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Partial gasification combined cycle technology: a practical pathway for clean coal advancement

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A Practical Pathway for Clean Coal Advancement

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The Challenge for Coal

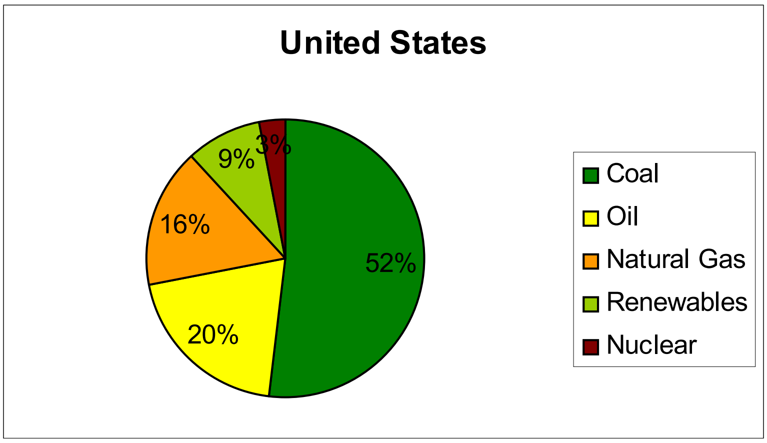
Environmental concern and policy will continue to shape the power supply infrastructure around the globe. The world's power infrastructure today is very much the result of earlier environmental pressures: the emergence of fluid bed combustion technology for coal in the 1970s, the global decline in nuclear technology during the 1980s, and the dramatic increase in natural gas technology in the 1990s. These trends have been most evident in industrialized nations and history has shown that developing countries eventually adopt the environmental standards of their more developed neighbors.

Over the past decade the environmental standards for the power industry have increased dramatically led by industrialized countries such as the United States, European Community and Japan. Advanced natural gas combined cycle (NGCC) technology is setting ultra low standards for NO_x and CO at a few ppm and virtually zero SO_2 and particulates. Trace metal emission regulation for mercury, lead, cyanide, and arsenic, as well as fine particulate regulation (PM 2.5), are in the implementation stages of industrialized countries. Many countries around the globe are contemplating CO_2 regulation.

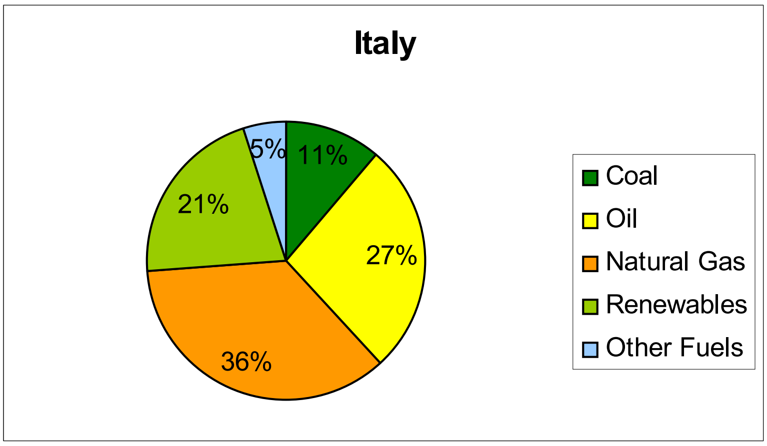
In the United States and in many other countries, while emission standards have been becoming more stringent, global emissions from power plants have not been correspondingly decreasing, a result of far too little investment in power infrastructure over the last 20 years. As power demand has increased, without new cleaner generation to meet the need, power producers are forced "to put everything on line" including their oldest, least efficient and highest emitting plants. According to the USA Utility Data Institute (UDI), about half (1962 GW) of the world's power is generated from coal and most of this power, about 87% of it (1716 GW), does not have any installed NO_x or SO_2 control equipment. Some of these older units emit over 10 times the emissions of current new plant standards.

