Technology Status and Project Development Risks of Advanced Coal Power Generation Technologies in APEC Developing Economies

APEC Energy Working Group
Expert Group on Clean Fossil Energy

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EXECUTIVE SUMMARY

This “Technology Status and Project Development Risks of Advanced Coal Power Generation Technologies in APEC Developing Economies” project, contract number PCS-APEC-0-LI-011-0004, examines the development status of advanced coal power generation technologies and the accompanying development risks of such technologies as they are adopted by the developing economies belonging to Asia-Pacific Economic Cooperation (APEC) region. As it is known to the international community, the Asia-Pacific Economic Cooperation is a forum for 21 Pacific Rim economies which organized themselves to regularly discuss the regional economy, cooperation, trade and investment. The membership of this group includes the following economies: Australia; Brunei; Canada; Chile; People’s Republic of China; Hong Kong, China; Indonesia; Japan; Republic of Korea; Malaysia; Mexico; New Zealand; Papua New Guinea; Peru; Philippines; The Russian Federation; Singapore; Chinese Taipei; Thailand; United States; and Viet Nam. Originally attended by 12 original member economies in 1989 during the first APEC meeting in Canberra, Australia, it has now grown to its present membership of 21 economies.

APEC works in three key broad areas to meet goals of free and open trade and investment in the Asia-Pacific by 2010 for developed economies and 2020 for developing economies, namely: (1) Trade and Investment Liberalization, (2) Business Facilitation, and (3) Economic and Technical Cooperation. The outcomes of these three areas would enable APEC Member Economies to strengthen their economies by pooling resources within the region and achieving efficiencies. Tangible benefits are also delivered to consumers in the APEC region through increased training and employment opportunities, greater choices in the marketplace, cheaper goods and services and improved access to international markets. It is on the basis of economic and technical cooperation, that efforts including this project, which is commissioned by the APEC Energy Working Group (EWG) Expert Group on Clean Fossil Energy (EGCFE), are pursued.

The methodology applied in getting information includes tapping information from various sources, such as the Internet, related studies coming from the APEC EGCFE and WorleyParsons databases. The study data collection also involves communicating directly with various power plants in the APEC developing economies, where these advanced coal power plant technologies are presently being developed. This study report cites the clean coal technologies (CCT) status in the APEC developing economies. Specifically, the following types of advanced coal power generation technologies are discussed in the Technology Status Review section:

- Supercritical (SC) pulverized-coal power plants
- Ultra-supercritical (USC) pulverized-coal power plants
- Integrated Gasification Combined Cycle (IGCC) plants and processes

The technology status review of these above technologies touches the historical backgrounds of each and progresses towards the most recent developments in each of these technologies. Although not dealing more deeply into technological discussions, the technology status review describes in brief advanced coal-based power generation technology cycle features and descriptions, current trends and future expectations.

Under the section dealing with advanced coal-based power technology project development risks, barriers and countermeasures are tabulated in Table 16, in which areas of concern are identified and perceived barriers are listed. Correspondingly, for each perceived barrier, suggested countermeasures are also proposed. The perceived project risks and corresponding proposals towards managing these risks are presented as they are seen in the light of current situations prevailing in the APEC developing economies. Likewise, the economic feasibilities of each of these three advanced coal power generation technologies are explored in this study report. The levelized life cycle cost of each of these technologies is evaluated, an effort which broadens the scope of the study into the economic aspect of project evaluation and technology assessment. In evaluating the levelized cost of electricity, multiple cost values are calculated, as derived from sensitivity case base assumptions. These levelized cost of electricity calculations with sensitivity cases are presented and discussed under Section 5 of this study report. The quantitative indicators and cost values of these advanced coal technology options are tabulated in each of the case studies discussed in Section 5.

In summary, this study shows the development status of the three advanced coal power generation technologies (Supercritical PC, Ultra-supercritical PC, and the IGCC) in the APEC developing economies. It identifies perceived barriers and offers countermeasures towards those barriers. Advanced coal power generation technology project risks and proposals to manage those risks are discussed. Likewise, project assessments are substantiated with calculated levelized cost values, including sensitivity case analysis based on key project parameters, such as installed cost, fuel cost and plant capacity factor.

Lastly, this report cites the future of coal to remain as a primary source of fuel for electricity generation in the APEC region, especially among the developing member economies. Coal as a source of energy is identified as a key factor for APEC developing economies, especially among the ‘emerging ones’ in sustaining their economic growth and developments. Of equal importance is the need for these APEC developing economies that depend largely on coal to keep up with the growing trend in the electricity generation industry to make significant strides in the area of emission mitigation. The Recommendation section of this report puts forward a number of suggestions which can serve as drivers towards the adoption of advanced coal-fired power generation technologies that can greatly contribute to cleaner coal utilization in the years to come.

Glossary of Acronyms

ACFBC	Atmospheric Circulating Fluidized Bed Combustion
AGR	Acid Gas Removal
APEC	Asia-Pacific Economic Cooperation
ASEAN	Association of Southeast Asian Nations
ASU	Air Separation Unit
AVT	all-volatile
b/d	Barrels Per Day
BGL	British Gas – Lurgi
BOP	Balance of Plant
BOT	Build Own Transfer
Btu/SCF	British thermal unit per Standard Cubic Foot
CBM	Coal Bed Methane
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Sequestration
CCT	Clean Coal Technology
CFB	Circulating Fluidized Bed
CEM(S)	Continuous Emission Monitoring (System)
CFD	Computation Fluid Dynamics
CER	Certified Emission Reduction
CO_2	Carbon Dioxide
COS	Carbonyl Sulfide
CTG	Combustion Turbine Generator
CWM	Coal Water Mixture
DNB	Departure from Nucleate Boiling
DOE	Department of Energy (USA)
EGCFE	Expert Group on Clean Fossil Energy
EIA	Energy Information Administration (USA)
EPC	Engineering, procurement, and construction
ESP	Electrostatic precipitator
EVN	Electricity of Viet Nam
EWG	Energy Working Group
FGD	Flue Gas Desulfurization
F-T	Fischer-Tropsch
FW	Foster Wheeler
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GT(G)	Gas Turbine (Generator)
GW	Gigawatts (Thousand MW or Million kW)
GWh	Gigawatt-hours (Million kWh)
H_2S	Hydrogen Sulfide
HEPSDI	Henan Electric Power Survey & Design Institute
HHV	High Heating Value
HP	High Pressure
HRSG	Heat Recovery Steam Generator
HTW	High-Temperature Winkler
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IP	Intermediate Pressure
IPP	Independent Power Producer
IPR	Intellectual Property Rights

KBR	Kellogg Brown & Root, Inc.
kW	Kilowatts
kWh	Kilowatt-hour
LHV	Low Heating Value
LNG	Liquefied natural gas
LP	Low Pressure
LPG	Liquefied Petroleum Gas
MBEL	Mitsui Babcock Energy Limited
MDEA	Methydiethanolamine
MHI	Mitsubishi Heavy Industries, Ltd.
MPa	Megapascal
MW	Megawatts (Thousand kW)
MWe	Megawatts of Electricity
NDRC	National Development and Reform Commission
NGCC	Natural Gas-Fired Combined Cycle
NOx	Nitrogen Oxides
NPHR	Net Plant
OECD	Organization for Economic Cooperation and Development
OEM	Original Equipment Manufacturer
OMB-CWS	Opposed Multi-Burner Coal-Water Slurry
OT	oxygenated treatment
O&M	Operation and Maintenance
PC	Pulverized Coal
PFBC	Pressurized Fluidized Bed Combustion
PRC	People’s Republic of China
Psia	Pounds-Force per Square Inch Absolute
R&D	Research and Development
RMB	Currency Unit of the People's Republic of China
SC	Supercritical
SCR	Selective Catalytic Reduction
SCGT	Simple Cycle Gas Turbine
SDEPCI	ShangDong Electric Power Engineering Consulting Institute
SRU	Sulfur Recovery Unit
STG	Steam Turbine-Generator
SXED	ShanXi Electric Power Design Institute
TTP	Thermal Power Plant
US or USA	United States of America
USC	Ultra-supercritical
VND	Viet Nam Dong
VT	Vertical Tube

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1 INTRODUCTION

The abundant reserves of coal in several of the Asia-Pacific Economic Cooperation (APEC) member economies make coal one of the region's most important resources for sustaining a viable and secure energy future. However, coal has its shortcomings, as it is widely known to produce pollutants when burned without careful handling, preparation and combustion control. It has proven to be affordable and reliable, yet harmful to long-term ecological preservation, if not handled properly.

There are alternatives to coal as fuel, such as fuel oil, natural gas, nuclear or renewable energy, yet there are equally challenging obstacles in these alternatives, such as high and fluctuating market prices; lack of assurance on continuity of supply; questions regarding safe storage and handling of wastes, in some cases, and lacking the economic viability for use in huge quantities over the long term. Therefore, coal remains a major energy resource, but at the same time, advanced technological means need to be adopted in order to control the polluting tendencies of burning coal.

The most widely known pollutants emanating from coal when it is burned as fuel are sulfur oxides, carbon compounds, nitrogen oxides, mercury and other metals, and particulates. Sulfur oxides contribute to acid rain when reacted in the atmosphere; carbon compounds, such as carbon dioxide (CO_2) are greenhouse gases; nitrogen oxides (NOx) cause smog.

However, science and technology can usually be used and adept at solving stubborn problems. In recent years, coal has been perceived as an undesirable fuel. Yet during this time there also have been marked advancements in technological research and applied sciences in the cleaner use of coal. For instance, Clean Coal Technologies (CCT) provide promising options, which keep coal competitive with other fuels for power generation. "Clean Coal Technologies" refer to a new generation of advanced coal utilization technologies that are environmentally cleaner and, in many cases, more efficient and therefore less costly than conventional coal-using processes. The use of advanced coal technologies such as Integrated Gasification Combine Cycle (IGCC) for power plants, or the construction of new coal-based power stations with supercritical (SC) or ultra-supercritical (USC) units, also mitigate the impact of burning coal. These CCT options also warrant substantial support for development.

This particular study focuses on advanced coal technologies now proven to have commercial viability and operational and technical reliability. As mentioned earlier, these advanced technologies are the IGCC, SC and USC coal-based power plant designs.

1.1 Background

During the Seventh Meeting of APEC Energy Ministers at Gyeongju, Republic of Korea on October 19, 2005, among one of the important points expressed by a joint message from APEC Energy Ministers was the following:

"The development and uptake of energy technologies will help APEC economies bring supply and demand into balance through increased production, diversification and efficiency and will reduce the environmental impact of energy production and use. It is estimated that adopting more advanced energy technologies could reduce growth in energy consumption of the region's electricity sectors by forty percent by 2030, saving more than 500 million tonnes of oil equivalent. APEC economies are global leaders in the development of many energy technologies, and the challenge is to leverage and build on this strength through effective cooperation and collaboration." [http://www.apec.org]

Likewise, two years later on May 29 2007 in Darwin, Australia, during the Eighth Meeting of APEC Energy Ministers, the following calls were made as stated hereunder:

"We also recognized the importance of our longer-term energy future of pursuing policies to promote the development of cleaner energy and the improvement of energy efficiency and conservation." During the same meeting the following was also stated: "We responded to APEC Leaders' instructions to report in 2007 on ways in which APEC might further contribute to policies and technologies that promote the development of cleaner energy and the improvement of energy efficiency, thereby enabling economies to meet increasing energy needs with a lower environmental impact and to address climate change objectives." [http://www.APEC.org]

It is basically along this line of purpose, as expressed by the APEC Energy Ministers during their two consecutive bi-annual meetings, that this study has been initiated by the APEC Expert Group on Clean Fossil Energy (EGCFE). This report will focus on the objectives as noted in the following section.

1.2 Project Objectives

The main objectives of this project are: (a) To survey and review recent experience in APEC economies regarding the development status of Integrated Gasification Combined Cycle (IGCC) plants and the implementation stage of supercritical (SC) and ultra-supercritical (USC) coal-based power generation plants in these various economies, and (b) After the collected information/data have been analyzed and synthesized, make recommendations regarding the appropriate drivers (policy measures or incentives) that can promote further use of these advanced coal power generation technologies in APEC developing economies.

These objectives are further elaborated below:

- To collect and assess information on accumulated experience in APEC economies with regard to the status, performance, relative costs, and project development/financing risks for IGCC, SC and USC power generating plants operating in different economies. Understandably, in searching for actual study cases, the project group, indeed, had, as a source of information, the entire APEC membership, encompassing the developed and developing economies, although to the extent possible preference was given to developing economies for case study choices.

- To make recommendations on policy measures and financial incentives needed to favor or foster projects, which utilize clean coal technologies in APEC economies, especially among the developing economies, where energy needs are expanding rapidly and coal is the fuel of choice. In this particular portion of the objective, the recommendations on policy measures and financial incentives were aimed and expressed to be more attuned to the conditions prevailing in APEC developing economies.

- To support APEC-EGCFE in the dissemination of recommended steps and measures, which promote greater deployment of advanced coal power generation technologies.

1.3 Scope

Activities conducted in this project are listed hereunder:

- Review existing experience in the commercial application of clean coal technologies for power generation within APEC and even beyond the boundaries of APEC, if only for comparison and reference, such as those belonging to the Organization for Economic Cooperation and Development (OECD) economies, and other international organizations.

- Identify barriers of implementation of commercial projects using clean coal technologies in APEC developing economies.

- Identify a number of suitable projects as case studies to illustrate the experience in advanced coal power generation technologies.

- Identify and collect relevant information/data needed for the case studies.

- Develop a framework that can be used for reporting the elements of the case study projects. The framework is intended to facilitate the comparative analysis among options/cases from where lessons can be drawn for future projects. The list of inputs includes:

    (a) Project Name/Identification
    (b) Project Participants
    (c) Project Cost
    (d) Performance of the Project
    (e) Identified Project Risk(s)
    (f) Risk Management
    (g) Nature of the barriers to Clean Coal Technology
    (h) Present measures (if any) used to alleviate the presence of these barriers

2 STUDY METHODOLOGY

The challenge of this study is to obtain information, which are extensive enough to cover the topics and sufficiently accurate to reflect the reality in those APEC economies covered by this study. The information was collected from following sources:

- EGCFE Reference Documents
- Information Sources from APEC and OECD
- Power Utility Companies
- Governmental Institutions
- Academia
- Experts
- Organized Groups
- Domestic/Local Media
- International Sources
- Organization for Economic Cooperation and Development (OECD)
- Other International Bodies/Groups
- Internet/Public Libraries/Visiting Technocrats from APEC Economies
- Personal communications
- WorleyParsons data bases

The collected information/data were screened and verified. Only those APEC developing economies which provided sufficient information for this study have been included. For instance, three study cases are based on the ongoing projects in Peoples Republic of China (PRC) because all three technologies, SC, USC and IGCC are being developed in that APEC economy and some information are available in the public domain. The approach of selecting three study cases from a single economy assures consistency of the evaluation of the three cases. The discussions regarding barriers to technology transfer, project risks and countermeasures, etc. are presented in a manner that can apply to any APEC developing economies.

Technology is a very effective tool in pursuit of information for survey materials. The Internet has contributed significantly both as a direct and indirect source of information from the public domain for materials pertinent to this study. Electronic communications through the worldwide web and other means of telecommunications made easier the study group's effort to reach out to people who hold vital information pertaining to key study materials. Equally important to the study group's effort was the special opportunity to meet with a delegation from the coal-based power generation industry of the People's Republic of China. The delegation comprised a number of power plant engineering and construction experts, who visited WorleyParsons, Reading, Pennsylvania, USA in December of 2007. They were interviewed and in return they had provided the members of the project study group a great amount of insight regarding the latest developments in the coal-based power generation sector in China. That valuable meeting with the Chinese delegation led to obtaining direct information from a vital APEC emerging economy, and those exchanges of information and ideas were documented and used as one of the references of this study.

The qualitative inputs—both positive and negative—for each of these advanced coal technologies, i.e. supercritical pulverized-coal, ultra-supercritical pulverized-coal or Integrated Gasification Combined Cycle, are obtained from recent studies. The outcomes of these recent studies were evaluated and were used as reference in this report. The sites of power plants that were used as reference for these advanced coal-based power technologies are mostly outside of the territories of the APEC developing economies. Where there were some studies identified as being sourced from an APEC developing/emerging economy, the final reports for such studies were sought and copies of such were obtained to serve as reference material for this work.

Where economic assessments were required in the study, a tool for evaluating the economic feasibility of a project was selected from a number of economic study approaches. An EXCEL spreadsheet program that calculates the Levelized Life-Cycle Cost of a power plant project was used in calculating key project viability indicators. The Levelized Life-Cycle calculation process is method known to the industry as a good approach to assess utility project economic feasibility. However, a number of parameters used in this report are assumed, given the hesitancy on the part of the base source information holders, who were concerned about releasing what they considered confidential information. An example of this information was the percentage of a plant's capital that was sourced through loans. Power plant sites either do not have ready access to this information or are not at liberty to release the figures. Likewise, tax figures are not readily obtainable. However, in reality most of the information relative to economic data can now be predicted with a fair amount of accuracy by using recent studies released into the public domain, i.e., Internet.

The results of the comparative analysis between the strengths and financial competitiveness of each technology option are presented in the case study section. On the other hand, sensitivity analyses are undertaken to measure the span of life-cycle cost stability under certain conditions. These conditions include parametric variables, such as installed cost or fuel prices that could significantly affect outcomes of project desirability. Multiple modes of sensitivity analyses were also conducted. As an example, major cost parameters like fuel costs and operating availability were varied to find out the impact on the levelized life cycle costs of the projects.

The results of the case study analyses are shown in Section 5: Economic Evaluations of Coal-Based Generation Options. Supporting calculations to the base cases for the three technology options are attached in the Appendix Section. As it can be seen, the base cases do not provide the best life cycle costs among the sensitivity sets presented in this report. It is so because the sensitivity adjustments were biased towards better conditions, i.e., lower fuel prices, reduced capital costs and improved plant capacity factors.

It is also important to note that all of the study case bottom-line data that are presented in the economic evaluation (case studies) section, including those of the sensitivity sets, are calculated using a uniform 15 percent rate of return on equity. It is done this way because relatively new technologies usually carry with them some degree of risk, which tends to lessen the attraction and excitement of potential stakeholders to such advanced technology coal-based power generation ventures. A business venture with a 15 percent return on equity can be competitive enough to draw more capital from potential stakeholders.

3 TECHNOLOGY STATUS REVIEW

This part of the report is presented to give a short review of these advanced coal technology status in the APEC member developing economies. The status of each technology in these developing APEC economies can be expected to move forward under different paces of development, depending on the economic strength and other logistical factors inherent to each APEC member. One factor affecting the direction of technology development in the coal power sector, for example, is the change in the fuel market landscape with the emergence of natural gas and the increasing importance attached to protecting the environment. For this matter, the coal industry has slowed in pace and although coal is still comparatively lower in cost, it has failed to compete with clean burning natural gas. However, the rise in price of natural gas and the increased focus on reduced emissions, while at the same time coal reserves are identified to be widespread and abundant, have fueled the heightened interest for continuing research and development of a number of advanced coal-based power generation technologies. Three of these advanced technologies, which are considered to have gained substantial inroads into commercial scale operations, are given special focus in this study. These are: the Integrated Gasification Combined Cycle (IGCC), the supercritical (SC) pulverized-coal, and the ultra-supercritical (USC) pulverized-coal-based power generation technologies. All three technologies could contribute greatly to the push for clean coal technology (CCT). These three advanced coal power generation technologies are given a short status review in the following paragraphs.

3.1 Summary of APEC Electric Energy Generation and Coal Consumption

It is difficult to equate the figures directly between APEC and global electricity generation and coal consumption in the sense that not all coal consumed in any economy are utilized for electric power use. However, the following tables are indicative of how coal plays a major role in the energy picture of the global stage. These tables do not identify how much of the electricity generated by thermal sources are coal, considering that natural gas and liquid fuels also fall under thermal fuel categories.

Table 1 World Total Net Electricity Generation

Source: Energy Information Administration (Billion Kilowatthours)
Table Posted: September 13, 2007

	For Year 2005	% of	For Year 2005	% of
APEC Member Economies	All Energy Sources	Total	Thermal Sources	Total
Australia	236.68	1.36	218.37	1.91
Brunei	2.74	0.02	2.74	0.02
Canada	609.60	3.51	152.24	1.33
Indonesia	120.33	0.69	103.4	0.90
Japan	1024.61	5.91	645.5	5.63
Republic of Korea	366.22	2.11	222.72	1.94
Malaysia	82.36	0.47	76.63	0.67
New Zealand	41.59	0.24	14.37	0.13
Philippines	53.67	0.31	35.96	0.31
Singapore	35.92	0.21	35.92	0.31
Thailand	124.59	0.72	115.72	1.01
U.S.	4061.98	23.41	2909.99	25.40
People's Republic of China	2371.83	13.67	1922.14	16.78
Hong Kong,China	36.14	0.21	36.14	0.32
Chinese Taipei	210.30	1.21	165.5	1.44
Mexico	222.40	1.28	175.23	1.53
Papua New Guinea	3.70	0.02	2.77	0.02
Chile	48.16	0.28	23.5	0.21
Peru	24.97	0.14	5.06	0.04
Russia	904.40	5.21	588.42	5.14
Vietnam	51.33	0.30	30.09	0.26
Total APEC	10633.52	61.29	7482.41	65.32
Total WORLD	**17350.58**	100.00	**11455.26**	100.00

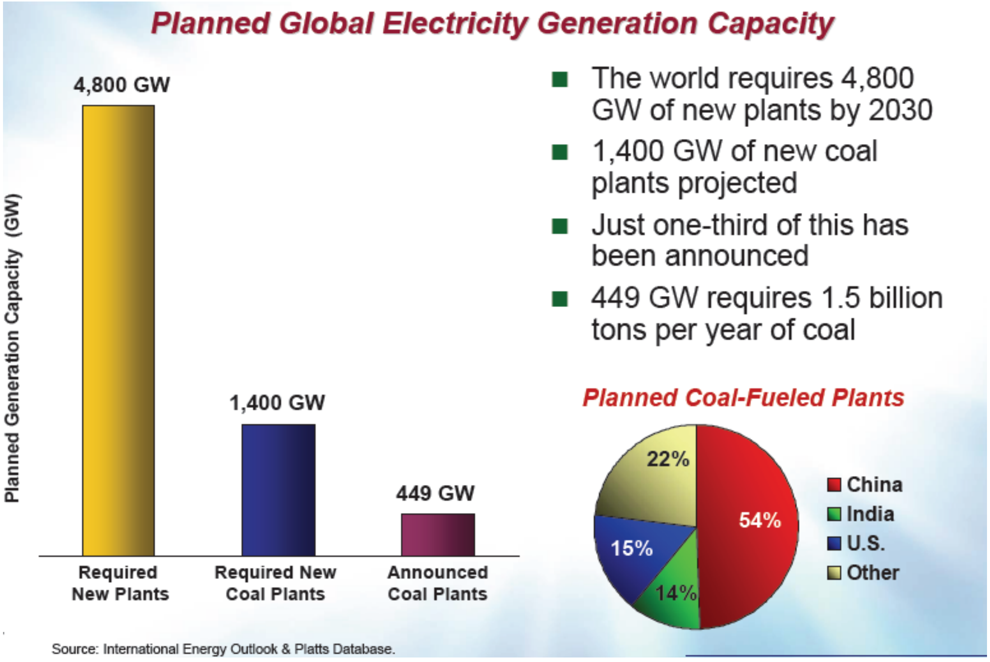
Table 2 World Total Coal Consumption

Source: Energy Information Administration
Table Posted: September 13, 2007 (Million Short Tons)

	For Year 2005	% of
APEC Member Economies	Coal Consumption	Total
Australia	158.150	2.44
Brunei	0.000	0.00
Canada	66.774	1.03
Indonesia	45.273	0.70
Japan	196.282	3.03
Republic of Korea	91.065	1.40
Malaysia	12.045	0.19
New Zealand	3.447	0.05
Philippines	11.813	0.18
Singapore	0.003	0.00
Thailand	33.248	0.51
U.S.	1125.476	17.36
People's Republic of China	2332.908	35.99
Hong Kong, China	11.933	0.18
Chinese Taipei	65.265	1.01
Mexico	19.907	0.31
Papua New Guinea	0.000	0.00
Chile	6.662	0.10
Peru	1.474	0.02
Russia	258.373	3.99
Vietnam	15.995	0.25
Total APEC	4456.093	68.74
Total WORLD	**6482.966**	100.00

In the long term, the prospect for coal as fuel for power generation is promising considering current plans to put up new power plants as indicated in the following figure taken from the International Energy Outlook & Platts Database.

Table 3 Outlook of Coal in Global Long-Term Power Generation



Source: International Energy Outlook & Platts Database.

3.2 Overview of CCT Status in APEC Developing Economies

1) People's Republic of China (PRC)

Being the world's most populous economy and now well known to have the highest electric power generation growth this decade and even beyond, the People's Republic of China (PRC) is the second largest consumer of primary energy, ranked after the United States. It is of advantage to the PRC that coal is one of its abundant natural resources and for this reason, coal comprises the bulk of its primary energy consumption; hence, PRC is both the largest consumer and producer of coal in the world. The People's Republic of China is also the world's second largest producer of electricity after the Unites States. Based on the source sited herein, the PRC's total generated electricity in 2006 was 28344 billion kWh, in which 78 percent was from coal power plants *[Data Source: www.serc.gov.cn]*. Considering the huge amount of coal consumption to match its economic growth rate, the PRC's environmental problem has been a concern to the international community. To a large extent, the use of coal as fuel for electric power generation, contributes to atmospheric environmental pollution, especially if such burning of coal is done inefficiently and if the combustion gases are allowed to escape to atmosphere without the proper methods of mitigating emission levels. Soot-type pollution associated with coal burning is the main source of air pollution in the PRC. Its carbon dioxide emissions are the second highest in the world, and the areas affected by sulfur pollution, in the form of acid rain, represent about 40% of its whole territory. PRC's coal combustion causes 80 percent of smoke and dust, 90 percent of sulfur dioxide, 79 percent of carbon dioxide, 82.5 percent of carbon monoxide and 70 percent of nitrogen oxides *[Jin and etc, 1999]*. It is estimated that, China's power generation capability will increase to 2,300 GW, and coal power plants will produce 63 percent of the total generated electricity, with a slightly falling percentage but increasing coal power capacity in 2030 *[http://www.chinairn.com]*.

In the early 1990s, the Chinese central government mapped out PRC's "Agenda 21," establishing a sustainable developmental strategy. Clean coal technology is an important element of the agenda. It has become a central strategic option of PRC's future energy development, given the nation's increasing electricity demand and its booming economy. The People's Republic of China has developed its categories of Clean Coal Technology (CCT), which include the following:

- Coal preparation technology
- Coal water mixture technology
- Coal briquetting technology
- Coal gasification technology
- Coal liquefaction technology
- Pressurized fluidized bed combustion (PFBC)
- Atmospheric circulating fluidized bed combustion (ACFBC)
- Coal bed methane (CBM) exploitation and utilization
- Flue gas desulfurization (FGD)
- Utilization of fly ash and coal refuse
- Pollution control measures for industrial boilers and kilns
- Integrated Gasification Combined Cycles (IGCC)
- Supercritical and ultra-supercritical power generation

The activities in the Clean Coal Technology (CCT) areas are summarized in following paragraphs.

