Commercial operation expected by 2000.	45% Enron, 55% API (Anonima Petroli Italiana)
4	**El Dorado** Kansas, USA	**Texaco:** entrained-flow gasifier, fired with petroleum coke and waste oils, oxygen-blown, cold gas clean-up system (CGCS)	Output 35 MWe + 80 t/h steam, +pressurized air, +O2, +N2 Efficiency NA	First IGCC plant in the USA exempt from the Resource Conservation and Recovery Act	Commercial operation with syngas started on June 1996	Texaco Gasification Power Systems, USA
5	**Puertollano** Spain	**PRENFLO:** entrained-flow, coal+ petroleum coke, oxygen-blown, Kopper´s Totzek proc. adopted by Krupp Koppers to pressurized system	Output: 318 MW Efficiency 47%	Project funded by CEC (Commission of European Community)and by German Ministry of R/D. Since 12/96 world´s largest IGCC.	Engineering and fabrication 08/92-07/95, Erection and assembly 05/93-07/1996, Commissioned 06/96-12/96, Coal gasf.operation -end 97	Elcogas S.A - an operating comp. formed by 8 European utilities and 3 suppliers
6	**Pernis,** Rotterdam, The Netherlands	**Shell:** entrained-flow gasifier, oil residue gasification, oxygen-blown, with hydrogen co-production	Output: 127 MW +400 t/h steam +hydrogen Efficiency - NA	SGHP (Shell Gasification Hydrogen Plant) construction is part of the 2 bn USD refinery upgrading project	Full operation scheduled for this year (1997)	Shell Pernis, which is a JV of the PER and Shell Refinery, both Netherlands

Tab. 3.: PFBC Projects

No.	Project	Technology	Parameters	Remark / Attribute	History	Ownership
1	Värtan, Stockholm, Sweden	ABB Carbon, Sweden Type 2 x P200 GT: GT35P from ABB Stal Fuel: imported low sulphur coal	Output 135 Mwe 224 MWth NOx 65 mg/Nm3 SO2 80 mg/Nm3	First commercial PFBC in the world	Operational 1991	Stockholm Energi
2	Escatron, Spain	ABB Carbon, Sweden Type 1 x P200 GT: GT35P from ABB Stal Fuel: local black lignite, 9% S	Output 80 MWe NOx 286 mg/Nm3 SO2 NA	Built by Consortium ABB & Babcock Wilcox Espanola	Operational 1992	ENDESA - -state-owned utility, Escatron, Spain
3	Tidd, Ohio, USA	ABB Carbon, Sweden Type 1 x P200 GT: GT35P from ABB Stal Fuel: Pittsburg bituminous coal	Output 73 MWe NOx 192 mg/Nm3 Efficiency 42.5%	Financial support from the US DOE	Operational 1992. End March 1995 shut down after successful 11400 of operational hours	American Electric Power at Tidd, Ohio, USA
4	Wakamatsu, Japan	ABB Carbon, Sweden Type 1 x P200 GT: GT35P from ABB Stal Fuel: bituminous low sulphur coal	Output 70 MWe NOx 190 mg/Nm3 SO2 166 mg/Nm3 Efficiency 42.5%	Fibre optic temprtr. sensors applied for the first time. Land reclamation project using solidified PFBC ash.	Operational 1993	Electric Power Development Company, Japan
5	Cottbus, Brandenburg, Germany	ABB Carbon, Sweden Type 1 x P200 GT: GT35P from ABB Stal low quality brown coal	74 MWe 220 MWth steam Efficiency 42.5%	230 M USD Contract. Turnkey supply from Consortium ABB Germany & ABB Carbon. Financial support from the US DOE.	Commissioning started in Summer 1998, the plant will be on line in Summer 1999	VEAG - the main distribution utility in Germany
6	Karita, Kyushu Island, Japan	ABB Carbon, Sweden Type 1 x P800, GT: GT 140P Fuel: pulverised coal	Output 350 MWe (70 MWe by GT + 280 MWe by ST) Efficiency 45%	Contractor IHI - licensee of ABB Carbon. 1st commercial unit with ceramic candle filters (Schumacher) instead of cyclones for particult. removal	Contract signed 01/1995 Completion scheduled 1997 Operation scheduled by 1998	Kyushu Electric Power Company
7	Lakeland, Florida, USA	Foster Wheeler topped, PCFB (Pressurized Circulating Fluidized Bed) combustion system with Westinghouse Hot Gas Filter.	170 MWe Efficiency 45%	Two projects originally planned for cities Moines (Iowa) and Calvert City (Kentucky) integrated in one 170 MW project in Lakeland	Demonstration stage 1997-2000. When successful, carboniser will be added and PCFB installed	Department of Electric and Water Utilities, Lakeland, Florida, USA