With new gas plants setting ultra low emission standards, and while many people are consuming low cost power from older dirtier plants, the industry is far from an equilibrium state. Implicitly, NGCC has set the ultimate target for coal power emissions and coal's future depends on how far technology can take coal environmentally while still fulfilling the economic and reliability hurdles set by the power market.

The situation is Europe shows variegated scenarios with different weight of coal in the power production, ranging from countries like Germany, Denmark, United Kingdom, where coal is an important fuel source, to countries like Italy where coal is marginally used and, for historical reasons, considered dirty and a pollutant up to now.
Figure 1 shows fuel sources for electricity generation in USA, and Italy: coal contribution is 52% in USA, 32% average in Europe and only 11% in Italy.



Source: U.S. Department of Energy Information Administration (2000)



Source: Electric Power and Gas Authority (2001)

Figure no. 1
Fuel Sources for Electricity Generation

However the trend is changing: over the past year interest and consensus on coal in the European countries and particurarly in Italy have increased, led by the necessity to ensure a safe energy supply in a floating and unstable scenario of natural gas and oil prices.

In Italy, the dramatic increase of Natural Gas Combined Cycle (NGCC) projects has resulted in the transfer of Italy's crude oil depedence risk to now a sole dependence on natural gas, sharing the same uncertainties related to international strains, price fluctuations and limited reserves. In 2001 the forecast of Year 2005 natural gas percentage showed a dramatic 58%.

One path toward national energy security is fuel diversity: coal with its large reserves, stable and low prices and a free competition market without political inteference, is the answer. However, in Europe, as well as in USA, the challenge for coal depends on technology to meet aggressive environmental and efficiency targets.

The Value of Efficiency

Coal technologies that utilize strictly Rankine steam cycles, such as pulverized coal (PC) or circulating fluid bed combustion (CFB) technologies, are limited thermodynamically by the relatively low Rankine cycle efficiency. Methods for substantial efficiency improvements can only be achieved by increasing steam conditions to supercritical pressures (more than 220 bar a) and to very high temperatures (more than 600°C for superheated and reheated steam). This means the need to continuously develop the boiler metallurgy to cope with higher and higher steam temperatures.

In contrast, today NGCC is the most efficient power technology and is expected to remain so in the future. Thermodynamically, the combined cycle utilizes the fuel's energy in the most efficient way and with a clean high-energy fuel, such as natural gas, requiring minimal pollution controls and energy losses to the cycle, NGCC technology sets the upper efficiency limit for all other power generation technologies. The drawback is the obliged link to the natural gas source and market.

Coal technologies that promise the lowest emissions utilize Integrated Gasification Combined Cycle (IGCC). Gasification acts as a bridge between coal and gas turbines. IGCC is the only coal based power technology that can approach the environmental performance of natural gas fired systems, because the synthesis gas (syngas) generated by gasification, before firing in the gas turbine, can be cleaned to reduce to very low levels contaminants such as sulphur compounds and particulates. Further, the syngas can be mixed with nitrogen and/or saturated with water to reduce similarly the nitrogen compounds.

IGCC technology benefits from combined cycle technology to increase the efficiency (5-10 points or 10-25%) with respect to conventional subcritical steam cycles.
It also benefits from advancement in combustion turbine (CT) technology. As CTs advance to more efficient and larger sizes, IGCCs also advance in size, efficiency, and economy of scale.
But unlike NGCC plants, they need to carry the energy loss penalty associated with gasifying solid fuel, producing oxygen used as reaction oxidant, and capturing the pollutants derived from solid fuels. As a consequence the IGCC net electrical efficiency falls below the supercritical/ultrasupercritical steam plants.

On the contrary Partial Gasification Combined Cycle (PGCC) technology described in this paper increases significantly the plant efficiency over the supercritical/ultrasupercritical steam plants, because it benefits both from use of gas turbine like the IGCC plant, and from generation of supercritical steam like supercritical steam plants.
In addition the PGCC auxiliary consumptions are lower than IGCC due to use of air as an oxidant instead of oxygen, and to the lower plant complexity.