(1) Coal washing, - This activity reduces the amount of ash in the raw coal to facilitate combustion and increases the energy content per ton. Coal washing technologies are well established in the PRC. Due to efforts to enforce the environmental protection policy, the proportion of washed coal reached 33.78 percent in 2003 *[CCICED, 2004*]. However, coal-washing technology in the PRC still has room for further improvement. More modern washing processes are needed to decrease the amount of water required and to increase the effectiveness of ash and sulfur removal. These improvements will depend upon the further development of existing equipment designs.

(2) Coal Water Mixture (CWM) technology – It began in the 1980s and has now entered the stage of commercial demonstration. The preparation technology for CWM with high concentration, originated by the People's Republic of China, has reached the world advanced level. However, due to insufficient attention given to market conditions, the demand for CMW has not materialized despite various efforts of the government *[Minchener, 2004]*. Future development will be focused on the study of highly efficient but inexpensive additives, advanced CWM gasification technologies, large scale oil-substituted CWM combustion processes and equipment and construction of projects for converting oil-fired power plant boilers into CWM-fired boilers.

(3) Coal Briquetting - Coal briquettes have advantages both in economics of transportation and utilization and applicability for environmental protection. Briquetting processes make coal cleaner through adding desulfurizing adsorbent and removing the ash content of the finished products. Coal briquetting technology is a mature technology in the PRC. The production

capacity of household briquettes in the PRC is 50 million tons per year, enough to supply 35% of consumption. However, Chinese industrial use of briquettes is limited. The main industrial consumers are gasification plants (22 million tons per year) and combustion boilers (2 million tons per year).

(4) Coal Liquefaction - It provides an efficient way to reduce PRC's reliance on crude oil imports. Coal liquefaction can be categorized into direct liquefaction and indirect liquefaction. Coal liquefaction projects are being built or proposed in China. The large-scale Shenhua direct liquefaction project is expected to be put in operation in September 2008. In April 2008, the Yulin 250,000-ton/year indirect liquefaction demonstration unit was successfully started. The construction of the second phase 500,000-ton/year unit is expected to be started soon *[http://www.tfcoal.com/Article/HTML/5825.html]*. Two other ongoing coal liquefaction projects are the Shanxi Luan coal liquefaction project and the Neimeng Yitai coal liquefaction project *[http://www.djtz.net]*. It is estimated that by 2013, 10 percent of PRC's oil imports will be replaced by coal-liquefied oil *[People's Daily Online, 2005]*.

(5) Circulating Fluidized Bed (CFB) – CFB combustion has the capacity to burn low grade and difficult fuels and meet emission limits at reasonable efficiency. It also has the advantage to reduce emissions of other pollutants. In past decades, Chinese engineers have developed their own designs of small fluidized bed boilers. Currently, efforts are being made to apply fluidized bed combustion technology on larger scale and higher operating parameters. Further development of the CFB technology, which promises great economic and social benefits, is needed in the PRC, the said APEC member economy now being focused on wider utilization of low-grade coal. A number of 'industrial-scale' fluidized beds have been constructed or planned in the PRC as a result of licensing agreements between Chinese and international suppliers. By the end of 2007, near 200 CFB boilers for power generation units with capability of producing 100 MWe have been manufactured including more than ten 300 MWe class boilers. Recently, a 300-MWe CFB power generation unit, the biggest CFB unit employing China's intellectual property rights, just started construction in 2007 in Fenyi, Jiangxi province. Pressurized CFB boilers also are being developed. A 15-MWe pilot pressurized fluidized bed combustion power plant has been built on the site of Jiawang power plant, and it is targeted to introduce 100-MWe class PFBC *[Zheng, 2003]*.

Due to the urgent need to reduce environmental pollution and increase efficiency of the power generation, PRC is actively developing and applying more advanced coal technologies. The PRC's equipment manufacturers have been working with manufacturers from developed economies to fabricate the supercritical and ultra-supercritical units locally. This greatly reduced the cost of applying the technologies and, hence, many supercritical and ultra-supercritical units have been or are being built nationwide during the last decade. More information about the development status of supercritical and ultra-supercritical coal power generation technologies is presented in Section 3.4.

(6) Integrated Gasification Combined Cycle (IGCC) – The People's Republic of China also shows great interest in Integrated Gasification Combined Cycle (IGCC) technology. With years of experience in gasification application in the chemical industry, local manufacturers are developing gasifiers and other key equipment for IGCC and have made important progress. Recently, several IGCC plants were under construction or proposed, including three ongoing demonstration plants supported by the Nation's 11th 5 Year Plan (2006-2010). More information about IGCC technology development in China is presented in Section 3.3.

2) Indonesia

This APEC-member developing economy has the 4th highest population after the People's Republic of China, India, and the United States of America in that order. Having this large number of population puts Indonesia under pressure to sustain the generation capacity expansion needs of the electricity power sector. Therefore, it is a great strategic advantage that this developing APEC economy has such a huge deposit of coal, which is a primary source of fuel for power generation. Indonesia is the world's biggest coal exporter today. In 2008, around 85 percent of Indonesia's coal, including 7 billion tons in reserves and an estimated 61 billion tons unmined, is considered to be low grade, requiring greater volumes of coal per unit of power produced *[http://aseanenergy.org/news/?p=1122]*. Coal power plants only occupy a relatively small portion of the total generated electricity in Indonesia. For instance, by 2001, total installed power plant capacity outside Java Bali is 5,385 MWe. Of that, Diesel Plants contribute 45 percent, followed by Combined Cycle Gas Turbines (CCGT) & Simple Cycle Gas Turbines (SCGT) 27 percent , Steam Power Plants 14 percent , Hydro 13 percent and the remaining 1 percent is comprised of geothermal, solar and others *[Sastrawinata 2001]*. However, with increasing oil and gas prices, Indonesia is reviewing the generation of power using domestic coal. Utilizing available local coal is the Government of Indonesia's long-term energy strategy *[http://www.Jakarta Post.com]*. This resulted in the initiation of the National Coal Policy, which is carried out through three stages from 2003 to 2020 *[Tjetjep, 2004]*.

The objectives of the National Coal policy are:

- The implementation of sustainable exploration and exploitation
- Mastering coal utilization technology
- Development of the capability for utilization of low-rank coal (lignite)
- Utilization of clean coal technology
- Establishment of a Clean Coal Technology Center
- Defining national coal legislation

Implementation of The Nation Coal Policy will be carried out through three stages:

- Short term (2003 – 2005)
- Middle term (2005 – 2010)
- Long term (2010 – 2020)

The implementation of coal technology utilization will be achieved through:

- Building pilot plant of coal briquette
- Building pilot plant of bio-coal briquette
- Direct usage of coal
- Coal gasification
- Use liquefied coal fuel
- Build pilot plant of upgrading brown coal

Recently, because of the power shortage in the nation and the price competitiveness of coal, a so called "10,000 megawatt crash" program was initiated by the government. The program aims at building coal power plants with total generation capacity of 10,000 MWe by 2010. In January 2008, the state power company, Perusahaan Listrik Negara (PLN), said it had secured loans for the construction of its five coal power plants to be built under the program. Financing of the remaining plants was expected to be secured soon *[www.Jakarta Post.com]*. Some of the planned plants under the program are:

Name	Location	Capacity (MWe)
Rembang plant	Central Java	600
Indramayu plant	West Java	600
Labuan plant	Banten	600
Paiton Baru plant	East Java	600
The New Suralaya plant	Banten	600
Pacitan plant	East Java	600
Pelabuhan Ratu plant	West Java	900
Teluk Naga	Banten	900
Tanjung Awar-awar plant	East Java	600

3) Mexico

This developing APEC-Member economy is the 11th most populous country in the world at close to 107 million population, according to a projection by Mexico's *Instituto Nacional de Estadistica y Geografia* (INEGI). Just like any other populous economy, Mexico is faced with a great challenge to meet the electricity needs of a growing population. The total power generation for 2004 in Mexico was 224,077 GWh, which is a 2.9 percent increase from 2003. Most of the power was generated by thermal generation (82 percent). Gas remains the dominant fuel used with 39 percent of the generation in 2004, followed by oil (31 percent), hydro (11 percent), coal (11 percent), nuclear (4 percent), new and renewable energy (3 percent). The contribution of coal power plants to Mexico's electricity generation has declined from 14.3 percent in 2003 to 10.7 percent in 2004, mostly as they have been replaced by natural gas and hydro.

More recently, the nation's first supercritical coal power plant is being built in Mexico City *[http://www.japancorp.net/Article.Asp?Art_ID=11851]*. This is a full-turnkey project that is being executed by Mitsubishi Heavy Industries, Ltd. (MHI). It will have the capacity to generate 700 MW (megawatts) of electricity, making it one of that nation's largest power plants. Operation is scheduled to commence in February 2010.

At this point of time only some research activities on Integrated Gasification Combined Cycle technology is undertaken in Mexico. Energy companies in Mexico showed interest in IGCC technology *[Altamirano-Bedolla and etc., 2007]*.

4) Philippines

The Philippines is another highly populated developing APEC-Member economy with a population of around 90 million and ranked the 12th most populous country in the world. As an economy comprising thousands of islands across its territory, it becomes a strong challenge for the electricity power generation planners and operators to strategically locate power stations in order to fully utilize and balance generation and transmission requirements. In 2004, total electricity generation reached 55,957 GWh. Thermal power generation is mostly derived from fuel oil and coal, which accounted for 66 percent of electricity production, followed by hydropower (15 percent) and others (18 percent).

Total in-situ coal reserves of the Philippines stand at 349 million metric tons in 2005. Total coal production of 47.2 MMMT is expected to fuel the coal power plants scheduled for commissioning within the ten year period. In boosting local production, the Philippine Department of Energy will conduct studies to identify additional coal exploration areas. The application of clean coal technologies will be a continuing strategy employed to provide a market for low-rank domestic coal.

The economy will continue to increase the utilization of indigenous fossil fuel reserves and also aggressively develop its Renewable Energy (RE) resources such as biomass, solar, wind and ocean resources. Furthermore, the use of alternative fuels will be increased and energy efficiency and enhancement programs will be strengthened and enhanced. The economy is targeted to achieve a 60 percent self-sufficiency level by 2010. In order to achieve this target, in the next ten years the economy is aiming to increase oil and gas reserves by 20 percent, reduce coal imports by 20 percent and increase Renewable Energy-based capacity by 100 percent. In addition, some oil-based power plants will be converted to natural gas-based power plants and targeted to be completed by 2010.

5) The Russian Federation

Although considered as a developed economy within the APEC group, the Russian Federation is included in this section of the report as a gage of development vs. its southern APEC member neighbors, namely: the PRC and the other South-East Asian economies. The Russian Federation coal power plants account for 16.7 percent of the total power generation in 2005. The largest portion of the electricity generation is from gas-fired power plants *[Siberian Coal Energy Company, 2006]*. In the next decade, both coal production and coal power generation are projected to increase mainly due to the increasing gas price and the fact that the Russian Federation possesses large coal reserves. Generally, existing Russian coal power plants have been operating for so many years now. About 60 percent of the installed units are more than 30 years old. Having been in service for quite sometime, these older power plants are now having low average efficiencies and high maintenance costs *[Kakaras and etc]*.

Coal power generation in Russia is expected to continue due to the very low cost of electricity produced by these plants – lower than in gas-fired combined cycle plants. However, it is not likely that many new conventional coal power plants will be built in the future. There is a range of new design solutions, which have been developed in the framework of the National Scientific Research Program, “Environmentally Friendly Energy.” The program is meant to promote development and introduction of new solid fuel combustion technologies into industrial production. This program is financed from the state budget and is currently pursued at a slow pace, due to the scarcity of available funding. Some design solutions supported by the program are *[Kakaras and etc]:*

- 800-MWe brown coal power generation unit with gradual combustion of preheated coal dust and fabric filters for ash and sulfur dioxide collection
- 300-MWe coal-Integrated Gasification Combined Cycle power generating unit
- 300-MWe coal unit using anthracite and bituminous low quality coals as a fuel combusted in a furnace with circulating fluidized bed

Despite the urgent need to reduce environmental pollution and increase efficiency of power generation, the relatively low electricity production cost in coal power plants will keep those plants in operation for several years to come. Further improvement of the economic situation in Russia should encourage wider introduction of gas-fired combined cycle plants. Coal - Integrated Gasification Combined Cycle power generating technology will have little chance in the market in the years immediately ahead, if investment decisions by the utilities are made strictly based upon price considerations. This will heavily affect technology development and manufacturing companies. Russia has extensive experience in the construction of large, efficient, supercritical pulverized coal power plants and is seeking to construct advanced supercritical units. The main areas where Western experience can be applied to these plants lie in emissions abatement systems, control and instrumentation and in operator practices applicable to a privatized generation market. The preferred technology for new coal power plants is likely to be supercritical pulverized coal-fired units, where low sulfur coal is available, and likewise circulating fluidized beds for higher sulfur coals *[Kakaras and etc]*.

6) Viet Nam

With the United Nation's estimated Viet Nam population figure of 87 million, Viet Nam is ranked number 13th most populous economy in the world. With a great number of people coupled with its rapid economic growth of 7.5 percent per annum over the past decade, just like its neighboring APEC developing member economies, Viet Nam is faced with a great challenge to meet a huge increase in electric power generation requirement in the immediate future. More specifically, with continued economic growth comes an estimated 16 percent per annum increase in power demand. To address power demand requirements, the Viet Namese government prepared the 6th Power Development Master Plan (PDMP). The plan identifies the need for new power generation, transmission, and distribution projects to be implemented to meet the nation's growing power demands.

In 2006 Viet Nam's power system had a total installed capacity of 11,340 megawatts (MWe), of which almost 78 percent or 8,822 MWe is generated by EVN, a state owned company. According to EVN, approximately 61 percent of Electricity of Viet Nam (EVN)'s installed capacity is with Thermal Power Plants (TPPs) including coal, oil, and gas-fired power generating plants. The environmental problems in existing TPPs were partly due to poor maintenance of equipment and out-of-date designs and technologies. EVN's management decided to introduce new combustion technology and design for its new coal-fired TPPs to achieve higher thermal efficiencies, and to incorporate environmental abatement equipment in project designs to minimize the adverse environmental impacts. For instance, the Mong Duong power plant will use circulating fluidized bed technology to efficiently burn domestic coal. The project is designed to ensure that emission standards for sulfur dioxide, nitrogen dioxide, and particulate matter are complied with. EVN has also decided that new coal power plants to be built in central and southern Viet Nam will all use supercritical boiler technologies and burn imported coal. The coal power plants are expected to eventually account for 22 percent of Viet Nam's total installed generating capacity by 2015 and 34 percent by 2020 *[Asian Development Bank-Technical Assistance Report, 2007]*. Recently, two 100-MWe coal power plants at Cao Ngam and Na Duong being built by VINACOAL will use circulating fluidized bed combustion technology *[IRG 2007]*.

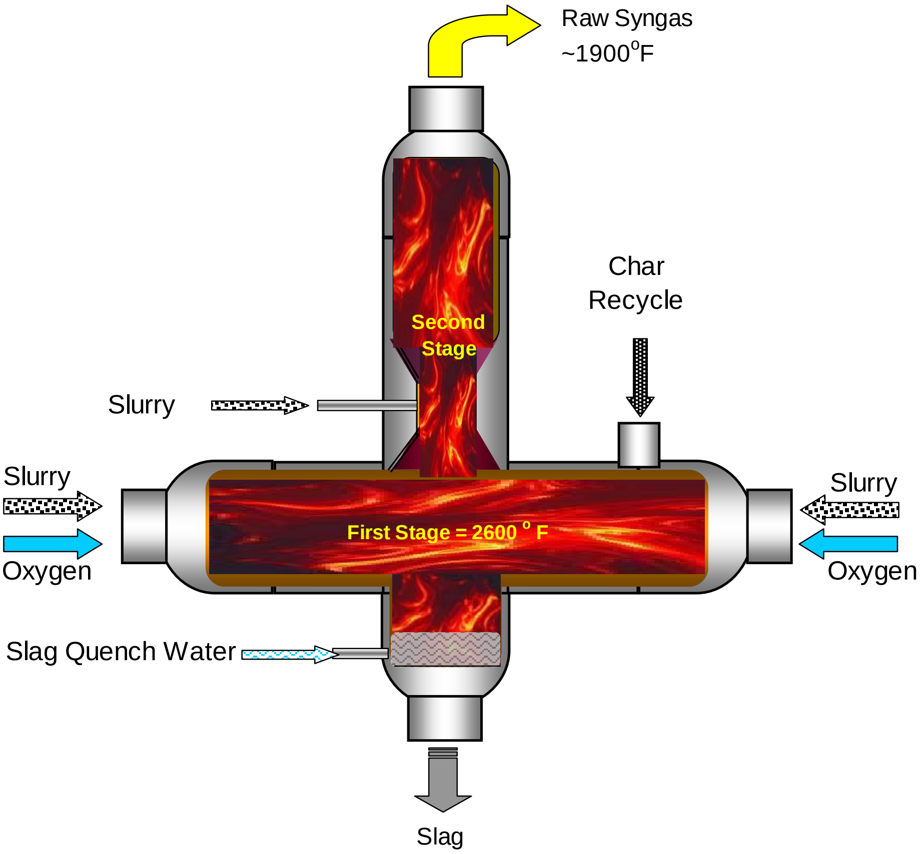
3.3 Integrated Gas Combined Cycle (IGCC) Technology

Coal gasification is the process of converting coal into a gas, called synthesis gas or syngas that can be used for a number of purposes, including electric power generation. So far the most successful method of producing electric power with coal gasification is the Integrated Gasification Combined Cycle (IGCC) process. IGCC is an emerging advanced power generation system that has the potential to generate electricity from fossil fuels, such as coal, with high efficiency and low emission levels.

The first part of the IGCC process involves the chemical conversion of coal into syngas, which is a mixture of hydrogen and carbon monoxide. This reaction occurs in a gasifier, shown in Figure 1, using very high temperature and only a limited amount of oxygen. When the syngas leaves the gasifier, it is cooled and cleaned of contaminants, such as sulfur, ammonia, chlorides, and particulates, so that it can be used to generate electricity in a combustion gas turbine generator (CTG). In the process, ash forms a slag that is removed from the gasifier for disposal or commercial use. The sulfur compounds, after being stripped from the syngas, are converted to elemental sulfur. This can be marketed commercially. The exhaust from the CTG, still containing a substantial amount of heat, is then directed to a heat recovery steam generator (HRSG) to produce steam that drives a steam turbine-generator (STG). The use of combined cycle technology, together with coal gasification, significantly improves the efficiency of utilizing coal for electric generation with very low emission levels.

At this stage of its technological development, IGCC appears to have a promising role as an alternative power generating source at commercial scale and be competitively strong for the future. IGCC plants are now claiming reduced CO_2 emissions in solid wastes and higher efficiencies when compared to conventional coal plants *[Doucet, 2005]*. IGCC plants also have lower capital costs potentially for adding CO_2 capture processes.

Figure 1 A Cross-sectional Illustration of a Gasifier
(ConocoPhillips E-Gas^{TM} Technology)



3.3.1 Overview and Early Developments of Coal Gasification

According to records, coal gasification was started in the early 19th century. The process was intended to create “town gas,” which mostly is comprised of hydrogen, carbon dioxide and methane. The first recorded public street lighting with town gas was in Pall Mall, London, on January 28, 1807. Thereafter, Baltimore in Maryland began the first commercial street lighting using syngas in 1816. Meanwhile, in Germany, Friedrich Bergius launched the German program for energy independence with the invention of high-pressure coal hydrogenation in 1810. In 1887, the first patent for a gasifier was granted to Lurgi GmbH in Germany. Then, Franz Fisher and Hans Tropsch built on the process by developing the synthesis of liquid fuels in the mid-1920s. Subsequently, coal gasification became widespread in the 1930s. In the 1940s, commercial coal gasification, to provide cities with gas for streetlights and domestic consumption, became common in Europe and the United States. In the early 1950s, refineries utilized gasification in order to dispose of low value refinery byproducts in the process of producing hydrogen and other kinds of chemical feed stocks. Then in the 1970s, Shell, Texaco, and Dow Chemical began to develop solid fuel gasification technology to replace natural gas. This interest in developing solid gasification technology was driven by the rising prices of fuel gas during that period. Eastman Chemical Company built the first commercial scale coal gasification plant in

1984 at Kingsport, Tennessee using syngas as a feedstock replacement for natural gas to make chemical products. These early beginnings formed the bases of the modern syngas process.

3.3.2 Venturing into Integrated Gasification Combined Cycle Concept

Gasification of coal for the main purpose of producing syngas dedicated to generate electric power right at the site of syngas production, while at the same time utilizing the concept of combined cycle (Brayton and Rankine Cycles) for more efficient syngas utilization, is an idea that has come of age. The basic IGCC concept was first successfully demonstrated at commercial scale at the pioneer Cool Water Project in Southern California from 1984 to 1989. There are currently a number commercial sized coal-based IGCC plants in the U.S. and several in Europe as well. The two projects in the U.S., Wabash River IGCC and Polk Power Station IGCC, were supported initially under the DOE's Clean Coal Technology demonstration program. They are now operating commercially without DOE support. The 262-MWe Wabash River IGCC re-powering project in Indiana started up in October 1995 and uses the E-Gas gasification technology (which was acquired by ConocoPhillips in 2003). The 250-MWe Tampa Electric Company Polk Power Station IGCC project in Florida started up in September 1996 and is based on ChevronTexaco gasification technology. The first of the European IGCC plants was the NUON (formerly SEP/Demkolec) project in Buggenum, the Netherlands, using Shell gasification technology. It began operation in early 1994. The second European project, the ELCOGAS project in Puertollano, Spain, uses the Prenflo (Krupp-Uhde) gasification technology and started coal-based operations in early 1998. In 2002, Shell and Krupp-Uhde announced that henceforth their technologies would be merged and marketed as the Shell gasification technology *[Booras, 2004]*.

3.3.3 IGCC Process

An Integrated Gasification Combined Cycle power plant is essentially a union of two blocks, one which is a chemical process block and the other an electric power generating block, with the former feeding the product (syngas) to the latter for fuel. The following paragraphs describe the entire IGCC system.

1) Process Block:

The gasification process block consists of several subsystems including coal preparation, slurry preparation for a wet-feed gasifier, gasification and high-temperature heat recovery, slag handling, particulate removal and low temperature heat recovery, sour water treatment, acid gas removal, and sulfur recovery. Each of these subsystems is briefly discussed below:

(a) Fuel Handling

The coal handling system provides the means to receive, unload, store, reclaim, and convey coal to the storage facility. Coal is delivered to the site by rail or even via water, if accessible by this means, and transferred to the gasification area through the coal unloading system to the crusher house. Coal also can be delivered by truck and dumped directly onto a coal pile when train deliveries are not available. Coal is transferred from the crusher house to the active coal storage pile by transfer belt conveyors. Coal is reclaimed from the active coal storage pile to the gasification plant coal silo by variable rate feeder-breakers and the reclaim belt conveyors. There are no significant differences for the coal handling system between the IGCC plants and conventional pulverized-coal power plants.

(b) Slurry Preparation

For a wet feed gasification system, coal slurry can be produced by wet grinding in a rod mill. After this activity, coal is delivered into the rod mill feed hopper by a conveyor. Water is added in order to produce the desired slurry solids concentration. The slurry water includes water that is recycled from other areas of the gasification plant. Prepared slurry is stored in an agitated tank. All tanks, drums and other areas of potential atmosphere exposure of the product slurry or recycled water are closed and vented into the tank vent collection system for control of vapor emissions.

(c) Gasification, High-Temperature Heat Recovery, and Particulate Removal

Some processes (one of them being the Wabash River Project) consist of two stages, namely: a slagging first stage and an entrained flow non-slagging second stage. The slagging section, or first stage, is a refractory lined vessel into which oxygen and recycle char and unreacted coal are fired via a mixer nozzle. The coal char and oxygen are fed sub-stoichiometrically at an elevated temperature and pressure to produce a high-temperature syngas. The oxygen feed rate to the mixers is carefully controlled to maintain the gasification temperature above the ash fusion point. The objective of doing this is to ensure good slag removal while producing high quality syngas. In this condition inside the gasifier, coal is almost totally gasified to form a synthetic fuel gas consisting primarily of hydrogen, carbon monoxide, carbon dioxide, and water. Sulfur in the coal is converted to primarily hydrogen sulfide (H_2S) with a small portion converted to carbonyl sulfide (COS); both of which are removed by downstream processing. Mineral matter in the coal forms a molten slag which flows continuously through the tap hole into a water quench bath located below the first stage. The slag is then crushed and removed through a continuous pressure let-down system as slag-water slurry. This continuous slag removal technique eliminates high-maintenance, problem-prone lock-hoppers and completely prevents the escape of raw gasification products to the atmosphere during slag removal. The slag is then dewatered and removed from the process. The raw synthesis gas generated in the first stage flows upward from the first stage into the second stage of the gasifier. The non-slagging second stage of the gasifier is a vertical refractory-lined vessel into which a portion of the coal slurry feed stream is injected via an atomizing nozzle to mix with the hot syngas stream exiting the first stage. This coal feed first lowers the temperature of the gas exiting the first stage by the endothermic nature of the reactions, thereby generating more gas at a higher heating value. Evaporation of the water entering with the coal slurry further reduces the syngas temperature. No oxygen is introduced into the second stage. The gas and entrained particulate matter, i.e., char and un-reacted coal, exiting the gasifier is further cooled in a fire-tube heat recovery boiler system where saturated steam at 1,650 psia is produced. Steam from this high-temperature heat recovery system is super-heated in the gas turbine heat recovery system for use in power generation. To remove solids from the syngas, the raw gas passes through a two-step particulate removal system consisting of a cyclone located upstream of the high-temperature heat recovery unit and a dry char filter system located downstream. The recovered char and coal particles which has not undergone reaction inside the gasifier, is recycled and sent back to the gasifier. This part of the process block is considered the heart of the gasification cycle.

(d) Slag Handling

A dewatering bin is provided at the gasifier to receive the slug slurry which exits from the quench section after passing through the slag crushers. The slag after leaving the quench section flows continuously through the pressure let down system and into this dewatering bin. The bulk of the slag settles out in the bin while water overflows a weir at the top of the bin and goes to a settler where the remaining solids are collected. The clear water gravity flows out of the settler and is pumped through heat exchangers where it is cooled as the final step before being returned to the gasifier quench section. Dewatered slag is loaded into a truck or rail car for transport to market or to storage. The fines slurry from the bottom of the settler is recycled to the slurry preparation area. The dewatering system contains dewatering bins, a water tank, water circulation pumps, and a flash gas scrubber to remove residual H_2S. A tank vent collection system is provided to receive the vents from tanks, bins, and drums in the slag handling area.

(e) Low-Temperature Heat Recovery

A certain amount of scrubbing is provided for the filtered syngas for the purpose of removing water-soluble contaminants. One of these contaminants is chloride. The scrubbed syngas is sent to the COS hydrolysis unit. Since COS is not removed efficiently by the downstream Acid Gas Removal (AGR) system, the COS is generally converted to H_2S in order to obtain the desired high sulfur removal level. This is accomplished by the catalytic reaction of the COS with water vapor to create hydrogen sulfide and carbon dioxide. The hydrogen sulfide formed is removed in the AGR section and the carbon dioxide goes with the raw syngas to the turbine. After exiting the COS hydrolysis unit, the syngas is cooled through a series of shell and tube exchangers before entering the AGR system. This amount of cooling condenses water, ammonia, some carbon dioxide and hydrogen sulfide in an aqueous solution, which is collected and sent to the sour water treatment unit. Some of the cooled syngas goes to the syngas recycle compressor for use in various areas of the plant. This gas is used for quenching in the second stage of the gasifier and back-pulsing the barrier filters. The heat removed prior to the AGR unit provides moisturizing heat for the product syngas, steam for the AGR stripper, and condensate heat. Cooling water provides trim cooling to ensure the syngas enters the AGR at a sufficiently low temperature. The cooled sour gas is fed to an absorber in the AGR unit where the solvent selectively removes the H_2S to produce a sweet syngas.

(f) Acid Gas Removal

Hydrogen sulfide (H_2S) in the sour syngas is removed at the AGR system. There are different types of AGR systems. In case of a methydiethanolamine (MDEA) system, H_2S is removed in an absorber column at high pressure and low temperature using a solvent, MDEA. After the hydrogen sulfide removal, the syngas is moisturized and heated before proceeding to the gas turbine. The hydrogen sulfide rich MDEA solution exits the absorber and flows to a stripper column where the hydrogen sulfide is removed by steam stripping at lower pressure. The concentrated H_2S exits the top of the stripper column and flows to the sulfur recovery unit. The lean amine exits the bottom of the stripper, is cooled, and then recycled to the absorber. Methydiethanolamine (MDEA) accumulates impurities over a period of time, which reduces the H_2S removal efficiency of the MDEA. In order to avoid fast degradation of the system efficiency, an online MDEA reclaim unit is provided to continuously remove these impurities.

(g) Sulfur Recovery Unit

As discussed above, hydrogen sulfide becomes concentrated at the AGR unit. Thus, the concentrated hydrogen sulfide from the AGR unit and the CO_2 and H_2S stripped from the sour water are fed to the Sulfur Recovery Unit (SRU) system and sulfur is recovered from the SRU system. There are different types of SRU. In case of a Claus unit, the acid gas rich in H_2S is fed into a reaction furnace, a waste heat recovery boiler, and then to a series of Claus catalytic reaction stages where the H_2S is converted to elemental sulfur. It is in this elemental form that sulfur is marketed for process cost recovery. The sulfur from the SRU is recovered as a molten liquid and sold as a by-product in elemental form. The tail gas stream composed of mostly carbon dioxide and nitrogen with trace amounts of sulfur dioxide exits the last catalytic stage and is directed to tail gas recycling. The tail gas is hydrogenated to convert all the sulfur species to H_2S, cooled to condense the bulk of the water, compressed, and then injected into the gasifier. This arrangement allows for very high sulfur removal efficiency with low recycle rates.

(h) Air Separation Unit

The Air Separation Unit (ASU) is required in an IGCC plant using oxygen-blown gasifier(s). There are different types of ASU. In case of a commonly used cryogenic type ASU, the system consists of several subsystems and major pieces of equipment, including an air compressor, air cooling system, air purification system, cold box, and product handling and backup systems. Gaseous oxygen leaves the cold boxes at moderate pressure and is then compressed in centrifugal compressors and delivered to the gasifiers. Nitrogen tanks with steam vaporizers provide gaseous nitrogen. These tanks also serve as transfer and buffer vessels for normal gaseous nitrogen production. In a more integrated arrangement, compressed air from the combustion turbine generator compressor stage is partly diverted to the ASU thus saving compression power and nitrogen (N_2) product of the ASU is also used to dilute the syngas coming from the gasifier at a point prior to entering the CTG combustors.

2) Power Block

In typical IGCC systems, the major components of the power block include gas turbine generator(s), heat recovery steam generator(s), and a lesser number of steam turbine generators, plus several supporting facilities which comprise the balance of plant of the power block. Basically, the power block in an IGCC is quite similar to the natural gas-fired combined cycle plants (NGCCs). The power block process is therefore given a relatively shorter space for discussion in this report.

(a) Gas Turbine, Heat Recovery Steam Generator and Stack

The CTGs receive the syngas from the Process Block after having been cleaned and scrubbed and stripped of harmful pollutants. After the syngas firing at the CTG combustors and the subsequent expansion of the combustion gases through the CTG turbine stages, the CTG exhaust gases are routed to the HRSGs and eventually to the stacks. Designs of IGCC's provide that another source of fuel, such as natural gas, is used as backup for the gas turbines during startup, shutdown, and short duration transients in syngas supply. The HRSG's receive the gas turbine exhaust gases and generate steam. The HRSGs generate high-pressure (HP) steam and provide condensate heating for both the combined cycle and the gasification facilities. Depending on process and balance of plant requirements, a unit HRSG can have multiple pressure levels. Normally, a unit HRSG is a fully integrated system consisting of all required ductwork and boiler components. Each component is designed for pressurized operation. The HRSG's boilers include steam drums for proper steam purity and to reduce surge during cold start. Large unheated downcomers assure proper circulation in each of the banks. Recent IGCC designs use heat transfer surface of the extended surface type, with serrated fin design in order to improve heat absorption from the exhaust CTG gases. To improve emission levels further, a selective catalytic converter (SCR) is installed within the HRSG to cut down on NOx emissions. Usually, a continuous emission monitoring (CEM) system is provided or installed in each HRSG stack to monitor the presence of pollutants in the combustion products.

(b) Steam Turbine

The steam turbine further converts the heat energy recovered by the HRSG to shaft power and eventually to electric power at the generators. Some STG designs have reheat stage(s) to improve efficiency and keep the steam dry at the low pressure stage prior to exiting at the condensers.

(c) Cooling Water System

In an IGCC plant, the cooling water system provides multiple functions and these are: (a) to provide the cooling duty for the power block, (b) to cool the air separation unit(s), and (c) for cooling the gasification facility. The major components of the cooling water system consist of cooling towers and circulating water pumps. All plant cooling requirements are provided via pipes running either underground or above ground in pipe racks or a combination of both.

Cooling systems can be a once through system, a natural draft cooling tower or a mechanical draft cooling tower system. In case of mechanical draft cooling tower systems, cooling towers are usually multi-cell, mechanically induced draft towers, sized to provide the design heat rejection at the ambient conditions corresponding to the maximum summer temperature. Cooling tower blowdown discharges to the wastewater management system. Chemical treatment systems, including metering pumps, storage tanks and unloading facilities provide the necessary biocide, pH treatment and corrosion inhibiting chemicals for the circulating water system. Other types of cooling systems may be adopted in later IGCC designs depending on the specifics of the sites these plants will be located and on the size and configurations of the plant itself.

(d) Balance of Plant

The BOP in an IGCC power block would not be much different from a conventional natural gas-fired combined cycle power plant. Condensate and boiler feed pumps will be there, as well as service and instrument air facility. Water that needs to be used in the steam cycle needs to be polished to required specifications, hence a polishing system is required; and water effluent from the plant needs to be treated, hence a waste water treatment is a must.

3.3.4 IGCC Technological Developments

IGCC technological developments up to the present have produced the following notable and commonly adopted gasification processes, namely:

1) Moving-Bed Gasifier (Dry Ash)

Figure 2 Moving Bed Gasifier
[Courtesy of EPRI, 2007]

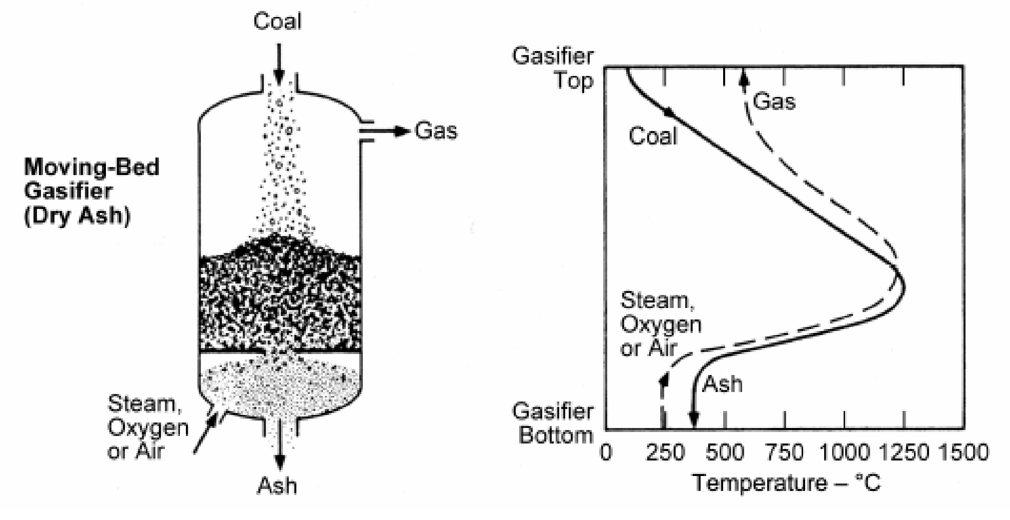


Table 4 Features of Moving-Bed Gasifier

Feature	Description	Remarks
Coal Feed	Dry	Top feed; uses lock hoppers
Coal and Oxygen/Air Flow Direction	Countercurrent	
Syngas Outlet Temperature	Relatively Low	316°C (600°F) – 538°C (1000°F)
Type of Coal Suitable	Lignite and lower rank coals	Needs mechanical stirrer if used with bituminous coals
Extent of Field Application	Worldwide operation	Lurgi dry ash, BGL,SASOL F-T, BEPC SNG, etc.
Note:	Steam is added to keep coal below ash softening point in dry-ash version; High hydrogen-to-carbon monoxide ratio	

In moving bed gasifiers, the gasifying medium (air or oxygen with steam) enters the bottom of the fuel bed and moves upwards while the fuel bed gradually moves downwards as the fuel at the bottom gets consumed. Because of the counter-current nature of the flow of gases and fuel, the sensible heat of the gases is effectively utilized by the incoming fuel. These gasifiers require the fuel to be in lumps, while the fines are generally not acceptable. The ash disposal could be either dry or in slag form. Moving bed gasifiers are the oldest and have been in existence for over two centuries. They have been used for conversion of coal into town gas (producer gas) for domestic lighting and heating before the natural gas replaced it. These gasifiers have also been used for industrial heating, production of chemicals and even synthetic motor fuels (SASOL project, South Africa). ‘Lurgi’ dry ash gasifiers and ‘British Gas – Lurgi (BGL)’ slagging-type gasifiers are among the prominent moving bed gasifiers.

2) Fluidized Bed Gasifier

Following figure shows a Fluidized Bed Gasifier.

Figure 3 Fluidized Bed Gasifier

[Courtesy of EPRI, 2007]

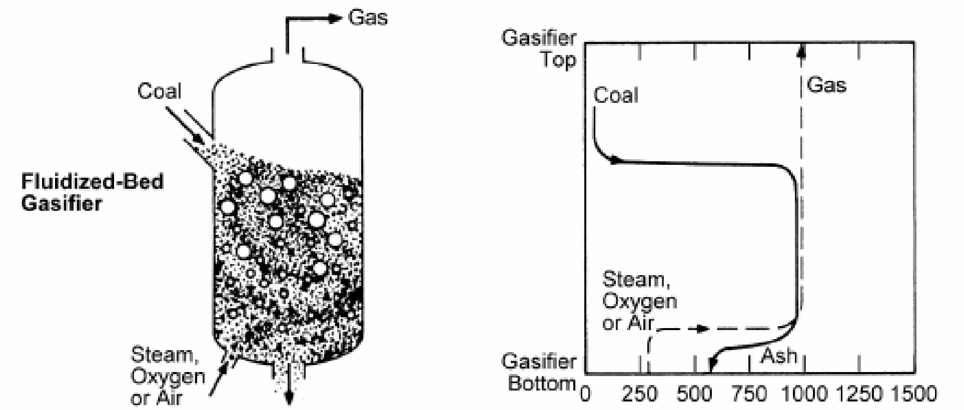


Table 5 Features of Fluidized-Bed Gasifier

Feature	Description		Remarks
Coal Feed	Dry		Coal Size: 1/8” or smaller
Coal and Oxygen/Air Flow Direction	Countercurrent		
Syngas Outlet Temperature	Medium		1000 °C or less
Type of Coal Suitable	Low rank coals		Main experience
Extent of Field Application	Worldwide operation		KBR, HT Winkler, U Gas, etc.
Modes and Velocities (fps)	Bubbling Bed	< 3	Users: GTI, U Gas, KRW
	Circulating	8 - 16	HT Winkler, GRI U Gas
	Transport	20 - 45	KBR
Note: Steam is added to keep coal below ash softening point in dry-ash version; High hydrogen to carbon monoxide ratio			

In the case of fluidized bed gasifiers, solid fuel is suspended in the gasifying medium (usually air) with air and solid particles together behaving like a fluid. In such gasifiers, the temperatures are usually maintained less than 1000ºC (1832 ºF) so that the ash remains in solid form. These gasifiers are suitable for both coal and biomass. High-Temperature Winkler (HTW), developed by British Coal Corporation and now marketed by Mitsui Babcock Energy Limited (MBEL) is one of the examples of fluidized bed gasifiers.

3) Entrained Flow Gasifier

Figure 4 Shows an Entrained Flow Gasifier.

Figure 4 Entrained Flow Gasifier
[Courtesy of EPRI, 2007]

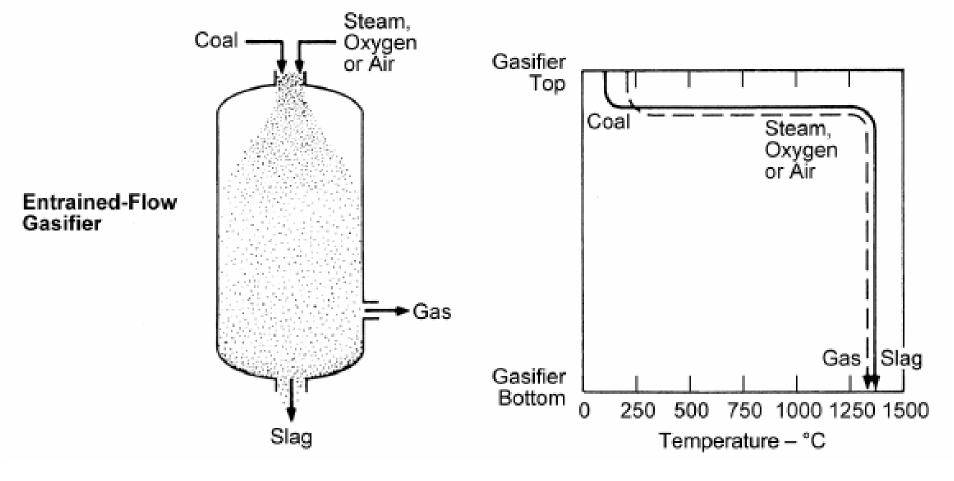


Table 6 Features of Entrained Flow Gasifier

Feature		Description	Remarks
Coal Feed	Dry	Handles a wide range of coals; needs pre-drying of high-moisture coal	Used by Shell, Siemens, Future Energy, Eagle and MHI
	Slurry	Can run up to 68.9 bar(g) (Eastman)	Used by Eastman, GE, COP
Coal and Oxygen/Air Flow Direction		Co-current flow (Same direction)	
Syngas Outlet Temperature		Relatively Higher	>677ºC ; operates in the slagging region of 1316 ºC-1649 ºC
Note: GE, COP and Shell are all proven in commercial size in IGCC application			

In an entrained flow gasifier, the pulverized fuel flow co-currently or in the same direction as the gasifying medium, which is usually oxygen. In such gasifiers, as shown in above table, uniform temperatures of 1000 ºC (1832 ºF) or higher are maintained. The fuel needs to be pulverized to a very small particle size, because the residence time of the fuel in the gasifier is very short. The high temperatures in the gasifiers ensure that the ash is removed in slag form. Most of the coal gasification based power projects in the world are utilizing entrained flow gasifiers.

4) Transport Bed Gasifier

Figure 5 shows a Transport Bed Gasifier.

Figure 5 Transport Bed Gasifier
[Courtesy of Gasification Technologies 2005]

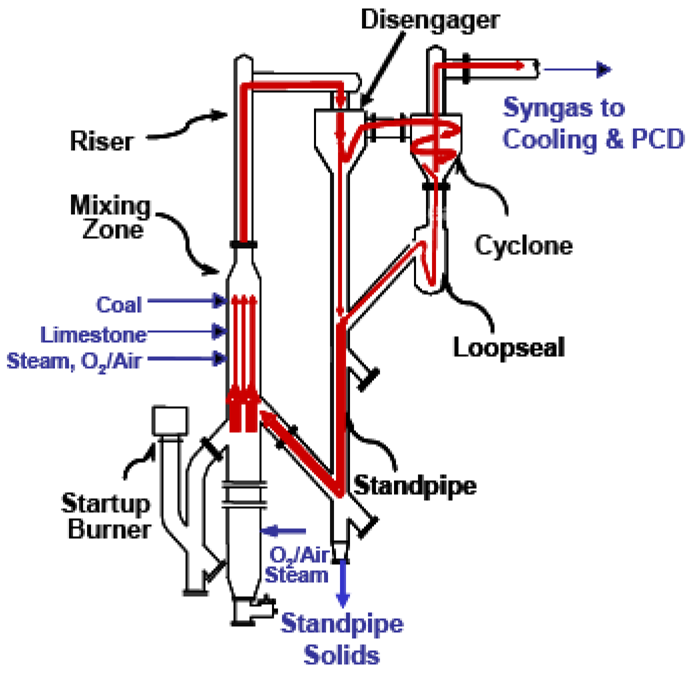


Table 7 Features of Transport Bed Gasifier

Feature	Description	Remarks
Coal Feed	Advanced circulating fluidized bed reactor	Used by Kellogg Brown & Root
Coal and Oxygen/Air Flow Direction	Most testing occurred in air blown gasification mode, a characteristic that differentiates it from its competitors.	
Syngas Outlet Temperature	816 °C (1501°F) to 1,066 °C (1951°F) and at pressures of up to 1.82 MPa (264 psia)	The gasifier has a high solids recirculation rate which results in excellent gas-solids contact in a highly turbulent atmosphere and a low mass transfer resistance between gas and solids
Note: Tested at the Power Systems Development Facility (PSDF), an engineering scale demonstration of advanced coal-fired power systems and high-temperature, high-pressure gas filtration systems. It is particularly well-suited for low-rank, high-moisture, and high-ash coals due to the low-temperature operation and high-circulating solids rates.		

The KBR Transport Gasifier is based on fluidized catalytic cracking (FCC) technology developed in 1940, driven by the need to produce gasoline from fractionated crude oil during World War II, when commercial scale 13,000-barrel/day (b/d) units were successfully scaled up from a 100-b/d pilot unit (130/1 scale-up factor). Current commercial FCC units have six-foot diameter risers and capacities of 150,000 b/d. Coal rates of 1,134 kg/2,500 lb to 2,268 kg/5,000 lb per hour are attained, yielding commercially projected turbine inlet syngas heating values of up to 5,484 kJ/Nm^3 (147 Btu/SCF) in air-blown gasification and up to 11,726 kJ/Nm^3 (298 Btu/SCF) in oxygen-blown gasification. Carbon conversion has been as high as 98%. The PSDF is co-funded by the U.S. Department of Energy, the Electric Power Research Institute, Southern Company, Kellogg Brown & Root, Inc. (KBR), Siemens-Westinghouse, Peabody Energy, the Lignite Energy Council and Burlington Northern Santa Fe Corporation. The gasifier has a small footprint due to its high heat release which results in a high-coal throughput. It is designed to operate at higher circulation rates, velocities and riser densities than a conventional circulating fluidized bed.

In the U.S. government-supported effort to develop and raise the status of the IGCC technology into commercial scale, the Wabash project in Indiana was initiated using the Dow technology, while the Texaco technology was applied in another project at the Tampa, Florida Plant. Meanwhile, in Europe, the Shell technology was utilized at the Buggenum plant in the Netherlands.

Apart from the three IGCC projects previously mentioned, some other projects in operation are listed in Table 8. While less information is available about projects outside the United States, there have been more than ten gasification facilities proposed outside U.S.

Table 8 List of Worldwide Operating IGCC Facilities

Owner	**Location**	**Gasification Technology**	**Syngas Output (MWth)**	**Online Year**	**Feedstock**	**Products**
Repsol/Iberdrola	Spain	GE Energy	1,654	2004a	Vac. Residue	Electricity
SARLUX srl	Italy	GE Energy	1,067	2000b	Visbreaker Res	Electricity & H_2
ISAB Energy	Italy	GE Energy	982	1999b	Asphalt	Electricity & H_2
Total France/edf/ GE Energy	France	GE Energy	895	2003a	Fuel Oil	Electricity & H_2
Shell Nederland	Netherlands	Shell	637	1997	Visbreaker Res	Electricity & H_2
SUV /EGT	Czech Republic	Lurgi Dry Ash	636	1996	Coal	Electricity & Steam
Global Energy	U.S.	E-gas	591	1995	Bit. Coal/Pet Coke	Electricity
Elcogas SA	Spain	PRENFLO	588	1997	Coal & Pet Coke	Electricity
Motiva Enterprises	U.S.	GE Energy	558	1999b	Fluid Pet Coke	Electricity
API Raffineria	Italy	GE Energy	496	1999b	Visbreaker Res	Electricity
NUON	Netherlands	Shell	466	1994	Bit. Coal	Electricity
Tampa Electric	U.S.	GE Energy	455	1996	Coal	Electricity
Exxon USA	U.S.	GE Energy	436	2000b	Pet coke	Electricity & Syngas
Esso Singapore	Singapore	GE Energy	364	2000	Residual Oil	Electricity & H_2
Nakoso IGCC	Nakoso, Japan	MHI, 2 stg, Air	250 MWe	2008	Coal	Electricity
Negishi IGCC	Yokohama Japan	GE(formerly Texaco) Direct Quench	342 MWe	1997	Heavy Oil	Electricity

Below is a global list of IGCC projects under development:

Table 9 A Global List of IGCC Projects under Development

Project	**Location**	**Gasification Technology**	**GT Model**	**Net Output (MWe)**	**Year**	**Feedstock**	**Products**
American Electric Power	Meigs County, Ohio	GE Energy	2 x Fr 7FB	630	2012	Coal	Electricity
Appalachia Power	Mason County, West Virginia	GE Energy	2 x Fr 7FB	630	2012	Coal	Electricity
BP/Edison Mission Energy	BP Refinery Carson, California	GE Energy	1x Fr 7FB	500	2012	Pet Coke	Electricity & H_2
Centrica/Progressive Energy	Teesside 2, UK	N/A	N/A	800	2013	Coal/Pet Coke	Electricity
Dubai Water & Power Authority	Dubai, United Arab Emirates	N/A	N/A	2000	N/A	Coal	Electricity & Water
Duke Energy Indiana	Edwardsport, Indiana	GE Energy	2 x Fr 7FB	630	2012	Coal	Electricity
E. On	Lincolnshire, United Kindom	N/A	N/A	450	2012	Coal	Electricity
Excelsior Energy	Holman, Minnesota	CoP E-Gas	2 x S5000F	600	2012	PRB/Pet Coke	Electricity
GreenGen	Tianjin, China	N/A	N/A	250	2009	Coal	Electricity
Luminant	Texas	N/A	N/A	600	2012	Coal/Pet Coke/Bio mass	Electricity
MDL Holding	Henderson County, Kentucky	GE Energy	2 x Fr 7FB	630	2012	Kentucky #9 Coal	Electricity & SNG
NRG Energy	Huntley, NY	MHI	Mitsubishi	630	2012	Coal	Electricity
Nuon Magnum	Eemshaven, Netherlands	Shell License	3 x M701F4	1200	2011	Coal/biomass	Electricity
Powerfuel/KRU	Hatfield, UK	Shell	N/A	900	2012	Coal	Electricity & H_2
RWE	Germany	N/A	N/A	450	2014	Lignite or Hard Coal	Electricity & H_2
Tenaska/MDL Holding	Taylorville, Illinois	GE Energy	2 x Fr 7FB	630	2012	Illinois Coal	Electricity & SNG
ZeroGen	Queensland, Australia	Shell	1 x Fr 6B	80	2014	N/A	Electricity
Mississippi Power		KBR	2 x GE 7FA	600	2012	Lignite	Electricity
Mountaineer IGCC	West Virginia	GEE (Radiant/Quench)	2 x GE-7FB	600	2010	Coal	Electricity
Dongguan IGCC	China	N/A	N/A	800	2011	Coal	Electricity
Banshan IGCC	China	N/A	N/A	200	2010	Coal	Electricity

3.3.5 Some Commercially Available Gasification Technologies for IGCC

Commercialization of the IGCC technology is the logical outcome of current rising trends in electric power demand and clamor for cleaner coal use for electricity power generation fuel. A number of technology suppliers have become notable to date such as:

ConocoPhillips: Owns the E-Gas^{TM} technology that was developed by Dow. ConocoPhillips purchased this technology from Global Energy in August 2003.

Shell: Developed its gasification technology together with Prenflo. The Prenflo technology is no longer licensed.

General Electric: Purchased the Texaco gasification technology from ChevronTexaco in June 2004. GE offers both Quench and Radiant (high-temperature heat recovery) cooler gasifiers.

Mitsubishi Heavy Industries: Developing an air-blown, two-stage entrained flow gasifier with dry feed. MHI intends to demonstrate this technology at a 250-MWe project in Japan.

Siemens: Used in one gasification plant at Schwarze Pumpe, a 200-MWe methanol and power cogeneration plant. Siemens technology has been geared toward biomass and industrial processing on a smaller scale, but it seems to be making an entry into the utility-scale power generation market. According to a May 2006 press release, Siemens plans to build a 1,000-MWe coal IGCC in Germany as a first step to commercializing its newly acquired IGCC technology.