Figure 2 shows an efficiency comparison of various power technologies expected over the next 10 years.

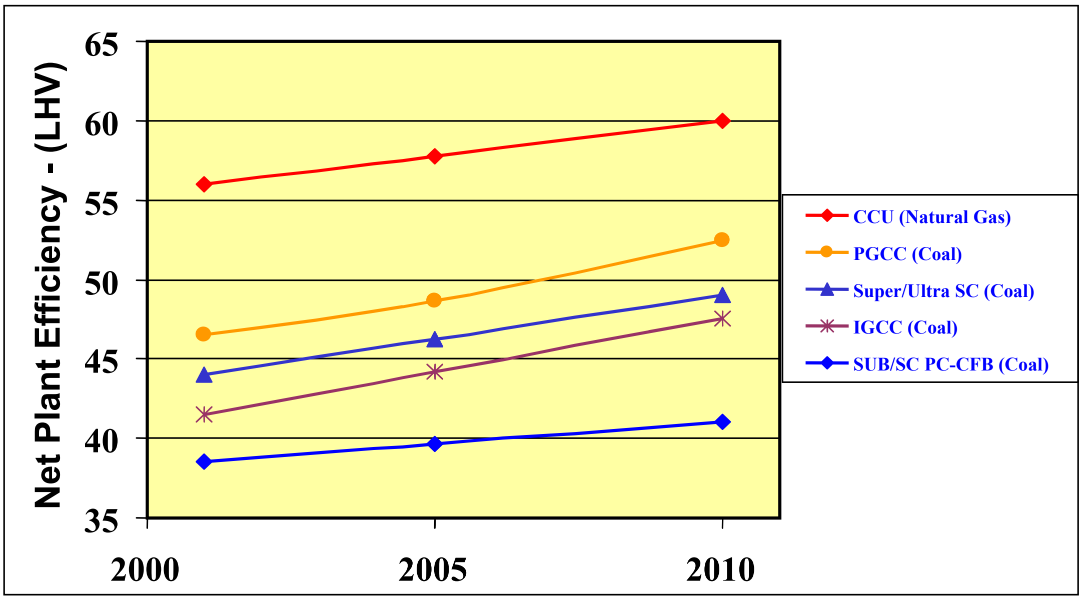


Figure no. 2
Net Plant Efficiency

Plant efficiency is the most effective way of reducing the environmental impact of power generation. Unlike gas cleaning technologies, which are specifically designed to remove select pollutants, an increase in plant efficiency reduces all plant emissions by preventing the emissions from ever being created. The pollutants or emissions either originate from the fuel, such as SOx, CO_2 and Mercury, or are created in the process such as NOx and CO. For each megawatt generated, higher efficiency plants use less fuel creating fewer emissions. Figure 3 shows the impact of plant efficiency on CO_2. A ten points increase in efficiency results in an approx. 25% reduction in all plant emissions.

From the practical standpoint, efficiency is a high value parameter for power producers. It gives them a hedge against future environmental regulation since it indiscriminately reduces all plant emissions including those yet to be regulated. But it also gives power producers benefits that can be realized today, such as savings in plant operational cost (fuel consumption and ash production), and plant capital cost (reduced plant size for the same megawatt output). Plant reliability benefits are also realized with higher efficiency plants, since multiple pollution control equipment can be avoided.

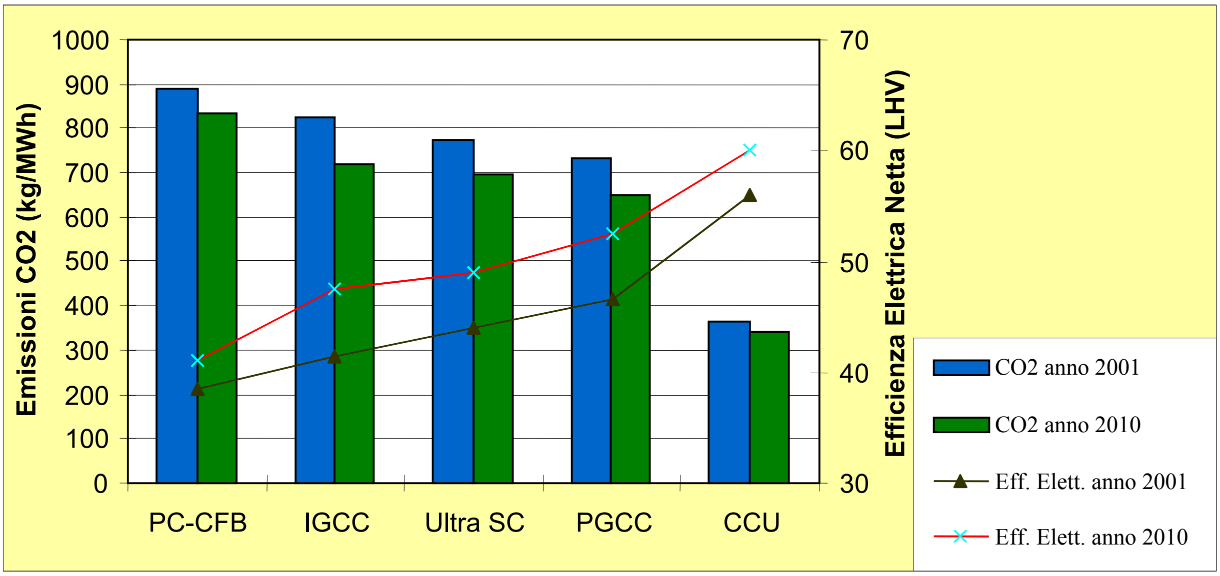


Figure no. 3
Efficiency Translate into Reduced Emissions

A Practical Pathway to Clean Coal Advancement

The benefits of gasification are clear. But, even though, several gasification technologies for power applications have been demonstrated on a full scale around the world as early as 10 years ago, gasification technology has not yet successfully penetrated the commercial power market. Most industry experts point to plant complexity, reliability and cost as the key technology hurdles that are preventing gasification from being commercially accepted in the power industry.

Partial gasification combined cycle (PGCC) technology shows promise for power applications since PGCC can realize the benefits of gasification while achieving the reliability, flexibility and economics of a commercial power plant. PGCC utilizes proven combustion power technology to simplify the gasification process and overcome the technology hurdles associated with it.

How Does PGCC Work?

As with all combined cycle plants, electrical power is generated from both a combustion turbine generator as well as a steam turbine generator. The CT is fueled by syngas generated by the gasification process and the steam turbine is powered by supercritical steam generated in either a supercritical PC or supercritical CFB combustion boiler. Figure 4 shows the PGCC configuration utilizing CFB boiler technology named: gasification fluid bed combined cycle (GFBCC) and figure 5 shows the PGCC configuration utilizing PC boiler technology named: gasification pulverized coal combined cycle (GPCCC).