3.3.6 Current Status of IGCC in APEC Developing Economies

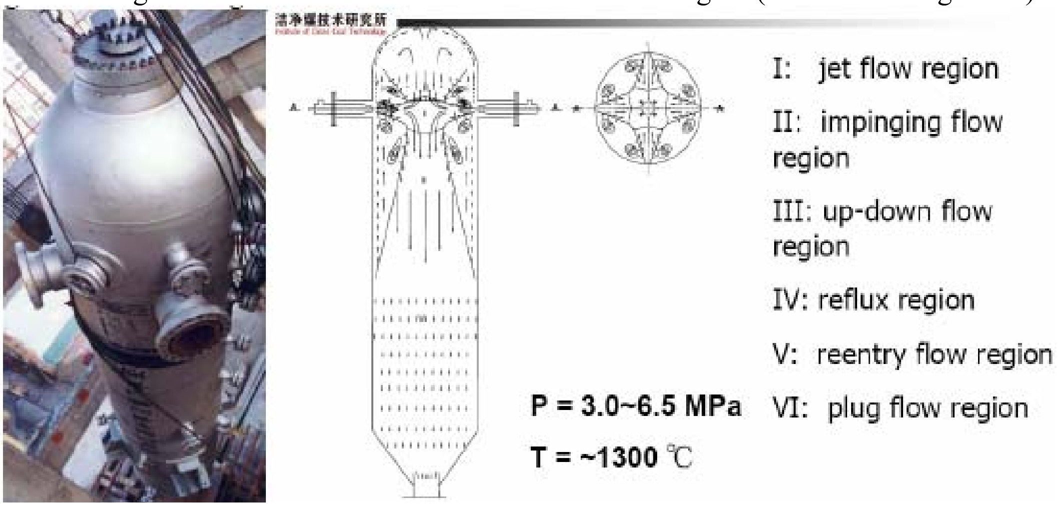
1) People's Republic of China

Among the APEC developing economies, China has the greatest growth rate and potential for growth in many areas of development. This is influencing a wide range of industrial and commercial activities, including gasification relating to coal-based power generation. China is the world's second largest producer of electricity after the United States. Since over 70 percent of the total electricity in China is from coal-fired power plants, naturally the biggest challenge lies in the mitigation of gases emitting from the various coal-burning power plants in this particular APEC developing economy. Consequently, developing clean and highly efficient power generation technologies in China and other equally high growth, coal-burning economies has become one of the extraordinary urgencies with both regional and global implications. Of significant focus within China today is coal gasification for electric power generation. Integrated Gasification Combined Cycle (IGCC) and poly-generation technologies are identified as providing significant environmental benefits through lower particle and other pollutant emissions. Additionally, this includes the potential for cost-effective pre-combustion CO_2 removal.

Coal gasification started fairly early in China. Through a combination of indigenous research and international cooperation, China has worked on pressurized and atmospheric coal gasification and fixed-bed, fluidized-bed and pneumatic-bed gasification with different kinds of coal supply. The gas obtained is mainly used in chemical industrial and household applications. At present, there are over 8000 gasifiers in China, 4000 of which gasify coal using atmospheric fixed-bed technology *[Watson and etc, 2000]*. There are already cleaner, more advanced gasifier designs that were introduced to China at some industrial sites. These include Texaco gasification technology for large-scale chemical feedstock gas production, fixed-bed gasifiers for industrial gas production and Lurgi pressured gasification technology for civil gas production.

As a result of the increasing effort in developing new power generation technologies, China has made many breakthroughs in their own IGCC and poly-generation key technologies such as gasification, Fischer-Tropsch (F-T) synthesis and methanol production plant design. Chinese engineers have also gained much experience in design, construction, and operation of these plants. A case-in-point is the development of the Opposed Multi-Burner Coal-Water Slurry (OMB-CWS) process. According to a recently released report *[Yu and et. al, 2007],* the coal-water slurry (CWS) and oxygen react in the gasifier to produce syngas consisting mainly of H_2 and CO, under temperature conditions of approximately 1300°C (2372°F) and pressures between 3.0 MPa/435 psi ~6.5 MPa/943 psi. Accordingly, at such high temperature and pressure, the chemical reactions themselves are so fast that the whole process of gasification is controlled by diffusion. Coal-water slurry along with oxygen is injected into gasifier reaction zone through four burners, which are located symmetrically on the same upper horizontal level of the gasification chamber. Large-scale cold model experiments indicated that the flow field of the OMB gasifier is composed of six different flow regions: jet flow region, impinging flow region, up-down flow region, reflux flow region, reentry flow region and plug flow region. The gasification regions are shown in Figure 6 below:

Figure 6 OMB CWS Gasification Flow Region (with an actual gasifier)



It should be noted that the above process, including equipment manufacture, is developed in China. The Institute of Clean Coal Technology (ICCT) at East China University of Science and Technology is one of the technology developers.

Other IGCC demonstration plants are also being constructed or proposed. One proposed IGCC project, Yantai IGCC Project, is a 300-400 MWe class IGCC. The feasibility study for the project has been approved. For some reason, the project has not yet moved forward. However, In China's 11th Five Year Plan (2006-2010), three ongoing IGCC Demonstration Units are being built in Tianjin, Zhejiang and Guangdong provinces respectively. Led by China Huaneng Group, the GreenGen project will build an IGCC plant near Tianjin, southeast of Beijing. A 250-megawatt plant will be built in the initial phase, expanding to 2 x 400MWe in later phases according to the project plan. The project started in 2007 and the plant is expected to be put in operation in 2009. Dongguan Taiyangzhou IGCC Project was approved recently which is a 4 x 200MWe plant. The plant is located in Guangdong province. Each unit is of 1 x 1 x 1 configuration. The project plans to apply the China-owned intellectual property. The first unit is expected to be started in 2011. Another demonstrated IGCC project is Banshan IGCC, which is a 200 MWe unit. The plant is located near Hangzhou City, Zhejiang Province. The project pilling work was started in January 2008 and will be put into operation in June 2010. Besides above mentioned three demonstration projects mentioned above in the Nation 11th Five Year Plan some proposed IGCC projects are in different development stages. Among them are Fujian IGCC Plant (multi-production); Tianjing Dagang 2 x 400MWe IGCC Project; Shenyang IGCC Multi-

Production Project; Shengzhen IGCC Project; Jiangsu Haimen IGCC Project; Hainan IGCC Project and Langfang IGCC Project.

2) Mexico

In Mexico, The Instituto de Investigaciones Electricas (IIE) has been working in the past few years on economical and technical evaluation studies of Gasification Technology as an alternative for power generation. The main energy company in Mexico, Commission Federal de Electricidad (CFE), is interested in the potential that the gasification technology offers for power generation in the following 5 to 10 years. Also, the main oil company, Petroleos Mexicanos (PEMEX), is interested in the gasification technology for power generation as well to obtain feedstocks for its refinery processes. The IGCC technology in Mexico is in the research and development stage *[Altamirano-Bedolla and etc, 2007]*.

3) Others

There is very little information on IGCC development activity that is available from other APEC developing economies. Among the developing APEC member economies, it is really the People's Republic of China that has shown the lead in coal gasification and has now started its program to utilize syngas for power generation.

3.3.7 Overall Coal Gasification Industry Outlook

On April 9, 2008, James M. Childress, Executive Director of the Gasification Technologies Council, testified before the U.S. Senate Commerce Committee, Subcommittee on Science, Technology and Innovation. He reported that worldwide gasification capacity is projected to grow 70 percent by 2015, with some 80 percent of the growth occurring in Asia. China is expected to achieve the most rapid growth as it moves aggressively to displace use of oil and gas in its chemicals and fertilizer industries. There are also seven coal-to-substitute natural gas projects in development in China. In addition, there are twelve proposed gasification-based IGCC power plants under evaluation by the Chinese government. Since 2004, 29 new gasification plants have been licensed and/or built in China. In contrast, no new gasification plants have started up in the United States since 2002. In the U.S., plans have been announced for some 45-50 new gasification-based projects in twenty-five states. However, whether these plants will actually be constructed depends on a number of factors, perhaps the most important of which is the lack of a clear regulatory framework addressing carbon capture and sequestration.

3.4 Advanced Pulverized-Coal Technologies

The most widely used technologies for coal-fired electric power generation fall under the Pulverized Coal (PC) technologies, where coal is ground to about the consistency of talcum powder and used as fuel for a boiler to heat water and produce steam. The steam drives a turbine, which in turn, drives an electrical generator, sending electricity throughout the grid to end users.

The advanced PC technologies currently use emission mitigation systems to generate electricity with much less pollution to atmosphere, and these systems include:

- Nitrogen oxide controls and Low-NO_x burners – to control NO_x in flue gas
- Selective catalytic reduction – also to control NO_x in flue gas
- Dry electrostatic precipitators – to control particulate matter in flue gas
- Wet electrostatic precipitators – also to control particulate matter in flue gas
- Sulfur dioxide scrubbers – to control acid forming sulfur compounds in flue gas

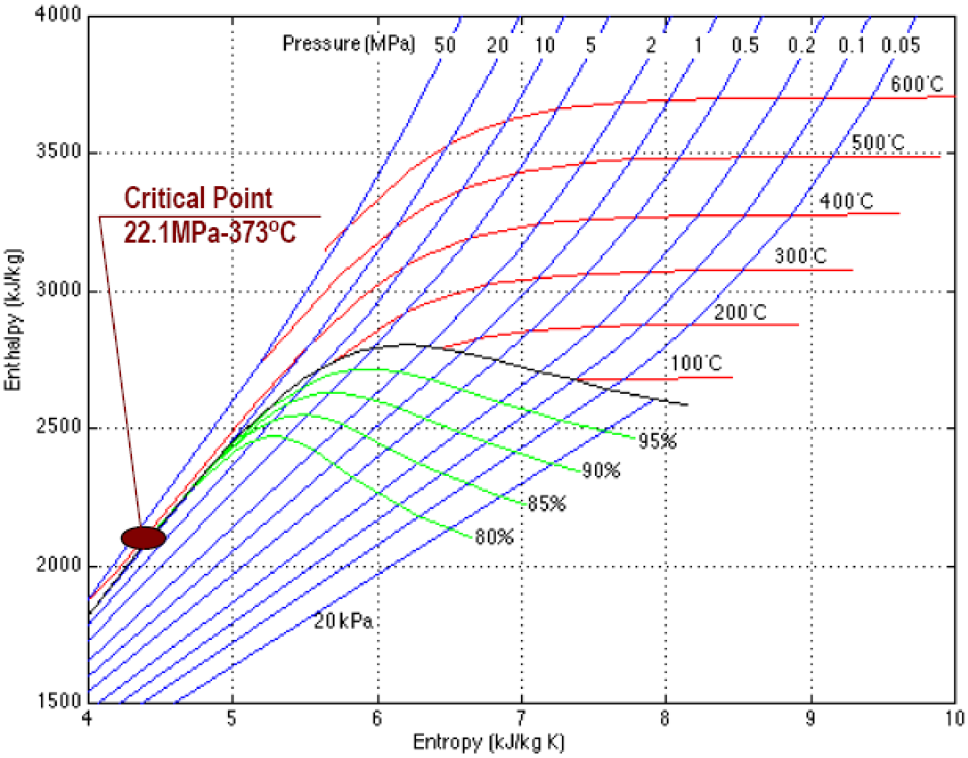
However, most importantly, these advanced PC technologies enable power plants to operate at above critical steam pressures and temperatures in order to attain higher thermal efficiencies than those obtained by subcritical PC power plants. Being able to operate at higher thermal efficiencies means less pollutants emitted per MWh of electricity generated by burning coal fuel. The (1) Supercritical PC boilers operating at 25 MPa (3625 psia) steam pressure and 540 to 566°C (1004 to 1050 °F) steam temperature, and the (2) Ultrasupercritical PC boilers operating at 27 – 28.5 MPa (3916 – 4134 psia) steam pressure and 580 to 620°C (1076 to 1148 °F) steam temperature, are considered belonging under the advanced Pulverized Coal technologies.

3.4.1 Supercritical Pulverized-Coal Units

In any thermodynamic process or cycle used in converting fossil fuel to electric power, the overall efficiency is always expressed in terms of how much of the energy that is fed into the cycle is converted into electrical energy. The greater the output of electrical energy for a given amount of energy input, the higher the efficiency. If the energy input to the cycle is kept constant, the output can be increased by selecting elevated pressures and temperatures for the water-steam cycle. But where does the line lie between the subcritical design conditions and the supercritical designs? The answer lies in the steam condition itself: Up to an operating pressure of approximately 19 MPa in the evaporator portion of the boiler, the cycle is sub-critical. This means that in the subcritical steam condition region there is a non-homogeneous mixture of water and steam in the evaporator part of the boiler. In this case a drum-type boiler is used because the steam needs to be separated from water in the drum of the boiler before it is superheated and led into the turbine. Above an operating pressure of 22.1 MPa in the evaporator part of the boiler, the cycle is supercritical. The cycle medium is a single phase fluid with homogeneous properties and for this reason there is no need to separate steam from water in a drum. Once-through boilers are therefore used in supercritical cycles.

Figure 7 is an enthalpy-entropy (Mollier) diagram indicating the location of the critical point in the Mollier steam chart. The critical point is shown as 22.1 MPa/3205 psi and 373°C/703°F.

Figure 7 Enthalpy-Entropy (H-S) Diagram of Steam

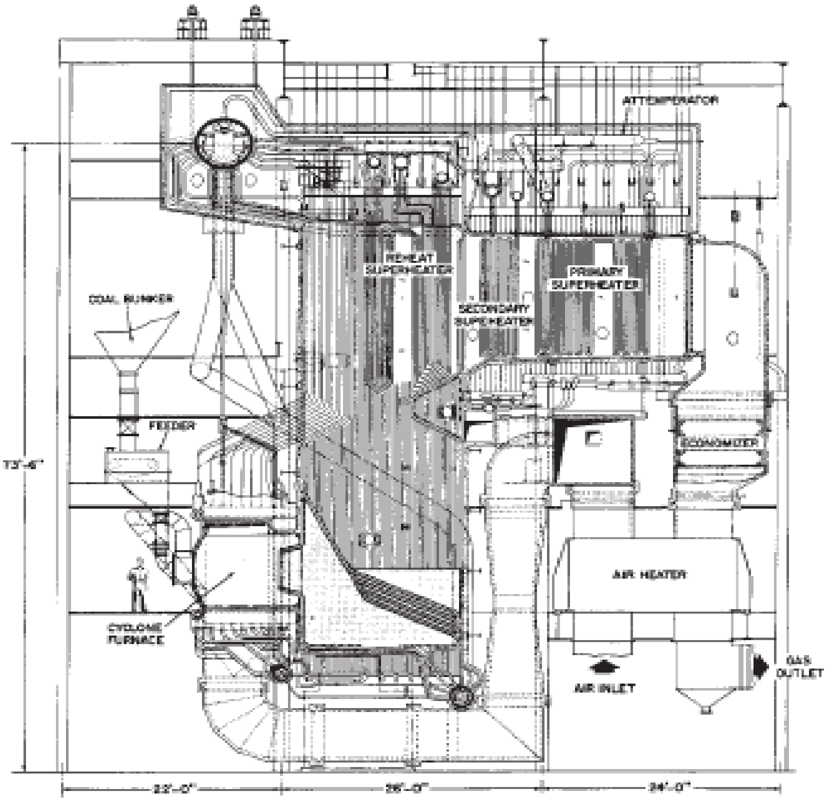


3.4.1.1 History of Supercritical Pulverized-Coal Power Generation

Supercritical steam generators are sometimes referred as Benson boilers. This name has been derived from Mark Benson, who in 1922 was granted a patent for a boiler designed to convert water into steam at high pressure. Safety was the main concern behind Benson's concept. Earlier steam generators were designed for relatively low pressures of up to approximately 10 MPa, corresponding to the state of the art in steam turbine development at the time. As development of Benson technology continued, boiler design soon moved away from the original concept introduced by Mr. Benson. In 1929, a test boiler that had been built in 1927 began operating in the thermal power plant at Gartenfeld in Berlin. This represented a first time operation in subcritical mode with a fully open throttle valve. The second Benson boiler began operation in 1930 without a pressurizing valve at pressures between 4 and 18 MPa at the Berlin cable factory. This application represented the birth of the modern variable-pressure Benson boiler. After that development, the original patent was no longer used. However, the Benson boiler name was retained. Developments on the boiler design continued to evolve addressing reliability and flexibility issues. While early experience with supercritical plants in the US indicated that they had poor availability, i.e., forced outages were greater than with subcritical plants, experience that takes account of plant performance in Japan and Europe as well as in China and South Africa (where these once through boilers plants are common) shows that these plants are just as reliable as subcritical plants. The era following the Second World War brought on rapid economic development in the United States. The rapid economic development increased the desire for more efficient power plant operation. The improved economic climate, coupled with improvements in both boiler tube metallurgy and water chemistry technology, brought a renewed interest in the supercritical cycle. This renewed interest has resulted in building many supercritical units worldwide in recent decades.

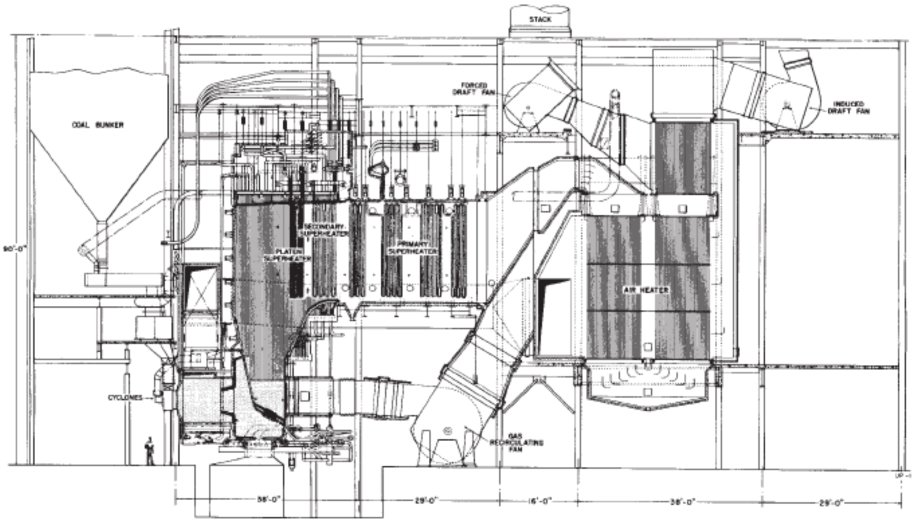
Operating boilers at pressures and temperatures above the critical point of water, which is 22.1 MPa and 373^{o}C (3208 psia and 705 ^{o}F), are not without issues. Years ago, high-thermal stresses and fatigue cracking in the boiler sections were significant contributors to frequent supercritical plants failures and higher maintenance costs, resulting in lower operational availability and reliability of supercritical electric power generating units than those of subcritical units. Main concerns were related to control valve wear-and-tear, to the turbine blade thermal stress and solid particle erosion problems, as well as to more complicated start-up procedures. Supercritical units are also more sensitive to feedwater quality, and for this reason, full-flow condensate polishing is required to protect the turbine from stress corrosion cracking. However, supercritical power plant units are more efficient and more flexible. Combination of supercritical steam condition design with once-through boiler technology results in better operational dynamics. Supercritical unit ramp rates are higher, for example a ramp rate of 8 percent/min over a wide output range and in sliding-pressure mode compared to about 3-5 percent /min for subcritical drum units.

Figure 8 90-MW Drum Boiler 1956 Design



In the U.S., the vision of the supercritical power plant was also held by companies such as American Electric Power and General Electric (for the steam turbine). American Electric Power entered into contract with both Babcock & Wilcox and General Electric to build the world's first ultra-supercritical power plant. This 125-MW installation (shown in Figure 9) at the Philo Plant operated at main steam condition of 31 MPa/4496 psi and 621°C/1150°F with two stages of reheating; first to 565°C/1049°F and then to 538°C/1000°F. The decision to proceed building this plant was made in 1953 and operation was begun in 1957. While the initial intent of the plant was to merely to demonstrate the feasibility of the supercritical pressure cycle, this unit has proven to be in service for a good number of years and was commercially operated until 1979.

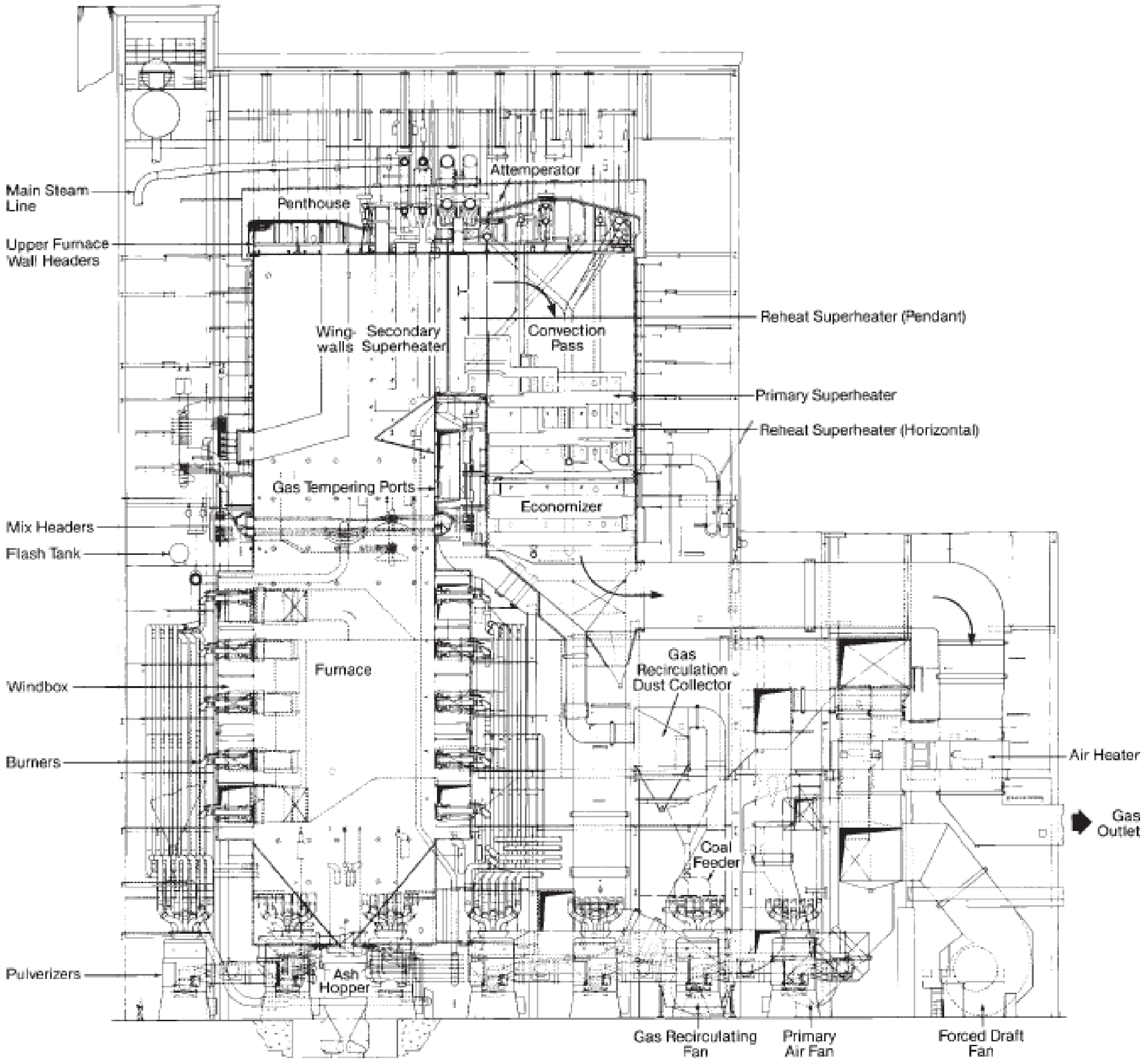
Figure 9 125-MW Boiler Design



The supercritical boiler design has introduced a number of configurations to attain highest possible efficiencies in given design conditions, without sacrificing operating reliability and maintainability features. For example there were designs of supercritical PC boilers that route hot flue gases in a horizontal path across most of the convection surfaces, such as the illustration shown in Figure 9. In later years, this horizontal gas flow over the majority of the convection surfaces was replaced by a gas path that is directed vertically upwards. The modified flow of gas and vertical orientation of boiler tubes are similar to that shown in

Figure 10. This unit is of the supercritical Universal Pressure (UP) design, which was intended for base-load and load cycling operation, as opposed to the start-stop mode of operation.

Figure 10 1300-MW AEP Zimmer Boiler (UP-142)
[Courtesy of Babcock & Wilcox]



In the 1960's the supercritical PC technology was introduced in Japan and is now adopted for all large capacity steam generators for electric power generation. Thereafter, electric power producers in several economies throughout Asia and Oceania, including Korea, the People's

Republic of China, Australia and India embraced supercritical technology. At present time, it is fast becoming the worldwide standard for large-capacity steam generators. Supercritical coal-fired power plants with efficiencies of 45 percent have much lower emissions than subcritical plants for a given power output. It has been reported that worldwide, more than 400 supercritical power plants are in operation.

3.4.1.2 Current Trends

Many of the large pulverized coal power plants in existence today produce supercritical steam, and have an efficiency of a little more than 40 percent. Today's state-of-the-art supercritical coal-fired power plants are capable of attaining efficiencies that exceed 45 percent, depending on cooling conditions. However, there are now ongoing efforts to develop materials that are capable of withstanding much higher pressures and temperatures that can be used to building these new breed of ultrasupercritical PC units which are the topic of discussion under Section 3.4.2. Options to increase the efficiency above 50 percent in ultra-supercritical power plants rely on elevated steam conditions as well as on improved process and component quality.

1) The Turbine Generator Set

As part of the advanced PC technology status review, the steam turbine-generator set is one of the most interesting components to be covered. For steam turbine-generators, there are several designs available for use in supercritical power plants. These designs need not fundamentally differ from designs used in subcritical power plants. However, because the steam pressure and temperature are more elevated in supercritical plants, the wall-thickness and the materials selected for the high-pressure turbine section really need careful consideration. In supercritical units, flexibility in operation is of utmost importance and, therefore, flexibility needs to be one of the important features in a supercritical turbine-generator set design. This must be so, because while subcritical power plants using drum-type boilers are limited in their load change rate due to the boiler drum (a component requiring a very high wall thickness), supercritical power plants using once-through boilers can achieve quick load changes when the turbine is of suitable design.

2) High-Pressure Turbine

At the High-Pressure stage of the turbine, steam is first introduced from the steam generators or boilers via a steam chest/throttle valve arrangement in order to regulate turbine speed. The steam entering the HP stage is then expanded from the main steam pressure throttle (steam chest) and governing valves to the pressure of the reheat system. Materials with higher percentage content of chromium, which possess higher material strength, are selected. In order to cater to the higher steam parameters in supercritical cycles, the wall thickness of the HP turbine section should be as low as possible and should avoid massive material accumulation such as oxides, in order to increase the thermal flexibility and fast load changes. This adoption of optimum, i.e., as thin as allowable pressure containing turbine parts, is one design feature that has to match with the steam generator (boiler) lack of thick and massive parts, an important aspect, which is the outcome of the steam drum and hopper header or mud drum omissions from design. The absence of massively thick steel pressure containing members allows the whole electric power generating unit to respond to load changes more quickly.

3) Intermediate-Pressure Turbine Section

It is common to steam turbine designs that steam from the HP stage first gets reheated back in the boiler to raise the steam superheat high enough for further expansion in the later stages of the turbine. Steam coming from the reheater is further expanded in the IP turbine section. The current trend in supercritical cycle design moves towards increasing reheat steam temperatures at the Intermediate Pressure (IP) turbine section in order to raise the cycle efficiency. This design trend does not affect overall turbine reliability provided that the reheat temperature is kept at a moderate level, i.e. approximately 560°C (1040°F), such that there would be no significant difference between the IP turbine section of a supercritical plant and that of a subcritical plant.

4) Low-Pressure Turbine Section

In the low pressure (LP) turbine section the steam coming from the IP stage is expanded down to the condenser pressure. The LP turbine sections in supercritical plants are not much different from those in subcritical plants.

5) Boiler

Apart from the turbine generator set, the boiler is a key component in modern, coal-fired power plants. Its concept, design and integration into the overall plant considerably influence costs, operating behavior and availability of the power plant. For supercritical boiler application, Once-Through boilers have been favored in many economies for more than 30 years. They can be used up to a pressure of more than 30 MPa (4351 psia) without significant change in the process engineering. Wall thicknesses of the tubes and headers, however, need to be designed to match the planned pressure level. As discussed earlier, the drum, which is very heavy and located at the top of the boiler in subcritical boiler designs, no longer becomes a part of supercritical once-through steam generator (boiler) design. Considering the many advantages of the once-through boiler design, one of which is its capability to be operated at a wide range of steam pressures, variable pressure operation was introduced into power plants at the start of the 1930s. This variable pressure design makes the operation of plants a lot easier and more flexible.

6) Balance of Plant

There are very few differences between the water-steam cycle equipment of a subcritical coal-fired power plant and that of a supercritical coal-fired power plant. These differences are limited to a number of components, such as the feedwater pumps and the equipment in the high-pressure feedwater train, which are downstream of the feedwater pumps. This balance of plant components that require redesign to match the requirement of supercritical cycle operations is estimated to represent less than 6 percent of the total value of a coal-fired power plant.

3.4.1.3 Recent Developments

1) Operational Issues

It was stated in a report by Ingo Paul, Head of Product Management for fossil-fueled steam power plants at Siemens Power Generation (KWU) that there are 400 supercritical power plants now operating in the U.S., Europe, Russia and Japan. Reportedly, due to different approaches in their design and operation, performance results regarding power plant operations are not uniform. While the rapid introduction of very large power plants in the U.S. in the early 1970s resulted in a number of problems affecting the reliability of these plants i.e. forced outages, and longer shutdowns, later feedbacks from other operators were very positive. Eventually, reports were received about much improved reliability of supercritical plants, even matching or exceeding those of similarly sized subcritical plants.

A number of power plants operate with once-through boilers with supercritical steam conditions in developing economies today. As an example, the South African utility, ESKOM, had been operating a number of once-through boilers for several years with local industry participation in the design and manufacture of these units. Another case to serve as an example is the 2 x 600MWe Shidongkou supercritical coal-fired power plants in the Shanghai area of China, which were put into operation in the early 1990s. There are no operational limitations that can be attributed to once-through boilers as contrasted to drum-type boilers. In fact, once-through boilers are better suited to frequent load variations than drum-type boilers, since the drum is a component with a high wall thickness requiring controlled heating. The massive drum with thick walls, limits the load change rate to 3 percent per minute. On the other hand, once-through boilers have no massive drums; they can step-up the load by 5 percent per minute. The capability for faster load up ramp rates due to the absence of massive metal walls in the boiler pressure containing parts, makes once-through boilers more suitable for fast startup as well as for transient conditions. To cite two cases in point, one of the largest coal-fired power plants equipped with a once-through boiler in Germany, the 900-MWe Heyden power plant, is even operating in two shift operations, as well as, the 3 x 660-MWe power plant in Majuba, South Africa.

2) Fuel flexibility

Once-through supercritical coal-fired units have a wide range of fuel flexibility. All the various types of firing systems (front, opposed, tangential, corner, four-wall, arch with slag tap or dry ash removal, and fluidized bed), which used to fire a wide variety of fuels, have already been made suitable for once-through boilers. All types of coal, as well as, oil and gas have been used and proven to work satisfactorily in a once through supercritical boiler design. The pressure in the feedwater system does not have any influence on the slagging behavior of the combustion/flue gas system, as long as steam temperatures are kept at a similar level to that of conventional drum-type boilers.

3) Water chemistry

It has been perceived that water chemistry could be more complicated in supercritical power plants. Problems experienced in the past were largely due to the use of deoxygenated all-volatile (AVT) cycle chemistry. The solution to these problems was the combination of a condensate polishing plant with oxygenated treatment (OT), which is a well-proven procedure. No additional installations for supercritical power plants relative to the conventional subcritical power plants are required.

In addition, once-through boilers do not have a boiler blowdown. This has a positive effect on the water balance of the plant with less condensate make-up needed to be fed into the water-steam cycle and less waste water to be disposed.

4) Steam Generator State-of-Art Designs

Some state-of-art approaches to common operating problems are addressed by design improvements, such as the following:

(a) Spiral Waterwall Design

Maintaining uniform fluid conditions during low load and lower pressure operation is quite critical for supercritical units using sliding operation as it could create a potential for tube damage caused by high metal temperatures. As a specific case or example, a design of a boiler: Hitachi-Naka Boiler No. 1 in Japan (please refer to Figure 11 below) has a boiler furnace region with a lower tube section arranged in spiral configuration, such that the fluid path wraps around the boiler as it travels up the furnace. The effect of this spiral configuration is demonstrated in an illustration showing a comparison of fluid temperature distribution between the conventional vertical wall and the spiral water wall as shown in Figure 12. It can be deduced from the illustration that due to the uniform waterwall fluid temperature profile that is achieved across the full range of boiler loads, the spiral waterwall design (shown in Figure 13, right hand illustration), does not require the design provision for any flow adjusting devices to be installed at the furnace inlet.

Figure 11 Hitachi-Naka No.1 Boiler with Spiral Lower Furnace Tube Configuration
[Courtesy of Mitsui-Babcock]

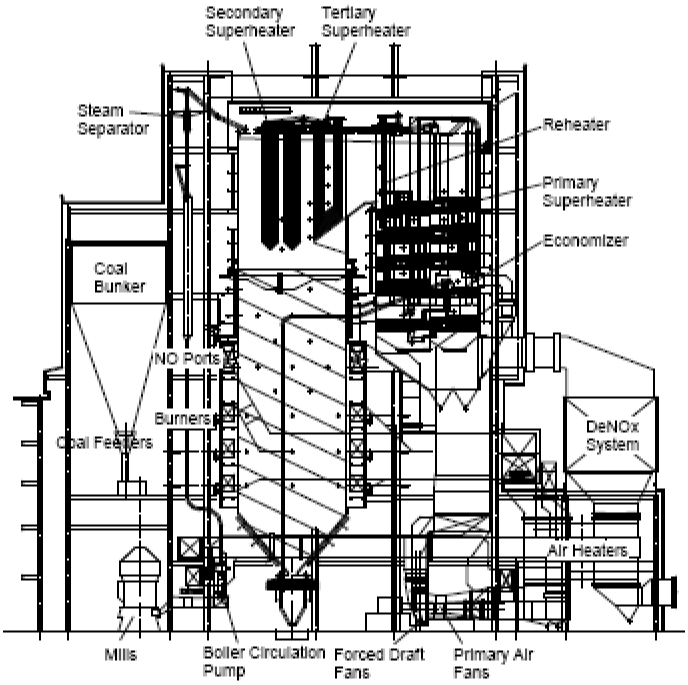
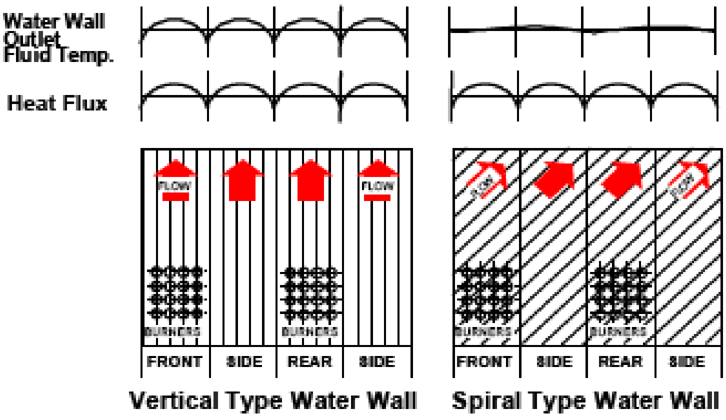
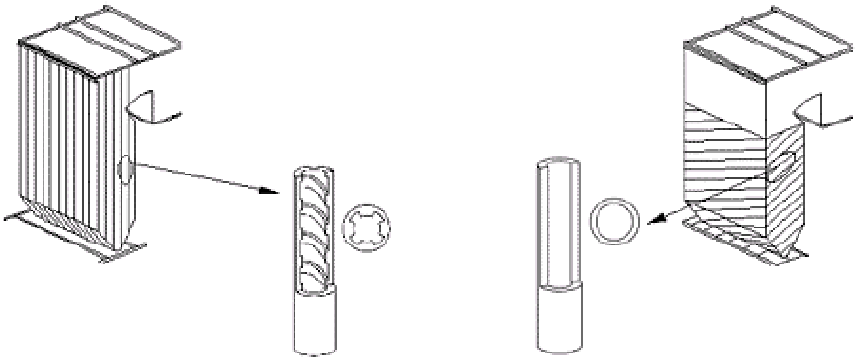


Figure 12 Fluid Temperature Profile Comparison for Water Wall Type



A similar approach of improving heat transfer is being used by MHI, which is using internally ribbed tubes for vertical tube waterwalls and smooth interior tube walls for tubes which are arranged in a spiral fashion around the furnace.

Figure 13 Vertical Rifled and Smooth Spiral Wound Tube Design (MHI)



In cases where there are low fluid mass flow rates in some part of the boiler envelope, adequate tube cooling may not be available to tubes with smooth wall internals. To counter this drawback, recent boiler technology ha led to the use of rifled tubes in high heat flux areas to eliminate this concern, i.e., rifled in the lower furnace, smooth-bore in the upper furnace. It has been mentioned by technical journals and actual accumulated field experience in the industry that the greatest concern for tube overheating occurs when the evaporator or boiler operating pressure approaches the critical pressure. In the 21 to 22 MPa (3046 to 3191 psia) pressure range, the tube wall temperature required to cause film boiling (departure from nucleate boiling – DNB) quickly approaches the fluid saturation pressure. DNB will occur in this region and a high fluid film heat transfer coefficient is required to suppress the increase in tube wall temperature. A rifled tube, with inner tube wall exposed for clarity, is shown in Figure 14.

Figure 14 Sample of a Boiler Tube with Rifled Inner Wall

The introduction of the rifled bore tubing for supercritical steam generator application led to the development of once-through boilers that no longer needed having spiral wound furnace tubing. This development offered reductions in support steel and improvements in power plant efficiency and operating characteristics.

(b) Metallurgical Enhancements

Of course, tube configuration and arrangement inside the boilers are not the only concern at much higher supercritical operating steam pressure and temperature. Metallurgy is of prime importance and for this particular application there are quite a number of steel alloys available for use in boiler tube manufacture. The more important alloying elements for high pressure and temperature applications are:

- Chromium – For corrosion and oxidation resistance; high-temperature strength
- Nickel – For increase in hardenability and impact strength
- Molybdenum – For increase in creep strength and hardenability
- Vanadium – For increase in yield and tensile strength

(c) Arch-Fired Pulverized-Coal Combustion

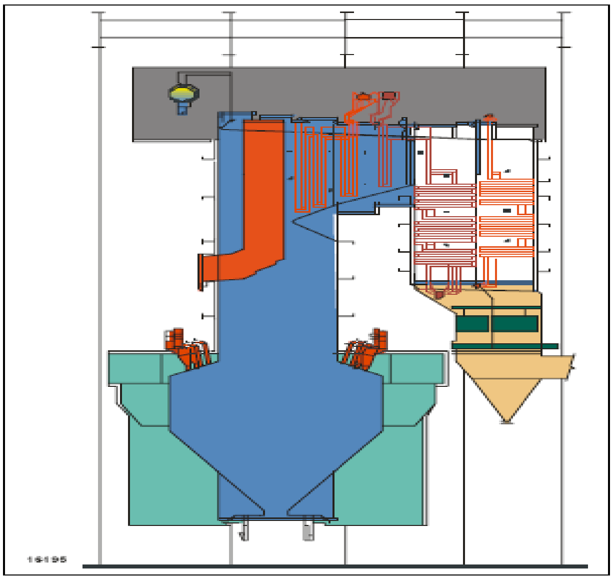
One interesting development in recent years was the introduction of arch-fired boiler design for supercritical steam generators using low volatile fuels in an APEC developing economy, China. One boiler company, Foster Wheeler. is currently offering once-through supercritical arch-fired boilers suitable for firing low volatile coals. Both designs incorporate the Siemens BENSON Vertical Tube (VT) technology for the furnace circuitry. Foster Wheeler has been reported to have licensed its arch-fired technology for supercritical cycles to a Chinese boiler supplier. Recent FW steam generators for low volatile fuels which were installed in China are listed below:

Table 10 FW steam Generator Applications in People's Republic of China

Project	Firing Mode	Capacity	Fuel	Service Date
Jiangzi JiuJiang	Arch-fired	2 x 385 MWe	Anthracite	2004
Hebei Hanfeng	Arch-fired	2 x 716 MWe	Anthracite	2000
Yangcheng	Arch-fired	6 x 380 MWe	Anthracite	2000 - 2002
Hubei Ezhou	Arch-fired	2 x 335 MWe	Anthracite	1999

The location of burners in an arch-fired boiler and the special features of the furnace and burner are shown in Figure 15, which distinguish them from conventional wall-fired units. These special features are provided in the design to address the poor ignition and burnout characteristics of the low volatile fuels.

Figure 15 Arch-Fired Boiler

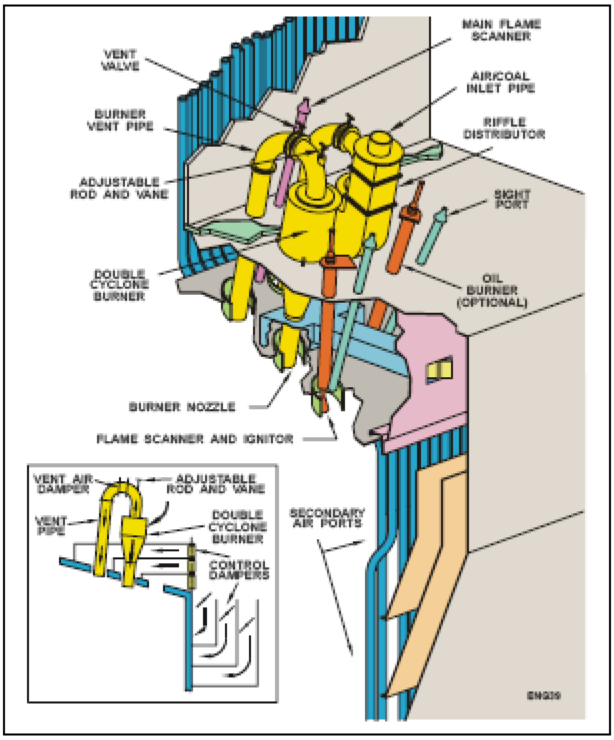


The main provisions employed in the burner design in order to get prompt and stable ignition are:

- Double cyclone burners for removal of air from the coal/air mixture entering the burner nozzles to discharge fuel-rich mixture to the furnace (See Figure 16) Note that this illustration was obtained from the Foster Wheeler Report [*Anthracite Firing at Central Power Stations for the 21st Century, by J. Antonio Garcia-Mallol, Allan E. Kukoski and Justin P. Winkin*].

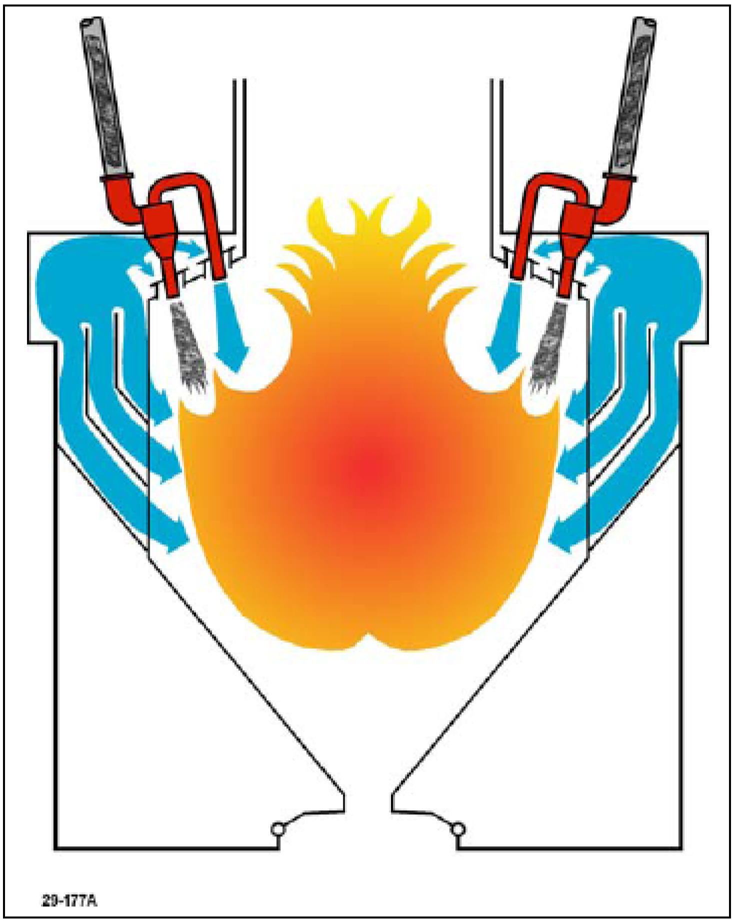
- Preheat-type burner nozzles to rapidly heat pulverized-coal particles to secondary air temperature prior to discharge to the furnace.
- Compartmented windbox with control dampers to proportion the air flow to limit the amount of combustion air in the ignition zone.
- Burner and arch geometry to induce backflow of some of the hot combustion gas into the ignition zone.
- Refractory lining of the lower furnace to radiate the heat back to the ignition zone.

Figure 16 Double Cyclone Burner



In order that a high degree of burnout, i.e., low combustible loss, of the ignited fuel is achieved, the furnace and burner should be in such a configuration that a “W-shaped” flame pattern is created. This flame shape will provide sufficient residence time in the hot portion of the furnace. This “W-shaped” flame will appear at a certain elevation above the furnace bottom similar to the one shown in Figure 17. This arched-fired combustion pattern is considered to be the most suitable pattern of combusting low volatile content coal. This type of burner design is particularly suitable to APEC economies, such as the People’s Republic of China, where there is a high percentage of anthracite coal available. Anthracite coal has relatively low percentage of volatile matter and therefore requires special burner designs, such as the arch-double cyclone burner design illustrated above.

Figure 17 Arch-Fired Combustion Pattern
[Courtesy of Foster Wheeler, North America Corp]



(d) Steam Generator Controls

Once-through, supercritical boilers, unlike drum-type boilers, do not have large steam drums to store energy. Due to this limitation in keeping energy reserve, as usually provided by the drum in drum-type sub-critical boilers, the control system in supercritical boilers must match, exactly and continuously, feedwater flow and boiler firing rate (both fuel and air) to the turbine's steam energy needs, to deliver the desired generator power. For supercritical plants, the accuracy and resolution of the DCS (distributed control system) is more important than in sub-critical units. A well-designed control system that provides tight regulation and the ability to hit and maintain set points can help utilities capitalize on the economic and environmental potential these units offer. Better control allows power generators to capitalize on the heat capture capabilities of supercritical unit designs. Therefore, the ability of the control system to control operations tightly leads to stable, steady-state operation, without oscillation. This is critical, as steady-state, base load operation is the key to achieving supercritical unit efficiency.

5) Dealing with Historical Issues

Apart from all above issues, typical issues are listed in Table 11. Historically, the original supercritical units installed in most parts of the world were designed for constant pressure operation, which means that the boiler operates at full load pressure from start-up and across the entire load range. For instance, for start-up, constant pressure operation boilers require a start-up bypass system, which is complex in configuration and operation compared with the new sliding pressure Benson boilers. As a result, the start-up time for constant pressure boilers is longer and the plant minimum load must be kept higher than those for sliding pressure units. Additionally, the load ramp rate of constant pressure operation is restricted because of the limit in temperature change rate in the high-pressure (HP) turbine stages during a load change. As a result, frequent valve maintenance on the start-up or throttle or governor valves is required considering the higher erosion rates caused by higher pressure differentials. Another major issue is the severe slagging on the waterwalls and the coils in older coal-fired boilers constructed during the 1960s and 1970s. This was primarily because the furnaces of those plants were relatively small in volume. However, later designs have provided ample furnace sizes for better performance. This includes proper proportioning of the furnace dimensions, including plan area (footprint), height and volume, which are provided to reduce slagging potential.

Table 11 Causes and Countermeasures of Boiler Problems

Problems Encountered in Older Supercritical Units	**Identified Causes**	**Counter-measures Provided in New Supercritical Boiler Designs**
Long start-up times	Complicated start-up system; ramping operation required; difficulty in establishing metal matching condition	Sliding pressure operation; simplified start-up system; low load recirculation
Low ramp rates operation.	Turbine thermal stress caused temperature change in HP turbine during load changing (due to constant pressure operation	Sliding pressure
High minimum stable operating load	Bypass operation & pressure ramp-up operation required	Application of low-load recirculation system.
Erosion of start-up valves	High differential pressure due to constant pressure operation and complicated start-up system	Sliding pressure operation, simplified start-up system and low load recirculation
Slagging	Undersized furnace size and inadequate sootblower system coverage	More aggressive use of air/steam sootblowing devices
Circumferential cracking of waterwall tubes	Metal temperature increase due to inner tube scale deposit and fireside wastage	Oxygenated water treatment(OWT); protective surface in combustion zone of furnace for high sulfur coal, i.e., by using thermal spray or weld overlay
Lower efficiency than expected (design)	High Air Leakage due to pressurized furnace; RH Spray injection required (inherent by design)	Tight seal construction; Single RH system with high steam temperature and temperature control by parallel damper gas biasing
Frequent acid cleaning	Inappropriate water chemistry	Application of Oxygenated Water Treatment (OWT)
Low availability	All of the above	All of the above

6) Design and Manufacture in Developing Economies

There is a misconception, that the components of supercritical coal-fired power plants can only be designed and manufactured in developed economies due to the complexity of the technology. As discussed, the differences in the technology between subcritical and supercritical coal-fired power plants are limited to a small number of components. All developing economies using coal in base load (e.g., China and India) have already large manufacturing capacity in the components common to subcritical and supercritical plants and are now building up capacity in those components that are specific to supercritical electric power generation. For example, manufacture of the turbine generator and boiler for the 2x900-MWe Waigaoqiao supercritical plant is being done in China.

3.4.1.4 Current Status of Supercritical Power Generation in APEC Developing Economies

1) The People's Republic of China

Supercritical and ultra-supercritical pulverized power plants are now regarded as commercially proven. The use of higher steam temperatures and pressures to increase the thermal efficiency of coal-fired power plants is an established practice in the People's Republic of China. Shidonkou No.2 was the first super-critical power plant in the PRC. The units were ordered in the late 1980s and put into operation in the early 1990s, utilizing ABB boilers and turbines. The units have been highly reliable in operation and have achieved a boiler efficiency of over 93 percent with a yearly net standard coal consumption of 312 g/KWh. There are a number of supercritical plants in operation in the PRC today. Some of the supercritical units with large capacity ratings and are currently in operation include the plants of Nanjing (2 x 300 MWe), Panshan (2 x 500 MWe), Yingkou (2 x 300 MWe), Yimin (2 x 500 MWe), Suizhong (2 x 800 MWe), Waigaoqiao (2 x 1000 MWe), Fuyang (2 x 600 MWe), Kemen (2 x 600 MWe), Wangqu (2 x 600 MWe) and Fangneng (2 x 800 MWe).

2) Indonesia

The nation is building coal-fired power plants with total generation capacity of 10,000 MWe by 2010. Some of the units are expected to use major equipment manufactured in the PRC. Most likely, the Chinese power plant units will be supplied using supercritical or ultra-supercritical technology designs.

3) Viet Nam

New coal-fired power plants to be built in central and southern Viet Nam will all use supercritical boiler technologies and burn imported coal.

4) Mexico

The first supercritical coal-fired power plant with a capacity of 700 MWe is being built near Mexico City, which is a full-turnkey project executed by Mitsubishi Heavy Industries, Ltd. (MHI). The plant is scheduled to commence in February 2010 *[http://www.japancorp.net]*.

3.4.2 Ultra-Supercritical Pulverized-Coal Units

As stated earlier in this report, supercritical power plants operate at temperatures and pressures above the critical point. This case of going over the critical point on the steam Mollier chart is even more pronounced in the case of the ultra-supercritical power plants. However, by bringing the edge of technology beyond the usual limits a number of years in the past resulted in a good number of benefits to the power industry. This effort to exceed previously attained power plant operating pressures and temperatures resulted in higher efficiencies – up to 46 percent for supercritical and 50 percent for ultra-supercritical – and lower emissions than those of power plants with earlier designs.

To further define the categories of coal-fired power plants according to their operating pressures and temperatures, the following table is shown in Table 9 below:

Table 12 Temperatures/Pressures for Different Boilers Using Bituminous Coal

Types of Steam Power Plant	**Temperature, °C (°F)**	**Pressure, MPa (psig)**
Sub-critical Boiler	538 (1000)	16.7 (2422)
Supercritical Boiler	540 - 566 (1004 -1050)	25 (3625)
Ultra-Supercritical Boiler	580 - 620 (1076 -1148)	27 - 28.5 (3916 - 4134)

One feature, which helps in the deployment of supercritical and ultra-supercritical power plants, is the similarity in the operational aspects of these advanced pulverized coal power plants with conventional power plants. This similarity allows supercritical power plants to be constructed and operated without significant retraining, thereby enabling faster deployment.

In as much as the USC plant temperatures and pressures are above those of currently designed supercritical plants, further efficiency improvements are certain to be attained, although new materials must be utilized to enable these USC power generating units to reliably continue in service under extreme operating conditions.

3.4.2.1 Materials for Ultra-Supercritical Power Plants

The major task leading to successful implementation of USC technology is identifying, evaluating, and qualifying potential materials that are needed for the construction of all critical boiler and steam turbine components. These components, when put together, shall result in a USC power plant that will be capable to operate beyond the SC pulverized coal power plant operating range of steam pressures and temperatures and shall attain much higher efficiencies than those reached by the present generation of SC power plants. Efficiency increase is expected to be achieved principally through the use of USC steam parameters by achieving main steam conditions of 760°C and 35MPa. Main steam temperatures of the most advanced and efficient fossil fueled power plants are currently within 600ºC range, representing an increase of about 60ºC within 30 years. Since ferritic steels are capable of meeting the strength requirements up to of approximately 620ºC there is no obstacle for USC technology within this temperature range. It is expected that the main steam temperature will raise another 70–150ºC in next 15-30 years. In order to make this considerable steam temperature increase commercially feasible, the development of stronger high-temperature resistant materials capable of operating under high stresses at ever increasing temperatures and pressures plays the most important role.