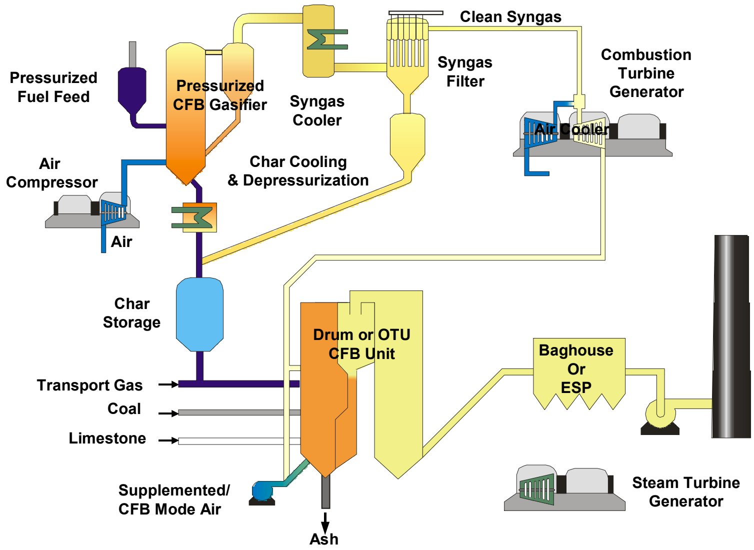


Figure 4. Gasification Fluid Bed Combined Cycle (GFBCC) Configuration

The gasification process is relatively simple, consisting of only four major systems or components: (1) gasifier, (2) syngas cooler, (3) particulate filter, and (4) char transport system. After being pressurized, solid fuel is gasified in a pressurized circulating fluid bed gasifier, the resulting syngas is cooled by a convective syngas cooler and then filtered of fine char particles by a hot gas filter (HGF).

The HGF utilizes durable sintered metal filter elements and is cleaned during continuous operation by periodic back pulsing a portion of the elements with steam or nitrogen. The char that is collected in the HGF and from the gasifier is depressurized and injected into the combustion boiler pneumatically by the char transport system. The char is not cooled any further by the transport system and is injected into the boiler hot.

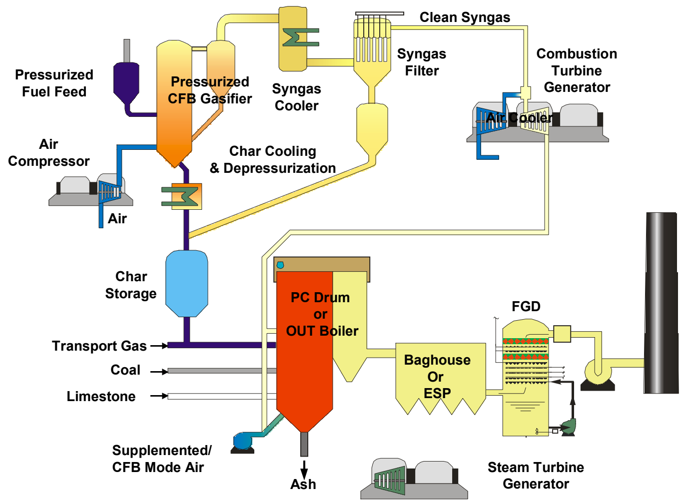


Figure 5. Gasification Pulverized Coal Combined Cycle Configuration

After passing through the hot gas filter, the syngas is sent to the CT for combustion. PGCC can utilize standard CT's configured with low heating value syngas burners, the same engines as utilized by other gasification technologies.

However, unlike other gasification technologies, PGCC does not remove the sulfur in the syngas, the hydrogen sulfide (H_2S) in the syngas combusts to sulfur dioxide (SO_2) in the CT combustion process. For PGCC, the sulfur is removed after the CT in either the CFB boiler (GFBCC) or in a standard flue gas desulfurization (FGD) system downstream of the PC boiler (GPCCC). Working with gas turbine manufacturers, for a wide range of fuels, it has been determined that the resulting sulfur concentrations in the CT gases does not effect CT life and maintenance.

Feasibility studies have been completed for two plant designs, one utilizing a General Electric 6FA combustion turbine and the other utilizing a GE 7FA CT. Table 1 shows key plant data and Table 2 shows the expected plant emissions for these two base designs.