3.4.2.2 Recent Advances in Designs for USC Power Plants

1) Boilers

To satisfy the needs for higher efficiencies and flexible operation, sliding pressure, once-through boilers are most suitable for supercritical and ultra-supercritical applications. For high-temperature SC and USC steam conditions, it is essential to use high-strength materials to reduce wall thickness of pressure parts, resulting in low thermal stresses. High-strength ferritic 9-12 Cr steels for use in boilers are now commercially available up to 620ºC and miscellaneous tests show that they capable of long term service up to 650ºC and possibly 700ºC. Boiler design technology is currently following the trend of ever higher creep rupture stress materials. Such high alloy steel materials are steels P91 to P92, austenitic steels 18-8 to 18-25, like for example, Super 304H, Esshete 1250, as well as, the high nickel alloys Inconel 718 and 740. The extra costs for nickel-based alloys can be partly compensated by reduction in the amount (weight) of material, because of thinner pipe walls and smaller dimensions of machinery. Also austenitic steel slightly reduces the wall thickness. Despite its unfavorable physical properties (thermal coefficient and conductivity) as compared to ferritic/martensitic steel, these highly alloyed materials are able to follow changing temperatures during accelerated start-up of the turbine. This flexibility in final operational application is the reason why austenitic steels are used for superheater pipes. Likewise, furnace walls need high-temperature creep-resistant ferritic steel. In this regard, T23 and T24 are probable candidates. In the case of choices for reheat section tube materials, there is not much to be concerned considering the fact that while reheat temperature is usually higher (typically by 15-20°C) than the main steam temperature, reheat pressure is typically 4-times lower than the main steam pressure. Consequently, less stringent quality material may be used for reheat systems and components than those required for the main steam system. Ultra-supercritical boiler size reduction may appear to become the decisive factor for even more intensive development of the USC technology, because this particular problem of extremely high cost of special steels and alloys has been traditionally the main obstacle for wider application of even the earlier generation of the advanced PC technology.

Past experience, present practice, and future outlook in the use of high-temperature materials for USC applications are shown in Table 13.

Table 13 High-Temperature Materials for USC Applications

Steam Conditions		**Materials Used**	**Period Used**
Pressure (MPa)	**Temperature (ºC)**		
<25.0	<520	X20	Since early 60's
<30.0	<593	P91 (9% Cr)	Since late 80's
<33.0	<620	P92 (NF616)	Start 2000
35.0 – 47.0	700 - 720	Super Alloys	Start 2010

2) Turbines

Where the boiler becomes subject to extreme steam conditions in both pressure and temperature, as in the case of ultra-supercritical electric power generation, so does the turbine that receives the ultra-supercritical steam. Steam turbine development can be described as an evolutionary advancement toward greater power density and efficiency. Power density is a measure of the amount of power that can be efficiently generated from a steam turbine of a given physical size and mass.

As experienced by steam turbine original equipment manufacturers (OEMs) and other experts in the power industry, improvements in the power density of steam turbines have been driven largely by the development of improved rotor and bucket alloys capable of sustaining higher stresses and enabling the construction of longer last stage buckets for increased exhaust area per exhaust flow. Improvements in efficiency have been attained largely through two kinds of advancements, namely: (a) Improvement in mechanical efficiency obtained by the reduction of aerodynamic and leakage losses as the steam expands through the turbine, and (2) Improvement in the thermodynamic efficiency attained by increasing the temperature and pressure at which heat is added to the power cycle.

The rising trend in turbine efficiencies was always coupled with rising steam generating capacities and even in the number of stages of feedwater heating and steam reheats. Thus huge turbines as shown in the following

Figure 18 and Figure 19 have begun to get into the mainstream of electricity power generating fleet.

Figure 18 A Combined HP/IP Section of Ultra-Supercritical Turbine
[Courtesy of GE Power Generation]

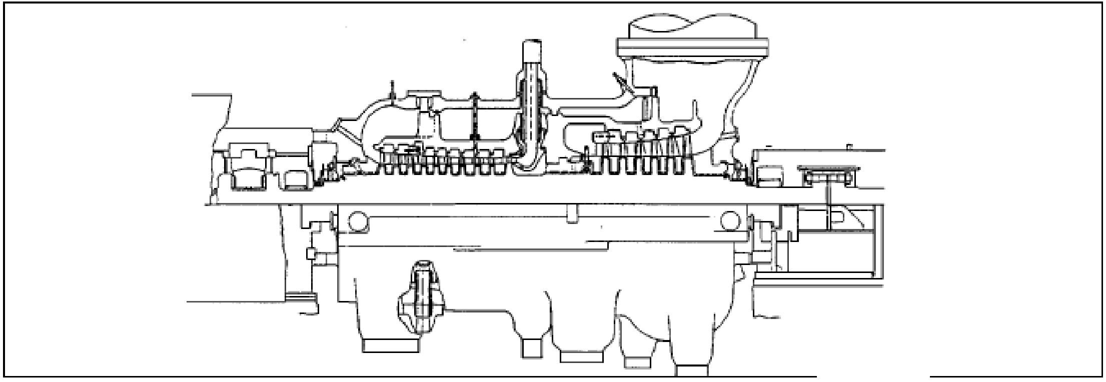


Figure 19 Separate HP and IP Sections of Ultra-Supercritical Turbine
[Courtesy of GE Power Generation]

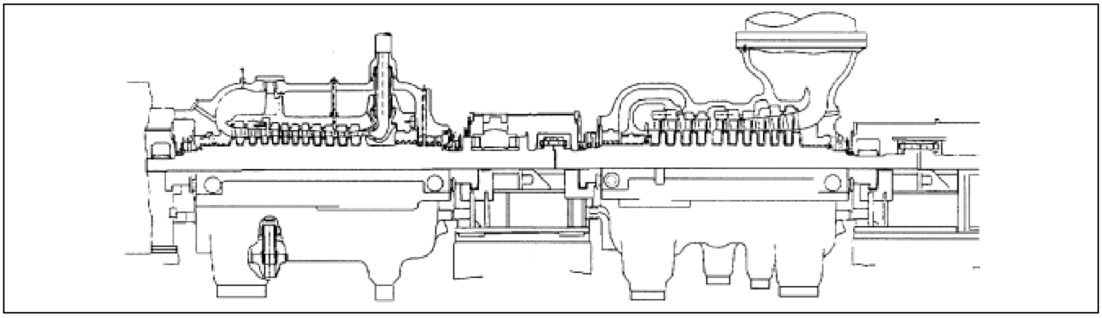
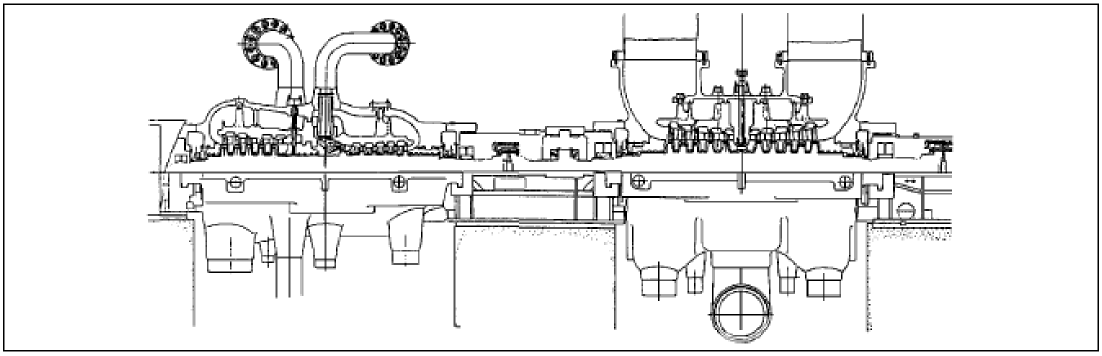


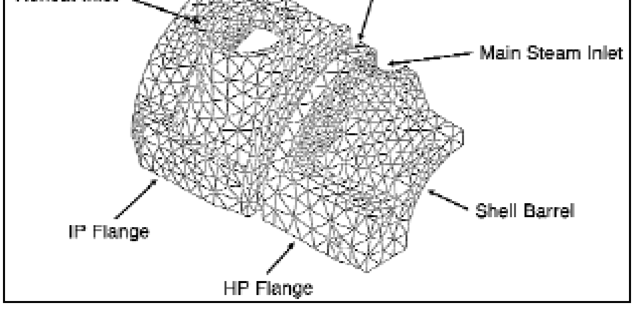
Figure 20 HP and RH Sections of a Double Reheat Ultra-Supercritical Turbine
[Courtesy of GE Power Generation]



Over the years, the design of high-temperature steam turbines had evolved and was strongly influenced by the development of improved materials and by the use of more effective cooling steam arrangements. Both factors are discussed for the various critical components, which are affected by advanced steam conditions. Major steam turbine OEM's, like for example General Electric, have extensive experience with two rotor alloy steels in high-pressure rotor applications: CrMoV and 12CrMoVCbN. The 12Cr steel is generally used when a higher rupture strength is required at elevated temperatures, or when a higher than normal operating temperature of 566°C (1050°F) is required. The first 12Cr rotor was placed into service in 1959. This material was developed in anticipation of a market need for steam turbines capable of operating at ultra-supercritical steam temperatures. These rotors have successfully operated in some of the most challenging applications in units rated between 500 and 1000 MWe. Buckets for the early HP and reheat stages of steam turbines must have good high-temperature strength and low thermal expansion to minimize thermal stresses. For ultra-supercritical applications, a 10CrMoVCbN bucket alloy similar to the rotor forging alloy was developed. This alloy possesses rupture strength nearly 50 percent higher at 566°C (1050°F) than the AISI 422 alloy traditionally used in applications of up to 566°C (1050°F). Together with use of axial entry-type bucket dovetails, judicious application of rotor cooling schemes, reheat pressure optimization. Low alloy CrMoV materials generally suitable for stationary components in turbines designed for conventional steam conditions are not suitable for the higher temperature regions of ultra-supercritical steam turbines. In various areas in the industry, high-strength martensitic stainless-steel casting alloys (10CrMoVCb) were developed in the late 1950s for valve bodies and nozzle boxes in applications with 566°C (1050°F) and 593°C (1100°F) inlet temperatures. HP sections of ultra-supercritical steam turbines generally utilize triple-shell construction to minimize the thermal and operating stresses that the various pressure containment parts are subjected to. The highest pressures and temperatures are borne by a nozzle box constructed of forged 12CrMoVCbN steel. The inner shells are constructed of cast 10CrMoVCb or CrMoV material depending on the specific temperatures associated with the ultra-supercritical application. With this type of construction, the outer shell is not subjected to elevated temperatures and can thus be constructed of traditional CrMoV material. The transition between the main steam leads and the outer shell has traditionally been designed as a flanged connection with thermal sleeves.

Today's ultra-supercritical designs employ a welded connection. The welded connection is cooled by the cold reheat steam on the inner wall to a temperature level of 550 - 565ºC(1025 - 1050ºF). To assure sufficient heat transfer near the weld, a small amount of steam is blown down to the next extraction point. IP sections of ultra-supercritical turbines utilize double shell construction with the high-temperature inner shell being constructed of cast 10CrMoVCb material and the outer shell and low-temperature inner shell constructed of traditional CrMoV material. Advancements in finite element (FE) calculation capabilities enable designers to assess the local stress field in these high-temperature components and, thus, selectively add material only where needed for strength purposes. This results in a shell design that satisfies all stress limitations and is thermally flexible to meet the shorter start-up times required by today's customers. Figure 21 shows an example of a FE mesh for an ultra-supercritical HP/IP inner shell.

Figure 21 Finite Element Model of USC HP/IP Inner Shell

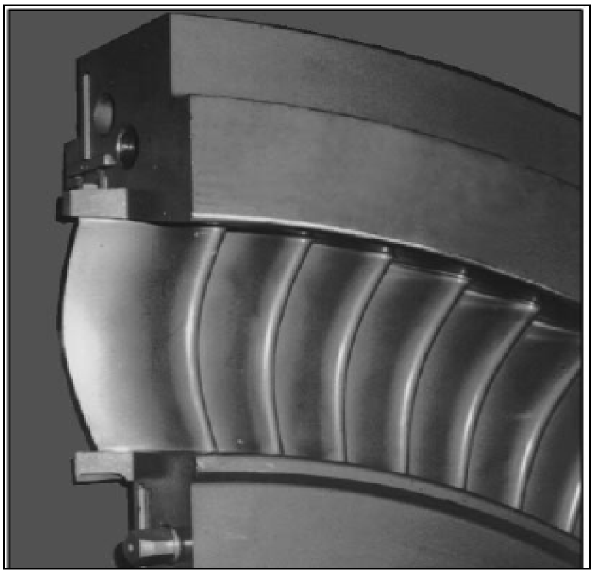


For shell bolting applications at temperatures up to 566°C (1050°F), 12Cr alloys and low alloy steels have been used. However, the more demanding ultra-supercritical steam conditions exceed the capabilities of these materials, thus dictating the requirement for nickel-based alloys in high-temperature regions. A comparison of candidate bolting materials possessing higher temperature strength was recently made and Inconel 718 was selected as the material possessing the best combination of all the bolting requirements. The use of Inconel bolts results in smaller bolt diameters and, therefore, narrower flanges. This, in turn, leads to lower transient thermal stresses during turbine start-ups. The primary LP section design issue associated with ultra-supercritical turbines is the elevated crossover temperature that is frequently encountered with these power cycles. It has been found that conventional NiCrMoV rotor materials have a tendency to embrittle at LP bowl temperatures above 350-375ºC (660-710ºF). In order to avoid this phenomenon, past high-temperature designs have used an internal cooling scheme that circulates the exhaust steam of the first LP stage into the upstream wheel space by virtue of special wheel hole scoops and a slightly negative root reaction. This design approach, however, results in a performance loss. Studies performed by EPRI and others over the past several years have demonstrated that NiCrMoV material can be made virtually immune to embrittlement by reducing the levels of P, Sn, Mn and Si. Utilization of this “superclean” chemistry combined with other enhancements such as raising the nickel content and gashing between the wheels prior to quenching, result in rotor forgings with superior embrittlement, fracture toughness and tensile ductility properties in comparison to previously available materials.

3) Advanced Steam Path Design

Recent years have seen the rapid advancement of computational fluid dynamics (CFD). Based on this new capability, turbine components can be better optimized for reduced flow losses. The performance of steam path components such as nozzles, buckets and seals have been significantly enhanced as a result of applying this new technology and the resultant performance gains have been verified both in test turbines and operating units. A segment of an IP section diaphragm utilizing advanced nozzle partition designs is shown in Figure 22.

Figure 22 Diaphragm Segment with Advanced Nozzle Partitions



In addition to the performance improvements attributable to CFD in the steam path, performance gains can also be achieved by optimizing stationary components such as valves, inlets and exhausts using the same tools. All ultra-supercritical designs in the future will incorporate these CFD-based design enhancements.

3.4.2.3 Current Status of Ultra-Supercritical Power Generation in APEC Developing Economies

People's Republic of China

Recently, PRC's power industry is paying more attention to coal-fired power generating plants designed with ultra-supercritical technology with large electric power generation capacity. As an example, the Huaneng Yuhuan Power Plant is the first 1000-MWe class ultra-supercritical coal-fired power plant in China. The plant is located at the southeast coast of Zhejiang province. Huaneng Yuhuan Power Plant plans to have 4 x 1000-MWe ultra-supercritical coal-fired units with a sea water desalination system on-site. The first unit was put into operation in November 2006, six months ahead of schedule, while the second unit was put into operation in December 2006. Two 1000-MWe ultra-supercritical units, Zouxian Unit #7 and #8, were also put into operation in December 2006 and June 2007, respectively. With gained experience and confidence through successfully building and running above ultra-supercritical units, more ultra-supercritical plants are under construction or in different development stages. A summary of twelve of similar 1000-MWe class projects in construction or design phase in China are listed in the following Table.

Table 14 1000-MWe Class Coal-Fired Plants Currently in Operation or Under Development in People's Republic of China

No	Plant name	Capacity MWe	Unit parameters (MPa/°C/°C) (psia/°F/°F)	Fuel	Operation Date
1	ZheJiang Yuhuan	4 x 1000	26.25 MPa 600ºC/600ºC (3807 psia/1112°F/1112°F)	Coal	In operation
2	Shandong Zouxian IV	2 x 1000	25 MPa 600ºC/600ºC (3626 psia/1112°F/1112°F)	Coal	In operation
3	JiangSu Taizhou	2 x 1000 (I) 2 x 1000(II)	25 MPa 600ºC/600ºC (3626 psia/1112°F/1112°F)	coal	2008
4	ShangHai Waigaoqiao (III)	2 x 1000 (III)	27 MPa 600ºC/600ºC (3916 psia/1112°F/1112°F)	Coal	2008
5	Beilun (III)	2 x 1000 (III)	26.25 MPa 600ºC/600ºC (3807 psia/1112°F/1112°F)	Coal	2009
6	ZheJiang Ninghai (II)	2 x 1000 (II)	26.25 MPa 600ºC/60ºC (3807 psia/1112°F/1112°F)	Coal	2009
7	TianJin Beijiang Power Plant	2 x 1000 (I) 2 x 1000 (II)	26.25 MPa 600ºC/600ºC (3807 psia/1112°F/1112°F)	Coal	2010
8	ShangDong Laizhou	2 x 1000 (I) 2 x 1000 (II)	26.25 MPa 600 ºC/600 ºC (3807 psia/1112°F/1112°F)	Coal	2009
9	GuangDong HaiMen	4 x 1000 (I) 2 x 1000 (II)	26.25 MPa 600ºC/600ºC (3807 psia/1112°F/1112°F)	Coal	2009
10	GuangDong Caozhou (II)	4 x 1000 (II)	26.25 MPa 600ºC/600ºC (3807 psia/1112°F/1112°F)	Coal	2011
11	GuangDong PingHai	2 x 1000 (I) 8 x 1000 (T)	26.25 MPa 600ºC/600ºC (3807 psia/1112°F/1112°F)	Coal	2010
12	HuBei PuQi (II)	2 x 1000 (II)	25 MPa 600ºC/600ºC (3626 psia/1112°F/1112°F)	Coal	2010

3.5 Comparative Assessments

A challenging aspect faced by the coal-based power generation industry is the phasing in of new technology and the phasing out of obsolete ones; both of these moves being undertaken, while being faced with the growing calls for environmental emission mitigation. However, these calls for environmental emission mitigation are expected to be complied within economic operational limits to do so. The focus for the comparative assessments among three advanced coal-based power generation technologies, i.e., IGCC, and advanced pulverized coal (SC & USC) technologies, are based on current developments in the People's Republic of China, which is an emerging APEC developing economy. At present there is no acknowledged definition of ultra-supercritical technology worldwide. In the People's Republic of China (PRC), a power generating plant is usually classified as ultra-supercritical, if the steam operating pressure is above 24.2 MPa (3510Psia) or the temperature is higher than 593ºC (1100ºF). For the ultra-supercritical units under construction in the PRC, the outlet parameters of the boilers are 26.15 MPa/605ºC/603ºC (3793 Psia/1121ºF/1117ºF) and the inlet parameters of the turbines are 25 MPa/600ºC/600ºC (3626 Psia/1112ºF/1112ºF). In this regard, different economies, including APEC economies, may have varying definitions of subcritical, supercritical and ultra-supercritical pulverized coal technologies. The capital costs of power generation projects may heavily depend on different economies, especially on where the major equipment is purchased.

Table 15 shows a brief economic and technical comparison among subcritical, advanced pulverized coal (supercritical & ultra-supercritical) and IGCC technologies in China. All the tabulated data herein were obtained from the PRC government agencies' guide data for newly built power plant in 2007 except the data for IGCC (China Huadian Corporation report), which is for the ongoing Banshan IGCC Demonstration project. From the Table 12 data, it can be seen that the capital cost of supercritical and ultra-supercritical units are quite close to each other and are lower than those of the subcritical PC and IGCC units. IGCC's capital cost is the highest and about double of that of the supercritical and ultra-supercritical units.

Table 15 Comparison of Three Power Generation Technologies

	Subcritical	**Supercritical**	**Ultra-Supercritical**	**IGCC**
Unit Capacity, MWe	300	600	1000	200
Steam Parameters at turbine inlet, MPa/°C/°C, (psia/°F/°F)(6)	17/540/540 (2466/1004/1004)	24.1/538/538 (3495/1000/1000)	25/600/600 (3807/1112/1112)	/
Typical Thermal efficiency(6)(7), %	38	41	44	≥45%(5)
Capital Cost, US$(RMB)/kW (2007)	587(4401)(1)(3)	486(3643)(1)(3)	498(3724)(1)(3)(4)	1130(8500)(2)(3)

(1) Target price per kWh for new plant using key equipments locally manufactured in China in 2007
(2) Banshan IGCC Project static capital cost data in 2007 (China Huadian Corporation Report)
(3) Currency exchange uses average rate in 2007
(4) Onshore plant use sea water once through cooling
(5) Expected efficiency specific for the Banshan project
(6) Data is from the report by Ai and etc, 2007
(7) All efficiencies are based on LHV.

4 DISCUSSIONS ON PROJECT DEVELOPMENT

4.1 Barriers and Countermeasures

This section presents the perceived deployment barriers of advanced coal technologies and suggests general countermeasures which can be applied to APEC developing economies. Hereunder are the likely barriers or obstacles, which are expected to be encountered while phasing in these advanced coal-based power generation technologies in any of the APEC developing economies: DISCUSSIONS ON PROJECT DEVELOPMENT RISKS

Table 16 Barriers to Advanced Coal-Based Power Generation Technologies Development with Corresponding Countermeasures

Areas of Concern	Perceived Barriers	Countermeasures/ Policy Proposals	Remarks	*
Cost and Finance	As of today, still higher than conventional system Lack of willingness to invest in new advanced technologies	Research; Economic incentives; Demonstration project; Education and communication; Standardization of system components such as IGCC	Cost can go down as technology matures	1
Advantages and Projected Performance of New Technologies	Perceived technical performance challenges	Demonstration project; Education and communication; Research and development of advanced technology	Performance can improve as technology matures	2
Business Relations Management	Multi-party relations required	Merging of multiple parties into one team, i.e., OEM like GE, and an Engineering Procurement Construction & Management Company like Bechtel	Power providers have to deal with OEMs, gasification technology providers and EPCM's	3
Institutional Obstacles	Lack of institutional channels to promote technological development	Long-term Plans such as: • Introducing market forces to the energy sector; • Permitting the import of foreign technology and capital; • Diversification of energy infrastructure	Institutions may be governmental bodies or non-governmental	4
Legislation	Existing Environmental Legislation not sufficient to stimulate demand for clean coal combustion technologies	Review the design and implementation of existing legislations pertaining to air pollution, etc.	Some legislation on Air Pollution may have imposed stricter levies to some sectors (ex. Transportation) but lenient on power generation.	5

Foreign Investment in the Power Sector	Complicated foreign participation policies	Ease restrictions to encourage more foreign partners in joint ventures	Foreign participation from developed economies enhances technology transfer	6
Power Project Permitting and Approval	A complicated and drawn-out licensing/permitting process for power projects	Streamline permitting and licensing procedures for projects related to advanced coal-based power generation projects	Complicated and long lead-time permitting approvals tend to discourage foreign capital/participation	7
Awareness Regarding Intellectual Property Rights	Challenges in developing appropriate mechanics to protect Intellectual Property Rights	Legislate more stringent laws protecting Intellectual Property Rights (IPR) then impose them more strictly; Apply flexible IPR approaches to reduce the time lag of technology diffusion	Laxity in protecting IPR discourages technology transfer; On the other hand, high patent fees are big hinders for technology diffusion	8
Energy Sector Support	Inconsistent and unstable energy sector policies	Review policies regulating power companies and ensure consistency and stability	Inconsistent and constantly changing policies discourage investors	9
Research Funding	Insufficient funding for research	More subsidies need to go to non-profit research groups	One of the biggest obstacles in APEC developing economies	10
Infrastructure	Insufficient infrastructure needed for new technologies	Support and incentives from government for infrastructure development	Coordination among different government sectors is very important.	11

Annotations to above tabulated Barriers (*):

(1) Cost of installation and operation of advanced technologies are still higher than traditional/conventional coal-based power technologies. For IGCC technology especially, the current project economics coupled with inadequate regulatory drivers and financial incentives, are creating significant obstacles to widespread adoption of IGCC in the power sector. In projects where future Carbon Capture and Sequestration (CCS) systems can be technically supported, even when the IGCC plants are being built, investments still may be slow to come unless price of IGCC electricity generation becomes competitive and meet industry reliability standards. The government and other stakeholders need to take some actions, including increased research and development activities, in order to reduce these costs. Technology-based or performance-based regulations can be applied as drivers. Measures such as taxes, subsidies, and tradable permissions, are economic or market-based initiatives. Another counter-measure would be to reduce energy market uncertainty. And, of course, that element of uncertainty in the market could be more on the pricing of the commodity itself, in this case electric energy, than the demand for it where the APEC developing economies are concerned. This is being said considering the general expectation that the APEC developing economies will be in a high growth, high electric energy demand phase in the coming years. A feature of highly competitive markets is that uncertainty about the future price of the product being supplied reduces the willingness to invest. In the electricity supply industry, uncertainty over the scope and details of

market liberalization deters investment in new and replacement capacity and motivates extension of the lives of current plants. Even after liberalization occurs, uncertainty may continue if there is an expectation that fundamentals of the regulatory regime might be changed in the future – including aspects of having to reduce greenhouse gas emissions. Policy makers and market regulatory authorities should, as much as possible, avoid creating a climate of uncertainty in moves toward liberalization of electricity markets and in regulation of markets thereafter. Environmental policy makers and regulators should, as much as possible, avoid the appearance of uncertainty over the future direction of policy and the implementation of regulations. At a minimum, governments can make sure that policies for energy efficiency are consistent and stable over time, so as to send reliable, long-term signals to businesses and consumers and to allow them to plan accordingly. It is also important that governments develop new mechanisms to support innovative efforts and that they use their own influence in support of their goals. Demonstration projects supported by government may show that a technology can be operated in a reliable and commercial way under certain circumstances (e.g., geographical or technical conditions). They provide cases of best practice, which might encourage companies or other governments to invest in a technology.

(2) Since these technologies are relatively new, like the IGCC's and USCPC's, power providers are still cautious about the long term performance and reliability of these advanced technologies. Demonstration projects may show that a technology can be operated in a reliable and commercial way and provide cases of best practice and overcome technical difficulties. Education and communication in the end-use sector is a useful means to address information related to the technology diffusion. The advanced technologies should, most importantly, be understood by the end-users or consumers, in this case the general public.

There have been a number of speculations about new technological developments and how it could harm the general public in the long term. For instance, some individuals and sectors in the society may have the idea and wrong notions that IGCC power plants could pollute the waters around the plant site even as it does cut down significantly the release of greenhouse gases. Inaccurate and untrue information about these advanced technologies can definitely impact on the political will of governments in APEC developing economies striving to improve the general welfare of the people.

However, there can be a number of measures that can be effective in addressing such barriers. A well-organized information and education campaign is just one of them. Governments and the public sector have an important role to play in transforming barriers into opportunities. Business associations, governments at all levels, utilities, private interests and others have developed a variety of approaches to promote acceptance of new concepts and ideas such as these advanced technologies that definitely promote energy efficiency. Measures range from introducing the new concepts of cleaner coal use for fuel (as an example) in small-town meetings, in schools, through non-government organizations, mass media, etc.

Finally, APEC economies would be best served if efficiency policies and programs set to motivate participants in all sectors of the economy, including individual consumers, are well established and implemented. These moves on mass information and education will be aimed to reduce market barriers by providing useful information aimed at reducing resistance to change and facilitating eventual acceptance; promoting improved practices, developing more efficient products and adopting energy-efficiency standards, targets and benchmarks. In doing so, these activities can help stimulate the demand side of the energy market and even extend to the adoption of more energy-efficient downstream facilities such as appliances, production processes and operating practices. Apart from end-user education, workshops, sight visits, networking activities in CCT technology may illustrate the applicability of a technology, and increase companies' awareness of technology-specific features like costs, reliability, environmental performance and etc. By convincing decision-makers, communication instruments may help to stimulate learning processes and overcome path dependencies which 'lock-in' outdated technologies. Research and development is a common way to further improve the performance of advanced CCT.

(3) The business relation management applies in lesser degree to SPC and USPC, but does apply greatly to IGCC. In order to construct a plant, energy providers have had to do business with multiple parties, including power equipment suppliers, gasification technology providers, and typically an engineering procurement contractor. Managing such a relationship and obtaining plant level performance and operating guarantees have been significant barriers to the commercial acceptance of IGCC. As an example, GE Energy's acquisition of the ChevronTexaco Worldwide Gasification business on June 30, 2004, and the subsequent Alliance work with Bechtel Corporation, provides a path to addressing these barriers.

(4) Some APEC developing economies have institutions, such as government arms or academic, industrial and technical/business organizations, that may not be ready yet to endorse these advanced technologies due to lack of exposure to them. Long term plans can be made through institutional channels to promote advanced CCT.

(5) The legislators and policy makers themselves have to be exposed and be fully briefed about the benefits and advantages of these new technologies and how these new technological breakthroughs in power generation can offer a boost to each developing nation's economic future, along with contributions to their region's environmental and public health.

(6) Foreign capital can be attracted to stay depending on an economy's attitude towards foreign investment. All capital stakeholders, whether foreign or local, are cautious about government intervention, but foreign capitalists, who could easily attract technological transfers, are very sensitive to policies affecting foreign investments and the business and economic climate that they are going to face.

(7) Bureaucratic red tape always is a hindrance to speedy and timely resolve of roadblocks to progress. Streamlined procedures without compromising safety and security of a developing economy can make a difference between sluggish development and a successful attainment of goals.

(8) Intellectual Property Rights (IPR) awareness is a very important aspect in economic development. It is most significantly felt in advanced coal-based power generation technologies where creativity and innovation are key factors to major breakthroughs. A significant part of the cost of new technology is the investment in R&D, and private companies want to recover R&D cost. So both foreign technology providers and local technological practitioners are wary about their intellectual property rights not secured, especially when it comes to critical inventions and innovation. So problems arise: a) how to protect IP rights but at costs lower for developing economies; b) How to shorten the significant time lag (generally one or more technology generation behind). This is actually being addressed by individual governments by considering at the same time the impact of introducing new regulations that are relatively new to some APEC developing economies.

Recommended IPR approaches are:

a) For technologies beyond primary development stage, IPR options are compulsory licensing and bilateral negotiations.

> **Compulsory licensing:** Government grants license to domestic manufacturers who must then pay a royalty to IPR holder. The key is that payment is over time, not up-front. For near commercial climate technologies, royalty could be paid to IPR holder on various bases depending on the technology. For example, royalties could be paid on the basis of annual kWh generated or sold electricity.

Bilateral negotiations: Economies reach an agreement with the IPR holder on potentially non-financial terms. For example, an agreement can be made for an exchange of Certified Emission Reductions (CERs) for climate technologies.

b) For technologies under development, a more flexible option for IPR is possible in addition to those above: IPR sharing.

Industrialized and developing economies commit resources to international organization that coordinates and develops new technology. Organization holds IPR and Technology is available to all.

(9) Policies and regulations affecting day by day operations of an electric power generating company have to be more predictable and consistent in order to promote more accurate forecasts and long term financial stability. Unpredictable and volatile policies can cause capital stake holders to withhold more aggressive business expansions.

(10) Continuing research for new technological solutions to prevailing problems facing these advanced coal-based power technologies is an assurance of a sustained entry of these new technologies to mainstream power generation. For example, R&D support of new technologies will be crucial for enabling widespread and rapid penetration of highly efficient coal-fired power plants and CO_2 capture and storage. Lack of research funds is one of the biggest obstacles in APEC developing economies. One of the means to generate funding is that research funds may be jointly raised by APEC economies acting hand-in-hand with the private sector and international bodies/foundations dedicated to the advanced coal technologies.

(11) In some cases, the use of new technology requires infrastructure investments that are beyond the capacity of any one market actor to provide. This is true especially to an IGCC facility that will be provided a room for carbon capture and sequestration (CCS) expansion. For example, additional infrastructure will be needed for CO_2 compression, piping, storage and final sequestration of the greenhouse gases.

The needed infrastructure (CCS upgrade) can be retrofitted into existing systems provided sufficient incentives exist for doing so, but the retrofits may be carried out by other parties, not the original technology provider at a later stage. Other infrastructural reinforcements could be provided to coal transport and handling towards green-field sites most suitable to these advanced coal-based power generation technologies. Close coordination of other sectors with the energy sector with regard to future developments, such as transport sector sharing information about plans for new airports and other transportation accesses (highways and waterways).

The needed infrastructure can be very extensive and involves the cooperation of various parties. Governments can invest directly in new infrastructure or provide incentives (such as tax incentives, subsidies and expedited regulatory review) for the private sector to be attracted to new technology ventures. To be effective, incentives must signal a long-term commitment to new ways of delivering energy services in order to provide needed investor confidence. Government efforts to increase demand for new technology can help overcome this particular barrier. Government also has a role in facilitating infrastructure investment decisions when multiple parties are involved. For example, there is ample evidence from several economies that such a role can help overcome obstacles to investment in various new technology energy ventures.

4.2 Project Risks and Risk Management

It is an axiom that any new technology trying to gain the confidence of a conservative industry, such as the power generation industry for instance, would have to struggle and prove its worth at its development stage. The advanced coal-based power generation technologies, namely the SCPC, USCPC and IGCC, are no exceptions. Although the supercritical boilers have been running for several decades now, ultra-supercritical pulverized-coal-fired steam generators still have to prove themselves to be as established as their SCPC predecessors in terms of reliability and material integrity encompassing all major system components down to their driven turbine – generators. On the other hand, the Integrated Gasification Combined Cycle technology is perceived even to be in a more challenging status. In some circles in the power industry, IGCC is still viewed as more of a chemical plant than a power generating plant. This mindset among some players in the industry must be overcome in order for IGCC to gain a wider acceptance. Yet, perhaps the principal obstacle to the development of advanced coal-based power technology projects are their capital costs. The IGCC is even more difficult to finance as the capital cost of a new IGCC facility is approximately 20 to 30 percent higher than the cost of a new conventional pulverized-coal-fired plant. Operation and maintenance costs are less certain because there is relatively little power industry operating experience with the IGCC technology. In short, IGCC is perceived to have operating risks that are neither clearly understood nor fully quantified.

In the case of an APEC developing economy, one option for facilitating the deployment of IGCC, as well as SCPC and USCPC, is called three-party covenant financing. Similar to a public/private partnership, it is an arrangement among participants of a group such as the government of any APEC economy, a state public utility commission, and an equity investor to finance and seek cost recovery of the major capital investments in an advanced technology project. This type of arrangement or covenant should seek to lower advanced technology capital costs by reducing the cost of debt, raising the debt/equity ratio, and minimizing the cost of construction financing.

Emission regulations may still be in the drawing board and may not be in effect as of today, but electric power generation companies that foresee regulation of greenhouse gas emissions understand well the benefits of fuel diversification, and desire to eliminate fuel price volatility to the extent possible. Accordingly, these companies are pressing the case for coal gasification in their long-term integrated resource planning.

Despite established alternatives to IGCC and USCPC, these technologies are broadly considered leading reasons for the recent rebound in interest in coal-fired generation. However, some concerns are casting doubts over their near-term commercialization. Therefore, these doubts must be addressed thoroughly and in a timely fashion to maintain momentum of this revived interest in coal use as fuel for power. In a report by Berlin and Sussman in 2007, some of the following suggestions were proffered to enhance interest and keep up the momentum for these advanced technologies:

- Demonstrate technology reliability. Prove the technology is suitable for re-powering of existing plants.
- Address the perceived risks, which are mainly availability/reliability and costs. New operating historical data (both operational and financial) on newly installed advanced technology coal-fired power plant facilities can be closely monitored and immediately analyzed.
- Financial and regulatory bodies associated with the development and operation of power plants using IGCC/USCPC/SCPC technologies have to be frequently updated with developments from the field.
- Convince the public that these new advanced technologies indeed lessen emissions to the benefit of the general public.
- Mitigate the financial risks of installations by spreading liabilities among several risk takers. This move can be further expanded to the limited forms of funding in structures for both equity and debt, and risk management through insurance.

In APEC developing economies, possible risks may be confronted to develop projects applying the three advanced technologies.

4.2.1 The Risks of Development, Construction and Trial Production of a Project

1) The risk at the phase of development, construction and trial production of a project

(a) Risk due to government approval

Government approval of the project is one of the most critical factors for financing the projects using either conventional or advanced coal technologies. As the project approval process often takes a long time, project financing should be initiated or even completed at the stage of submitting proposal. If the government approval process slows down because of macroeconomic policy adjustments or state investment system reforms, the project working procedures may be fundamentally changed. It will bring difficulties to the project, and the project's profitability may be greatly reduced.

(b) Credit Risk

Credit risk refers to the parties involved in the project that could not perform or would refuse to implement the provisions of the contract responsibility for whatever reasons. As soon as shareholders of the project, the project company and other relevant participants sign any agreement, corresponding commitment is formed. Once the costs of carrying out the agreement under the responsibility and obligation increase, the risk to evade its responsibilities also will increase; credit risk will then increase.

(c) Risks due to environment protection

Environmental risk refers to risk of increased investment or project failure due to meeting environmental regulations and requirements. It is possible that during the project period, because of stricter legislation for environmental protection additional investments to improve the performance and meet the regulation is needed; hence the project construction and production costs would increase, and the productivity and competitiveness would decrease. However, due to the relatively superior environmental performance of these three advanced coal technologies, the risk is expected to be within manageable limits, especially for IGCC.

(d) The risk of project completion

The project completion risk refers to the possibility that project construction could not be finished in accordance with the provisions of the scheduled time and to meet the economic and technical indicators in the schedule. Projects may have high cost overruns and are therefore forced to halt.

The delayed project completion may increase the construction costs, and loan interest and result in investment cost overruns. Consequently, the project cash flow may not be realized as planned; the expected return may not be achieved. If the project were delayed for too long, labor and raw materials costs could also increase. The delay may have serious impact on the economic benefits of the project so that the sponsors and creditors may consider giving up this project. Therefore, the risk of project completion is one of the most critical risks.

The project completion risk may be caused by, but not limited to, the following:

- Technical difficulties
- Political condition changes

- Project contractor
- Market issues
- Labor or raw materials supply
- Plant site availability
- Unexpected events such as natural disaster, wars, etc.

2) Management of the risk at the phase of development, construction and trial production

For a project applying new coal technology, especially in IGCC case, project risk can be minimized through progressive stages of project definition: feasibility study, FEED, EPC and commercial operation.

A good practice of risk management for project completion risk is a "turnkey" contract with fixed-price and fixed schedule so that contractor will take most of the risk. This is the best model for the funder, as it shifts the risk to the contractor. However, in today’s environment, most contractors may not accept a “lump-sum, turnkey” contract. There are other contracting paradigms, however, that share the burden of the risk to varying degrees between the funder and the contractor that can successfully be employed.”

In a “turnkey” power project, the completion standard in the contract is structured in a way such that not only the plant construction should be finished within the scheduled time frame, but also plant performance meets the design technical and economic targets as the indicators of completion.

The project sponsor or other participators should have the ability to provide for a certain level of budget overruns due to project uncertainties attendant to the use of new, advanced coal technologies, or to the increase in cost of materials or other inflationary issues, so that there is no disruption to the project’s progress and ultimate completion.

Good supervision of project construction is absolutely necessary to assure that the plant meets the design targets and stays on schedule and within budget.

To reduce the risk, all parties involved in the project should have good credit, business performance and management capabilities.

Project sponsors may take measures to seek government support in project financing within reasonable limits to create a supportive environment. The support may include but not limited to:

- Positive economic policies such as tax credits, tradable instruments, etc.
- Administrative approval of the project by government agencies.
- Support in the project’s external environment, such as necessary approvals for the construction site, water source and other public utilities.

Power project environmental risks arise when the project environmental indicators do not conform to government environmental policies/regulations, or the government environmental policies/regulations change during the project development process.

4.2.2 The Risk and Risk Management at Production and Operation Phase

1) The risks at production and operation phase

The production and operation of the project can encounter risks due to management, technology, energy and raw material supply, labor conditions and other factors. Considering that the three advanced coal technologies are relatively new in APEC developing economies, well trained operation and maintenance staff are crucial for the project to meet design technical and economic performance targets.

Like other conventional coal power generation projects, the market risks are mainly a function of electricity price and demand, fuel cost/availability, labor costs, etc.

Interest rate risk and exchange rate risk are two major economic risks in project financing.

Situational and political changes within the government could shift preferences and priorities and may greatly affect the chances of failure or success of power generation projects, as there would be changes to the structure of credits and debt repayments.

The risk could be due to a particular economy's political stability and maturity of economic policy. The project may involve energy, environmental protection, taxation and other policies. On the other hand, the changes in policies may cause increasing production costs and reducing revenues.

Risks also exist due to an incomplete or immature legal system in the area of energy and/or environmental law and regulation. Such could increase the project financing risk.

2) The risk management at production and operation phase

Operating and maintenance staff can be trained by equipment suppliers or other running facilities. As diminishing development risks can be gauged by how much new coal-based power generation projects in the APEC developing regions have adopted these advanced technologies, then perhaps this trend is being seen today in the People's Republic of China (PRC) power industry. The slowly growing acceptance by stakeholders in adopting these advanced technologies can be discerned from the following dialogue proceedings between the APEC/EGCFE (EWG)-WorleyParsons Study Group and a Chinese delegation of power industry key players.

Presented below are excerpts taken from the interaction/dialogue between the APEC/EGCFE (EWG) –WorleyParsons Study Group and the Chinese delegation of electric power engineering and construction experts, held on December 6, 2007 in Reading, Pennsylvania, U.S.A. A photograph taken during the visit to record the event is included in this report and attached as part of the Appendix 2. For the full text of the dialogue proceedings, please also refer to Appendix 2

Query from the APEC-ECFMG-WorleyParsons: "Are there current plans to extend operating life of plants which are now at 25-30 years of operation by moving from base-loaded to 2-shift operations?"

Response from the Chinese Delegation: "*There are no such plans considering it has now become a general government policy or program to retire older generating units within the next 5 years. These are mostly small capacity units. The new coal-fired power plants and those still planned to be built are usually rated 300-MWe or larger*".
[**Note**: When the APEC-ECFMG/EWG project study director added a question regarding the approximate number of power plants in China that are likely to be retired soon, the answer to the query was: "…… *about 10,000 MWe of old generating capacities shall be replaced with new*

ones annually for five years resulting in a total of 50,000 MWe's of capacity scheduled to be retired."]

There was a follow up question:

Query from the APEC-ECFMG-WorleyParsons: "How many of the newly-built coal-fired power plants in China today (approximate in terms of percentage to total number of plants being built) are designed with supercritical or ultra-supercritical steam pressures in order to attain greater operating efficiencies?"

Response from the Chinese Delegation: "*In China today, all new 600-MWe power plants are of the supercritical or ultra-supercritical design. The same applies to 300-MWe cogeneration plants."*

From the study team's direct interaction and personal exchanges of information with the very people running the coal-based power show in PRC today, it was learned that advanced technologies, particularly the SCPC and USCPC, are becoming the standard for future coal-based power generation. IGCC was also mentioned in that dialogue, and it was confirmed that there are now IGCC units being constructed in the PRC.

5 ECONOMIC EVALUATION OF COAL-BASED GENERATION OPTIONS

In this part of the report, the economic strengths and viability of the three coal generation technologies, namely: the supercritical, the ultra-supercritical, and the Integrated Gasification Combined Cycle technologies are tackled. While there are various ways of assessing the economic viability of each option, the most widely used approach in the electricity industry for this purpose is employed below, i.e., the calculation of the *levelized cost of electricity*.

In any given electricity generation project, the levelized cost represents the constant stream of costs over the life of the plant, which when discounted back to present value dollars is equal to the present value of the actual stream of costs. Levelized cost is calculated by annualizing the present value of total costs and dividing this quantity by the annual energy produced. The cost of capital shall be picked in such a way that it is at a certain level where it remains competitive against all other options where money could be deployed for fruitful ends. Although the cost of capital to be used in the assumption of the study cases may not necessarily represent the opportunity cost of capital, still it should offer some indication of the relative risk profiles of the different ownership alternatives.

As the study cases are presented in a later part of this section, the following features of the levelized electricity costing methodology shall be noted:

- The assessment or evaluation exercise will reflect a situation in an APEC developing economy, where there is a real surge in the demand for additional electric power generation.

- The levelized costing calculates in current dollars all capital, fuel, and operating and maintenance costs associated with the plant over its lifetime, and divides that total cost by the estimated output in kWh over the lifetime of the plant. The capital shall be stated in percentages whether borrowed through bonds or owners equities. Fuel, in this case coal, will be calculated based on the estimated consumption on an annual basis and at the price predicted to prevail in the particular APEC developing economy of choice for the study.

- Another variable included in the levelized costing calculations will be the economic life of the project or plant under study. Usually a 25- or 30-year life span is used. In this instance, a conservative 25-year life span is used.

- The capacity rating of the plant, as well as the degree of its utilization, meaning up to what level of the nameplate rating is delivered or utilized and how much of the time are the generators of electricity running, are likewise important components of the economic evaluation.

- No attempt shall be made in this analysis and calculations to include in the levelized cost quantification of the benefits or penalties due to environmental factors, such as criteria pollutant control and CO_2 capture and sequestration, as these factors are beyond the scope of this study.

- The report also will not attempt to capture site-specific factors, such as radial transmission additions, fuel delivery, system upgrades and plant site elevation. In addition, the levelized cost analysis does not capture all of the system attributes that would typically be examined by a portfolio manager when conducting a comprehensive comparative value analysis of a variety of competing resource options.

The cost inputs used in the levelized cost evaluation are discussed briefly herein for the sake of clarity in this presentation. Costs associated with electric power facilities fall into three main categories, namely: investment cost, annual operations and maintenance cost, and variable operating costs.

(1) Installed Cost - Initial investment costs are those which are spent in planning, permitting, constructing, and plant start up. In the presentation of this case study this will be plainly referred to as the Installation Cost. This cost is typically financed through a combination of loans, i.e., debt financing, as in bonds, and investment ownership or equity financing. Built into the levelized costing evaluation is the provision that these costs must be repaid to lenders and investors over the life of the project. Debt financing usually has fairly rigid conditions related to the term of the loan, the required periodic payments and the security of repayment, much like a home mortgage. Bonds are other forms of non-equity financing. A bond is an interest-bearing or discounted government or corporate security that obligates the user to pay the bondholder a specified sum of money, usually at specific intervals, and to repay the principal amount of the loan at maturity. On the other hand, equity financing is usually repaid from the residual revenues remaining after paying all other costs and, as a result, has a higher risk of not being fully repaid compared to debt financing. This levelized cost analysis makes the assumption that these investments are recovered on a relatively constant annual basis without regard to the amount of generation output. This annual expenditure is then divided over the annual generation to derive the average cost per kWh for the investment or capital component.

(2) Annual operations and maintenance (O&M) costs – These costs do not necessarily vary directly with the amount of output, but would cease if plant operations ended. Operational costs include labor and management, insurance and other services, and certain types of consumables. Maintenance costs include scheduled overhauls and periodic upkeep. As with capital costs, these costs are summed and divided over the annual generation output to arrive at the average cost per kWh. However, unlike capital costs that are relatively insensitive to operational mode, the mode of operation can greatly affect these types of costs. For example, intervals between overhauls may be extended if a plant shifts from intermediate to peaking operations. In some APEC developed economies, for instance, less labor may be required for an electricity generation plant that operates only during the seasonal peak period, as contrasted to one that is operated as a base-load power plant. However, this case of seasonal power plant loading may not happen in APEC developing economies where the demand for electricity has been on the surge in recent years and is anticipated to continue in coming years. In addition, these costs typically escalate over time, compared to capital costs that are considered constant and fixed once the initial investment is made. Nevertheless, once the mode of operation is determined, the annual O&M costs will vary little and are quite highly predictable over time.

(3) Fuel and Other Variable and Costs – Fuel, in this study being coal, varies in its costing calculation with load. Variable costs are derived from fuel consumption, maintenance expenditures for forced outages, and other input costs driven directly by hourly plant operations.

The values of levelized costs of electricity in the study case analysis portion show the results of the cost analyses for the three advance coal-based power generation technologies covered in this report. Expected levelized costs, constant annual payments made over the life of the plants, are shown to provide a common basis of measurement. In the manner in which the numbers are presented, levelized costs are given as constant, or real, dollars. Therefore, considering that money values fluctuate or more predictably inflate over time, this report uses a base year of 2007.

5.1 Advanced Coal Technology Cost Risk Management Strategies

Advanced coal-based power generation technologies generally promote environmentally cleaner operations, and in many cases, in the long term, could be more efficient and less costly than conventional/sub-critical coal-power generating systems. Hopefully, these technologies will contribute to the major objective of enhanced national energy strategies for many APEC member economies. The abundant domestic reserves of coal in several APEC economies, such as the U.S., Indonesia, China and Australia, provide one of APEC's most important resources for sustaining a secure energy future. Some APEC-member developed economies have pursued research and development (R&D) programs to increase the use of coal while improving environmental quality. However, technologies displaying potential at the proof-of concept scale in an R&D program must be operated at a larger scale to demonstrate readiness for commercialization. The research and development programs in these APEC-member developed economies have helped move promising technologies from R&D to the commercial marketplace through demonstration. Successful demonstrations also help position a given country to supply advanced coal-fired combustion and pollution control technologies to a rapidly expanding world market. On the other hand, other APEC economies like Japan and China have been moving forward on their own in developing funding to accelerate commercial deployment of advanced coal-based technologies for generating clean, reliable, and affordable electricity.

However, while experiments in the downstream conversion of coal liquids into usable products have proven successful, China's first primary coal liquefaction plants did not work as smoothly as expected. In Pingdingshan, in central China's Henan province, a 500,000 metric tons liquefaction plant launched in 1999 failed when local coal proved to have too much sulfur and ash content to be suitable for liquefaction. Nevertheless, in 2001, under the Ministry of Science & Technology's '863 program,' the government increased its involvement in funding high-tech coal liquefaction research projects. In 2003, China overtook Japan as the world's second largest oil consumer behind the US. In addition, oil prices started to rise, adding even greater impetus to the development of upstream coal liquefaction projects.

China established, in 2004, an Energy Bureau to focus on national energy security issues and to plan and manage the nation's energy supply and related industrial development. A year later, the National Development and Reform Commission (NDRC) issued China's medium-and-long-term energy development strategy, which highlighted ten key projects to complete in the nation's eleventh Five-Year-Plan period. Among them is the development of alternatives to oil, through specific measures such as accelerating coal liquefaction projects. Those earlier developments have now contributed to the growing confidence in China to engage in more advanced coal utilization, not only in mere liquefaction, but also in merging the chemical process block of coal liquefaction into a combined cycle power block of an Integrated Gasification Combined Cycle process. This move to enhance its coal liquefaction technology, of course, has not lessened this particular economy's push towards more power generation capacity build-up using the advanced pulverized-coal technology, i.e., SCPC/USCPC.

The efforts of APEC member economies in building commercial scale advanced coal projects can demonstrate and showcase to prospective domestic and overseas customers an operating facility rather than a conceptual or engineering prototype, and this provides a persuasive inducement to replicate the technology. Data obtained on operational characteristics allows prospective customers to assess the potential of the integrated technologies for commercial application. Successful demonstration enhances prospects of exporting the integrated technologies to other APEC and Non-APEC economies and could provide the United States, Japan, Australia, China, and others with an important advantage in the global competition for new markets. A particular APEC member economy's capability to build more advanced technology coal-based power generation facilities also reduces the risk in installing future power plants utilizing these technologies.

5.2 Case Study

This section presents actual cases of advanced technology coal power generation projects. These projects are identified to represent the current trend of shift from the conventional to the advanced technology coal-based power generation. Both cases are located in the People's Republic of China, which among the APEC developing economies has the greatest number of power plants built in the last decade.

5.2.1 Case Study 1: Kemen Power Plant (Supercritical Pulverized-Coal Plant)

In this case study, Kemen Power Plant Project of the People's Republic of China is selected for the supercritical pulverized-coal technology case study.

1) Project Name/Identification and Background Information

Kemen Power Plant is an on-shore coal-fired power plant, which is located at Fujian province. Two 600-MWe supercritical units of the 1st phase of the plant, unit #1 and unit #2 are already in operation. The 2nd phase has the same 2 x 600-MWe supercritical units (unit #3 and #4). Unit #3 is expected to be put in operation in June 2008 and unit #4 is planned to be in commercial operation by November 2008. The units are designed mainly for base load operation with capability of peak load operation.

Boiler, steam turbine and generator will be all supplied by China Shanghai Electrical Group. The boiler is supercritical once through type using plasma technology as the main ignition system and fuel oil ignition system as backup. The plant applies a sea water once-through cooling system. The design thermal efficiency of the units is 43.48 percent (unit #3&4).

2) Project Participant(s)

The project is funded and owned by China Huadian Corporation. The plant was designed by Fujian Electric Power Design Institute (FEDI).

3) Project Cost

First Phase + Second Phase: 4 x 600-MWe, Total investment is US$ 1200 M or 9.0 billion RMB (US$500/ kW or 3750 RMB/kW).

4) Performance of the Project

Units #1 and #2 have been put in operation successfully and Units #3 and 4 are expected to be started as scheduled.

5) Identified Project Risks and Risk Management

Concerns for project risks regarding a supercritical power plant, especially one that is sited in the People's Republic of China, are the lowest among the three cases (SCPC, USCPC and IGCC) presented in this report. The power industry has accumulated significant experience in this area as compared with the other two cases under study. The price of fuel (coal) can spell the difference between high and low return of equity, but this is something that the coal industry is working on diligently to sustain growth for all the players in the market. Environmental pollution problems are being addressed in the same diligent fashion as all who are involved with the pulverized-coal technologies (the other technologies being the sub-critical and ultra-supercritical PC’s). The development in the post-combustion cleaning of coal emissions is gaining momentum and progress just as the pre-combustion cleaning approach is getting a lot of attention, along with the development of IGCC technology.

6) Sensitivity Analysis for Case 1

In order to predict the degree of desirability or undesirability of a project under study, sensitivity analyses are normally conducted if only to ensure how much would be at stake in the event that major parametric values vary negatively or positively.