Table 1

Predicted Key Plant Design Parameters			
Main Fuel		Pittsburgh # 8 Coal	
Main Fuel Sulfur Content	% wt a.r.	3.0	
Startup/Backup Fuel		Natural Gas	
Altitude	m	Sea Level	
Ambient Temperature	°C	15	
Ambient Humidity	% RH	60	
Gas Turbine Model		**GE-6FA**	**GE-7FA**
GT Gross Output	MWe	87.5	197.5
Gasification Auxiliary Load	MWe	15	30.5
Net Gasification/GT Power	**MWe**	**72.5**	**167**
ST Gross Output	MWe	250.1	411.3
ST Aux Load	MWe	21	32.8
Net ST Power	**MWe**	**229.1**	**378.5**
Total Plant Gross Output	MWe	337.6	608.8
Total Plant Auxiliary Load	MWe	35.1	63.3
Total Plant Auxiliary Load	%	10.4%	10.4%
Plant Net Output	**MWe**	**302.5**	**545.5**
Net Plant Efficiency	%LHV	44.9	46.8
Net Plant Heat Rate	kcal/kWh	1915	1837
Coal Flow to Gasifier	t/h	47	94
Coal Flow to CFB or PC Boiler	t/h	36	51
Char Flow to CFB or PC Boiler	t/h	18	34
Limestone Flow to CFB	t/h	22	38
Total Plant Ash Discharge Flow	t/h	32	56
Steam Cycle		OnceThru Supercritical	
Steam Flow (SH/RH)	t/h	545/571	841/896
Steam Pressure (SH)	bar a	270	270
Steam Temperature (SH/RH)	°C	580/600	580/600
Condenser Pressure	bar a	0.042	0.042
Cooling Water System		Cooling Tower	
Estimated Plant EPC Cost	$/kWe net	1200-1400	1100-1300

Table 2

Predicted Plant Emissions				European Directive 2000/80/CE
	% Capture	kg/MWh	mg/Nm^3 @ 6% O_2 vol	mg/Nm^3 @ 6% O_2 vol
SOx	96	0.63	200	200
NOx		0.47	150	200
CO		0.47	150	
Hg	50		1 ppmv	
Particulate	99.995		< 20	30

The Virtue of PGCC Flexibility

Key virtues of PGCC are its operational, fuel and design flexibility. Unlike most other gasification technologies that require 100% of the plant's fuel to be gasified, the amount of gasification and combustion of the fuel within PGCC can be adjusted to optimize plant characteristics, such as plant output, reliability, efficiency and cost, to meet the needs of a specific project. This flexibility is a result of the limited integration among PGCC's three fundamental technologies (gasification, combustion turbine, and a steam plant).

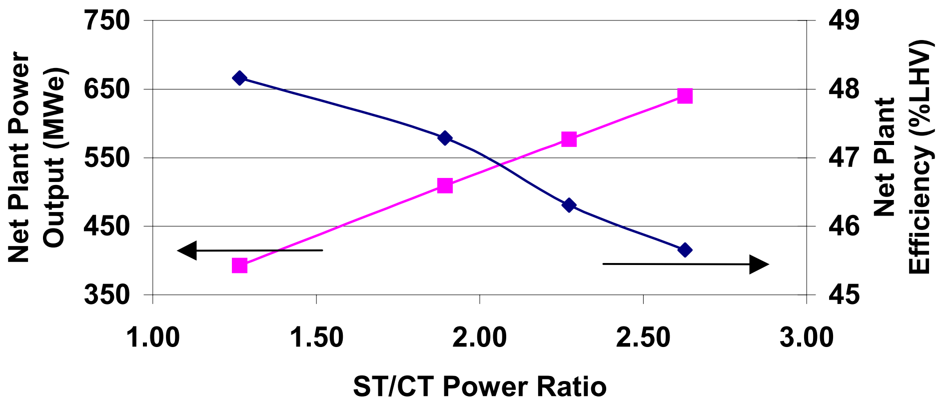
Both the CT and the steam plant can operate independently and separately from the each other or the gasification process. This gives power produces additional reliability, since alone, both the steam plant and the CT are proven commercial power generation technologies with established track records. Full plant power and efficiency can be achieved without the gasification system operating, and most importantly, with 65%-75% of this power derived from coal or other low cost fuels.

Very few design constraints are imposed on the steam plant in the PGCC configuration. For a given gasification and CT design, the steam plant can be sized as large as desired and designed for virtually any steam conditions (both subcritical and supercritical), as well as, designed for alternative fuels such as, waste coals, that may not be appropriate gasifier fuels. In contrast, for most other gasification technologies, the steam plant size is strictly determined by the CT size and the gasification system design.

For PGCC, the only significant design constraints for the steam plant is that it be large enough to receive the CT exhaust gas flow and burn the char from the gasification process. Any larger size is possible, giving designers the ability to custom size a plant for a given project. As the steam plant size increases, overall PGCC plant reliability is expected to increase since more plant power is derived from one mostly independent leg of the plant. However, increasing steam power also has the effect of reducing plant efficiency.

Overall plant efficiency falls since a larger proportion of the plant's power is coming directly from the less efficient Rankine cycle. This gives power generators the flexibility of trading off higher plant reliability against plant efficiency and lower emissions. Figure 6 shows the relationship between CT/ST power ratio and overall plant capacity and efficiency for the 609 MWe (GE 7FA) plant design. As can be seen, both plant power and efficiency are optimum when the steam turbine power is about twice the combustion turbine power. In contrast, NGCC plants typically have CT/ST power ratios between 0.5-0.6, nearly the inverse of PGCC plants. This is understandable since NGCC plants are designed primarily to achieve high efficiency instead of maximum power.

Figure 6. Steam to Gas Turbine Power Ratio Impact for GFBCC (600 MWe 7FA Design)



The Commercial Demonstration Opportunity

Development and pilot scale testing of PGCC technology has been conducted by Foster Wheeler over the last several years and the technology is ready for the next step: a full-scale commercial demonstration. Both FW and the Department of Energy (DOE) are committed to demonstrating this technology and are together searching for a host. To help break through the first-of-a-kind barrier, substantial DOE matching funds are available to the demonstration project host.

The design selected for the demonstration project is the 300 MWe GFBCC design utilizing the GE 6FA combustion turbine. A recent economic study of the demonstration project has shown that with the DOE funding the host can achieve 'all in' bus bar electricity rates 15-30 % below other conventional plant options for adding capacity. Of course, the savings opportunity depends very much on the specific project site ranging from repowering of an existing site to a complete greenfield application. Figure 7 summarizes the project schedule assuming a full project release by January 2003.

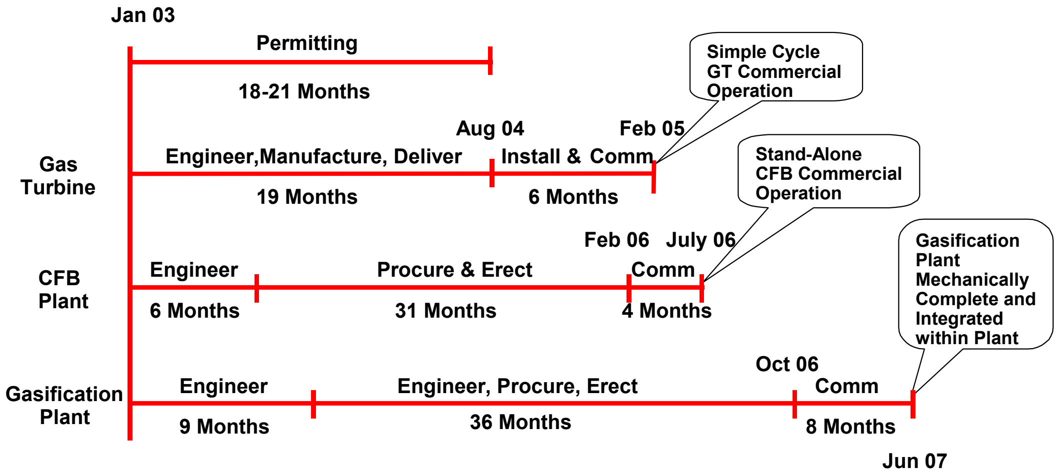


Figure 7
Estimated GFBCC Demonstration Project Execution Schedule

Final Remarks

More than just a gasification technology, PGCC is a platform that can be used as a pathway to ultra clean coal plants. It can be built today with existing technologies and achieve efficiency levels well beyond other coal technologies. For the future, its open platform can incorporate advances in gasification, combustion turbine, steam, and fuel gas cleaning technologies, setting the standard for future coal technology.