Table 17 Summary of Sensitivity Study for Case 1

Case 1 – Kemen Power Plant (SCPC), People's Republic of China				
	Base	**Sensitivity Set No. 1**	**Sensitivity Set No. 2**	**Sensitivity Set No. 3**
Project Life, Years	25	25	25	25
Installed Capacity, kW	2,400,000	2,400,000	2,400,000	2,400,000
Installed Cost, KUS$	1,200,000	1,200,000	1,080,000	1,080,000
Output per Year, MWh	16,819,200	18,921,600	18,921,600	18,921,600
Capacity Factor, %	80	90	90	90
Fuel Cost/yr, KUS$	647,502	728,440	728,440	636,078
O & M Cost/yr, KUS$	92,384	98,566	98,566	98,566
Bonds, % of Capital	40	40	40	40
Heat Rate, BTU/ kWh	9210	9210	9210	9210
Sensitivity Conditions				
Reduced Installed Cost	Reference case (not applicable)	Not applied	YES; Installed cost to be 10% lower than base	YES; Installed cost to be 10% lower than base
Increased Availability	Reference case (not applicable)	YES; from 80% to 90%	YES; from 80% to 90%	YES; from 80% to 90%
Reduced Coal Price	Base Coal Price = US$4.18/mmBTU	Not applied	Not applied	YES; same as U.S. price of coal = US$3.65/mmBTU
Required to meet sensitivity condition	Reference case (not applicable)	A) Training; preventive maintenance	B) Improved EPC Efforts; more local material content	Same as A) and B) in Sensitivity Sets Nos. 1 and 2
Levelized Cost, US$/kWh	0.06282	0.06128	0.06032	0.05455
Improvement of Cost over Base Case	-	2.45%	3.98%	13.16%

5.2.2 Case Study 2: Laizhou Power Plant (Ultra-Supercritical Pulverized-Coal Plant)

In this case study, Laizhou Power Plant Project is selected for the case study. In this project, two ultra-supercritical units are being under construction at present time, and two other similar units are being planed.

1) Project Name/Identification and Background Information

Huadian International Laizhou Power Plant is an on-shore coal-fired power plant, which is located at Laizhou City, Shandong province. The current planned capacity of the plant is 4×1000-MWe. Phase I (Units #1 and #2) was put in operation in November 2007 and the first unit is planned to be in commercial operation by December 2009, while the second unit is planned to be in commercial operation by April 2010. Boiler, steam turbine and generator will be all supplied by China Dong Fang Electrical Group with technical support from Babcock-Hitachi Company (Boiler, Japan).

The boiler has the following characteristics:

- Ultra-supercritical operation, variable pressure,
- Concurrent, single reheat, balanced draft, dry bottom,
- Entire steel boiler truss, suspended structure,
- Π-type configuration,
- Front wall and rear wall counter flow combustion with low-NOx burners,
- BMCR of the boiler is 3033 tonne/hr, and
- Outlet parameters of 26.25 MPa/605ºC/603ºC (3807 psia/1121ºF/1117ºF).

The steam turbine has the following characteristics:

- Single intermediate reheat,
- Single shaft, four cylinders and four exhausts, double back pressure,
- Condensing turbine with eight stages of regenerative extractions,
- Combined admission mode (nozzle governing + throttle governing),
- Rated capacity of 1039 MWe,
- Inlet steam parameters of 25 MPa/600ºC/600ºC (3626 psia/1112ºF/1112ºF) using sea water cooling,
- Nominal power generation of 1039 MWe,
- Rated voltage of 27kV,
- Power factor of 0.9,
- F grade insulation required, and
- Generator cooling type is water-hydrogen-hydrogen.

2) Project Participant(s)

The project is funded and owned by Huadian Power International Company Ltd, which is one of the largest power producers in China. The company constructs and operates power plants and oversees other businesses related to power generation. At present, Huadian Power operates a total of 12 power plants with a total installed capacity that exceeds 10,300 MWe. The company owns the entire interests in Zouxian Power Plant, Shiliquan Power Plant, and Laicheng Power Plant. Huadian Power manages power plants that represent more than 20 percent of the total installed capacity of Shandong Province. The company was founded in 1994.

3) Project Cost

First Phase: 2 x 1000MWe, Total investment is US$ 1120 M or 8.4 billion RMB (US$569/ kW or 4200 RMB/kW).

4) Performance of the Project

Construction of this project began in January 2006 and is expected to start operation by December 2009.

5) Identified Project Risks and Risk Management

Table 18 Identified Project Risks and Risk Management

Item	Identified Project Risk	Risk Management / Comments
1	Ultra-supercritical pulverized-coal power plants pose particular risk challenges for maintaining equipment reliability and flexible operation at more advanced main steam conditions	Dramatic improvements in materials technology for boilers and steam turbines since the early 1980s, plus improved understanding of power plant water chemistry, have led to increasing numbers of new fossil power plants around the world that already employ supercritical steam cycles. Additionally, the reliability and availability of more recent supercritical power plants have reportedly matched or exceeded conventional units in base load operation, after early problems in first- and second-generation supercritical boilers and steam turbines were overcome.
2	A major challenge for USC steam technology is the selection or development of candidate alloys suitable for USC use.	Since the materials for USC boiler (ferritic alloy SAVE12, austenitic alloy Super 304H, the high Cr-high Ni alloy HR6W, and the nickel-base super-alloys Inconel 617, Haynes 230, and Inconel 740) have been already identified, a remaining major challenge is the selection or development of candidate alloys suitable for use in the USC steam turbines.
3	Project financing challenges considering the plant is solely funded by Huadian Power International Co.	In the company's Interim Financial Report, the company (Huadian) has expressed to actively explore additional fund-raising channels so as to lower the Company's finance costs and rationalize its capital structure, and prepare ahead for meeting future financing needs arising from business expansion. The company has endeavored to complete the Company's proposed issue of A shares in the second half of the year 2004.
4	Management and internal control challenges	The company owning the power plant has utilized computerization to introduce single entry point for multiple entry and improved accuracy.
5	Long engineering time during construction phase	A China-North American /China-Japan or European engineering cooperation can enjoy 7x24 hour around-the-clock engineering activities because of time zone strategic positions.

6) Sensitivity Analysis for Case 2

Table 19 Summary of Sensitivity Study for Case 2

Case 2 – Laizhou Power Plant (USCPC), People's Republic of China				
	Base	**Sensitivity Set No. 1**	**Sensitivity Set No. 2**	**Sensitivity Set No. 3**
Project Life, Years	25	25	25	25
Installed Capacity, kW	2,000,000	2,000,000	2,000,000	2,000,000
Installed Cost, KUS$	1,120,000	1,120,000	1,008,000	1,008,000
Output per Year, MWh	14,016,000	15,768,000	15,768,000	15,768,000
Capacity Factor, %	80	90	90	90
Fuel Cost/yr, KUS$	507,362	570,783	570,783	498,411
O & M Cost/yr, KUS$	68,146	73156	73156	73156
Bonds, % of Capital	40	40	40	40
Heat Rate, BTU/kWh	8660	8660	8660	8660
Sensitivity Conditions				
Reduced Installed Cost	Reference case (not applicable)	Not applied	YES	YES
Increased Availability	Reference case (not applicable)	YES; from 80% to 90%	YES; from 80% to 90%	YES; from 80% to 90%
Reduced Coal Price	Base Coal Price = US$4.18/mmBTU	Not applied	Not applied	YES; same as U.S. price of coal = US$3.65/mmBTU
Required to meet sensitivity condition	Reference case (not applicable)	A) Training; preventive maintenance	B) Improved EPC Efforts; more local material content	Same as A) and B) in Sensitivity Sets Nos. 1 and 2
Levelized Cost, US$/kWh	0.06066	0.05905	0.05797	0.05255
Improvement of Cost over Base Case	-	3% lower than base case	4.5 % lower than base case	13.4 % lower than base case

5.2.3 Case Study 3: Banshan Power Plant (IGCC Plant)

1) Project Name/Identification and Background Information

Banshan Integrated Gasification Combined Cycle (IGCC) Power Plant, which is located in Hangzhou city, Zhejiang province, is selected in this case study. This IGCC plant is a 200-MWe power generation unit. It is one of the three ongoing IGCC demonstration power plants in China's 11th Five Year 863 Plan (2006-2010). The construction of the unit is planned to commence in 2008, and the unit is expected to be put in operation in 2010.

The system has the following characteristics:

- ASU type: Low temperature rectify,
- Gasifier: Slurry feed & oxygen, Opposed 4 Nozzle Gasifier (2112t/d, 3.5 MPa),
- E class gas turbine with nitrogen dilution,
- AGR type: MDEA,
- Radiant & Convective syngas cooler,
- Heat recovery of acid gas removal system,
- Heat recovery of air extraction from GT,
- Aux. Steam system located on the end of convective cooler,
- HRSG type: triple pressure with reheat and deaerator,
- Energy under 120℃ recovery: LiBr absorption refrigeration.

2) Project Participant(s)

The project is funded and owned by China Huadian Corporation, which is one of China's top five power generation companies. This project intends to demonstrate some key IGCC technologies developed in China, and listed below are project participants that are working on different areas of the project:

- China Huadian Corporation,
- National Power Plant Combustion Engineering Technology Research Center,
- East China University of Science and Technology,
- Institute of Engineering Thermophysics, Chinese Academy of Sciences,
- Zhejiang Electric Power Design Institute,
- Hangzhou Huadian Banshan Power Generation Co., LTD.

3) Project Cost

Total static investment is 1,979,990,000RMB (US$264Million in year 2007).

4) Sensitivity Analysis for Case 3

Table 20 Summary of Sensitivity Study for Case 3

Case 3 – Banshan Integrated Gasification Combined Cycle (IGCC), PRC				
	Base	**Sensitivity Set No. 1**	**Sensitivity Set No. 2**	**Sensitivity Set No. 3**
Project Life, Years	25	25	25	25
Installed Capacity, kW	200,000	200,000	200,000	200,000
Installed Cost, KUS$	264,000	284,000	255,000	255,000
Output per Year, MWh	1,226,400	1,401,600	1,401,600	1,401,600
Capacity Factor, %	70	80	80	80
Fuel Cost/yr, KUS$	44,502	50,859	50,859	44,411
O & M Cost/yr, KUS$	9030	9343	9343	9343
Bonds, % of Capital	40	40	40	40
Sensitivity Conditions				
Reduced Installed Cost	Reference case (not applicable)	Not applied; reverse is true	YES; Installed Cost lower by 10% than Base	YES; Installed Cost lower by 10% than Base
Increased Availability	Reference case (not applicable)	YES; from 70% to 80%	YES; from 70% to 80%	YES; from 70% to 80%
Reduced Coal Price	Base Coal Price = US$4.18/mmBTU	Not applied	Not applied	YES; same as U.S. price of coal = US$3.65/mmBTU
Required to meet sensitivity condition	Reference case (not applicable)	Spend extra US$100/kW for additional gasifier	10% installed cost reduction due to manufacturing localization	Same as Sensitivity Set No. 2
Levelized Cost, US$/kWh	0.08429	0.08154	0.07840	0.07296
Improvement of Cost over Base Case	-	**3.3 % lower than base**	**7 % lower than base**	**13.5 % lower than base**

5.3 Summary of Cases

Table 21 below displays the base and best cases of all three technologies under study. This table summarizes the entries of Table 17, Table 19, and Table 20. This presentation shows at a glance the key parameters that go into the Levelized Life-Cycle Cost calculations of all three (3) advanced coal–based power generation technologies in one table:

Table 21 Comparative Values of Base and Best Sensitivity Cases
(All 3 Advanced Technologies)

BASE CASE VALUES				
Levelized Cycle Cost Parameters	**Case 1**	**Case 2**	**Case 3**	**Remarks**
	Kemen SCPC	**Laizhou USCPC**	**Banshan IGCC**	
Project Life, Years	25	25	25	All the levelized life-cycle costs of all 3 cases presented herein do not provide for carbon capture and sequestration (CCS); Carbon Capture and Sequestration is not included in the scope of this study.
Installed Capacity, kW	2,400,000	2,000,000	200,000*	
Installed Cost, US$ M	1,200,000	1,120,000	264,000	
Output per Year, MWh	16,819,200	14,016,000	1,226,400	
Capacity Factor, %	80	80	70	
Fuel Cost/yr, KUS$	647,502	507,362	44,502	
O & M Cost/yr, KUS$	92,384	68,146	9030	
Bonds, % of Capital	40	40	40	
Levelized Cost, US$/kWh	0.06282	0.06066	0.08429	
BEST CASE (Sensitivity) VALUES				
	Kemen SCPC	**Laizhou USCPC**	**Banshan IGCC**	The best case levelized costs are picked from the sensitivity case sets containing all factors that are deemed to bring down the life cycle costs, i.e. lower installation cost, higher capacity factors, lower fuel price, etc.
Project Life, Years	25	25	25	
Installed Capacity, kW	2,400,000	2,000,000	200,000	
Installed Cost, US$ M	1,080,000	1,008,000	255,000	
Output per Year, MWh	18,921,600	15,768,000	1,401,600	
Capacity Factor, %	90	90	80	
Fuel Cost/yr, KUS$	636,078	498,411	44,411	
O & M Cost/yr, KUS$	98,566	7,3156	9,343	
Bonds, % of Capital	40	40	40	
Levelized Cost, US$/kWh	0.05455	0.05255	0.07296	

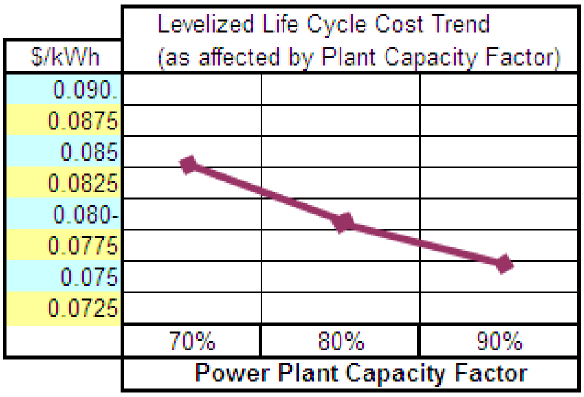
*Note: It should be noted that the sizes of actually built IGCC plants at present are yet much smaller in capacity ratings than those of the more mature supercritical and ultra-supercritical technologies

The parameters that have been adjusted in order to explore the potential of improved levelized life cycle cost performance for all three cases are as follows:

- Reduced Installed Cost
- Increased Availability
- Reduced Coal Price

There were various sub-sets which were generated within each technology case and the lowest points are herein picked as the ‘best’ values. The lowest points are arbitrary in the sense that sensitivity values could be set towards values that would result in more attractive costs, but the possibility of achieving these costs in real life situation would be much more remote. For instance, as a relatively less proven technology to date, the IGCC technology cannot be assigned a 90 percent plant capacity factor to bring the levelized cost further down to US$0.07555/kWh. This is because, at this point, an 80 percent capacity factor is estimated to be the best achievable capacity factor attainable for this kind of technology given the recently reported problems related to plant availability.

Table 22 Impacts of Plant Capacity Factor on Levelized Life Cycle Cost of an IGCC Plant



Capacity Factor, %	Levelized Cost, $/kWh
70	0.08429
80	0.07937
90	0.07555

The preceding chart gives the projected levelized life cycle cost trend of a typical IGCC power plant as impacted solely by capacity factor improvement. As explained earlier in this report, capacity factor is the ratio of the actual electrical energy generated while running the plant at its full nameplate capacity over the elapsed period considered that the plant is supposed to be operated at its full rated capacity. For example, if a given power plant rated at 200 MWe is able to produce electric energy equivalent to 25,200 MWh in a given week, then its capacity factor is only 75 percent. This is because if run continuously at the nameplate rating of 200 MWe, the same power plant would have delivered to the grid electrical energy equal to 33,600 MWh for the same period. However, the best case point presented in this report for the IGCC case as impacted by capacity factor is only up to 80 percent (as shown in Table 21) considering that it is the more conservative projection at this time for a relatively new coal-based technology. However, this projection may be updated as more efforts are documented that would demonstrate improved availability of the IGCC process.

5.4 Sensitivity Analyses – Multiple Modes

In the preceding section, the sensitivity analyses/assessments on the viability of each advanced coal technology were applied with the major cost factors, i.e., Installation Cost, Operations and Maintenance Cost and Fuel (coal) Cost, simultaneously changing from one case to another. Indeed, it is a common occurrence in the real world that these major factors fluctuate or vary simultaneously. As may be noticed, the outlook predicted in the preceding cases was on the optimistic side of the base values; meaning, the sensitivity cases have bottom-line values, which are all better than any of those in the base case. This situation was because the base case values are perceived as having already approached the upper threshold limit of economic feasibility. However, a more comprehensive project evaluation usually requires the key statement that establishes the difference between proceeding and forestalling a move. In such case, a more extensive application of sensitivity analysis is deemed necessary. The following section addresses the area of project risk assessment, which uses the sensitivity analysis approach.

Before proceeding to apply multiple modes of sensitivity analysis, the cost share of each major parameter is presented below in tabulated format:

Table 23 Case 1 – Levelized Cost Components Share to Total Value

Case 1 - Base (SCPC)

LEVELIZED LIFE-CYCLE COSTS		
	Current (US$/kWh)	% Share
Capital	0. 00862	14%
O&M	0.00636	10%
Fuel	0.04458	71%
Income tax	0.00200	3%
Gross rev tax	0.00126	2%
Total	0.06282	100%

Table 24 Case 2 – Levelized Cost Components Share to Total Value

Case 2 - Base (USCPC)

LEVELIZED LIFE-CYCLE COSTS		
	Current (US$/kWh)	Share to Total
Capital	0.00966	16%
O&M	0.00563	9%
Fuel	0.04192	69%
Income tax	0.00224	4%
Gross rev tax	0.00121	2%
Total	0.06066	100%

Table 25 Case 3 – Levelized Cost Components Share to Total Value

Case 3 - Base (IGCC)

LEVELIZED LIFE-CYCLE COSTS		
	Current (US$/kWh)	Share to Total
Capital	0.02601	31%
O&M	0.00853	10%
Fuel	0.04202	50%
Income tax	0.00604	7%
Gross rev tax	0.00169	2%
Total	0.08429	100%

Table 23 for Case 1, Table 24 for Case 2, and Table 25 for Case 3 have indicated that Capital (Installed Cost), Operations and Maintenance (O&M) and Cost of Fuel (coal) are the major elements that go into the levelized life cycle cost and therefore become the focus of interest in the project feasibility evaluations.

To give greater emphasis on sensitivity analysis as a tool in this advanced coal power generation technology evaluation, it is further defined and discussed below prior to the graphical data presentation of another set of multiple mode sensitivity analysis:

Sensitivity analysis

According to various authorities in this particular field, sensitivity analysis involves systematically examining the influence of uncertainties in the variables and assumptions employed in an evaluation on the estimated results. It encompasses at least three alternative approaches.

One way sensitivity analysis – This systematically examines the impact of each variable in the study by varying it across a plausible range of values while holding all other variables in the analysis constant at their "best estimate" or baseline value.

Extreme scenario analysis - This involves setting each variable to simultaneously take the most optimistic (pessimistic) value from the point of view of the intervention under evaluation in order to generate a best (worst) case scenario. Of course, in real life the components of an evaluation do not vary in isolation nor are they perfectly correlated. Hence it is likely that a one way sensitivity analysis will underestimate, and extreme scenario analysis overestimate, the uncertainty associated with the results of economic evaluation.

Probabilistic sensitivity analysis – This is based on a large number of simulations and examines the effect on the results of an evaluation when the underlying variables are allowed to vary simultaneously across a plausible range according to predefined distributions. These probabilistic analyses are likely to produce results that lie between the ranges implied by one way sensitivity analysis and extreme scenario analysis, and therefore may produce a more realistic estimate of uncertainty.

As explained in the preceding definitions, the following charts represent the application of the One-Way Sensitive Analysis Approach, where the impact of each variable in the study is being examined as each is varied within certain plausible ranges while holding all other variables in the analysis constant. The result of calculations for the levelized life cycle costs within the specified ranges has resulted in a family of curves for each advanced coal technology case. The following graphs, Figure 23, Figure 24 and Figure 25, illustrates the impact of major cost component value swings within a wider range for each of the three advanced coal-based power generation technology cases. The supporting values and other details for all of these graphs are contained in Appendix 1.

Figure 23 Case 1 (SCPC – Kemen Power Plant) One-Way Sensitivity Analysis

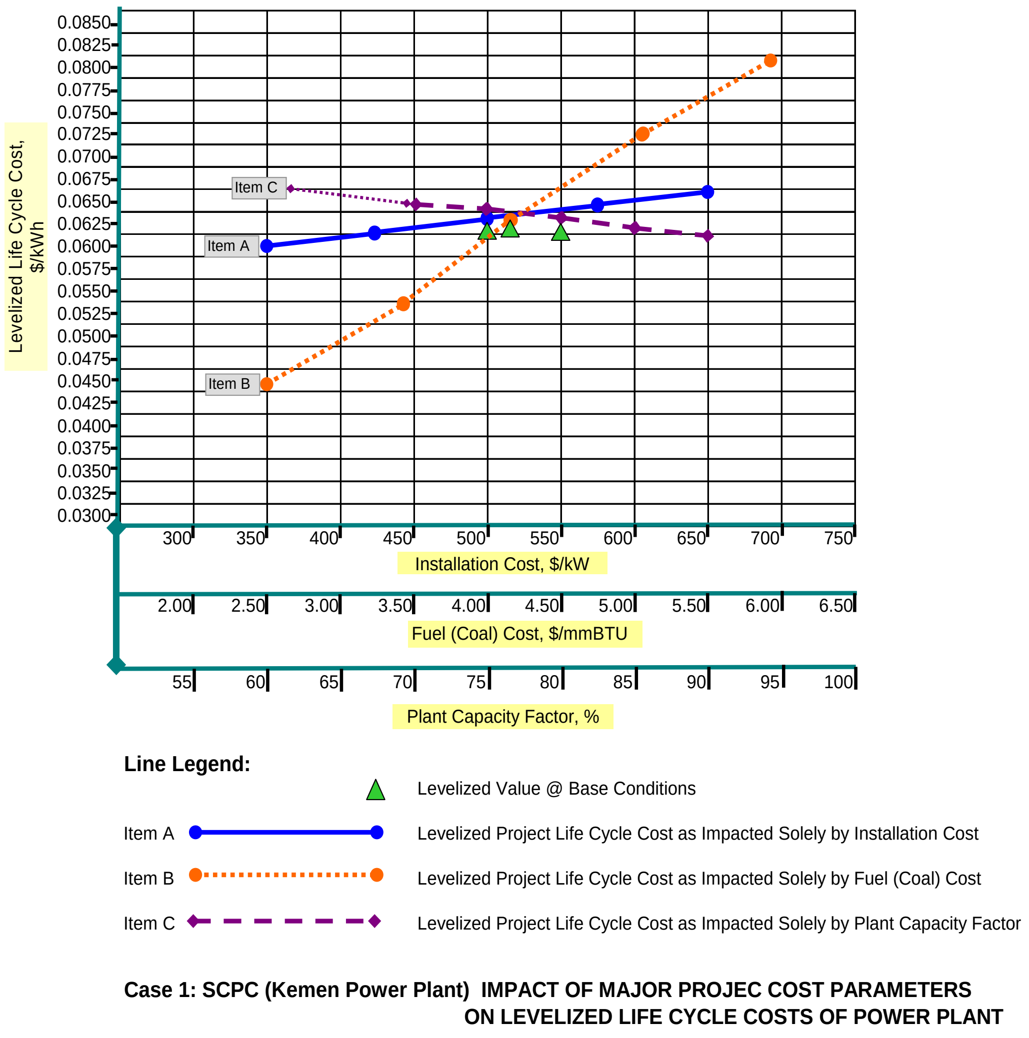


Figure 24 Case 2 (USCPC – Laizhou Power Plant) One-Way Sensitivity Analysis

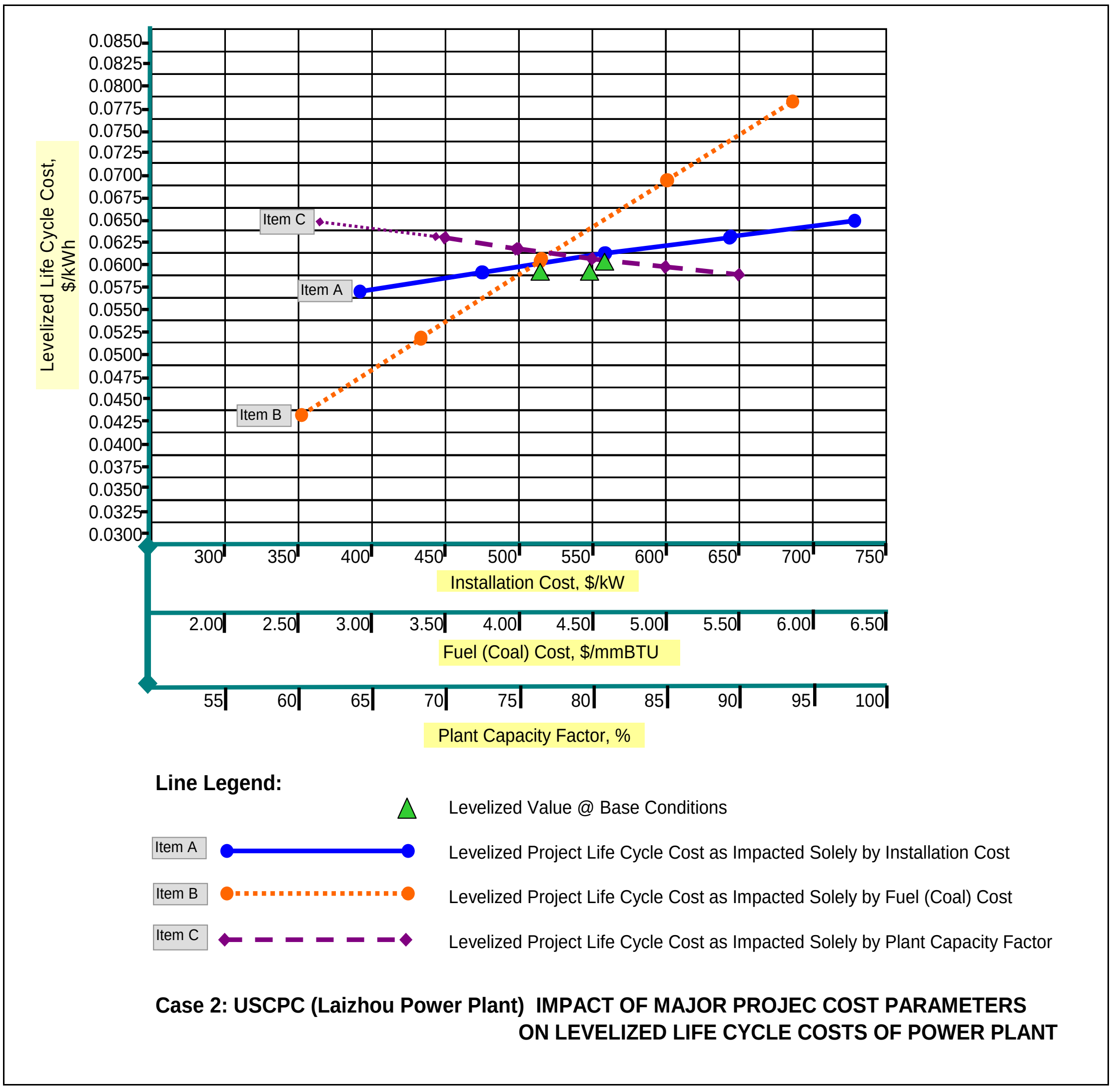
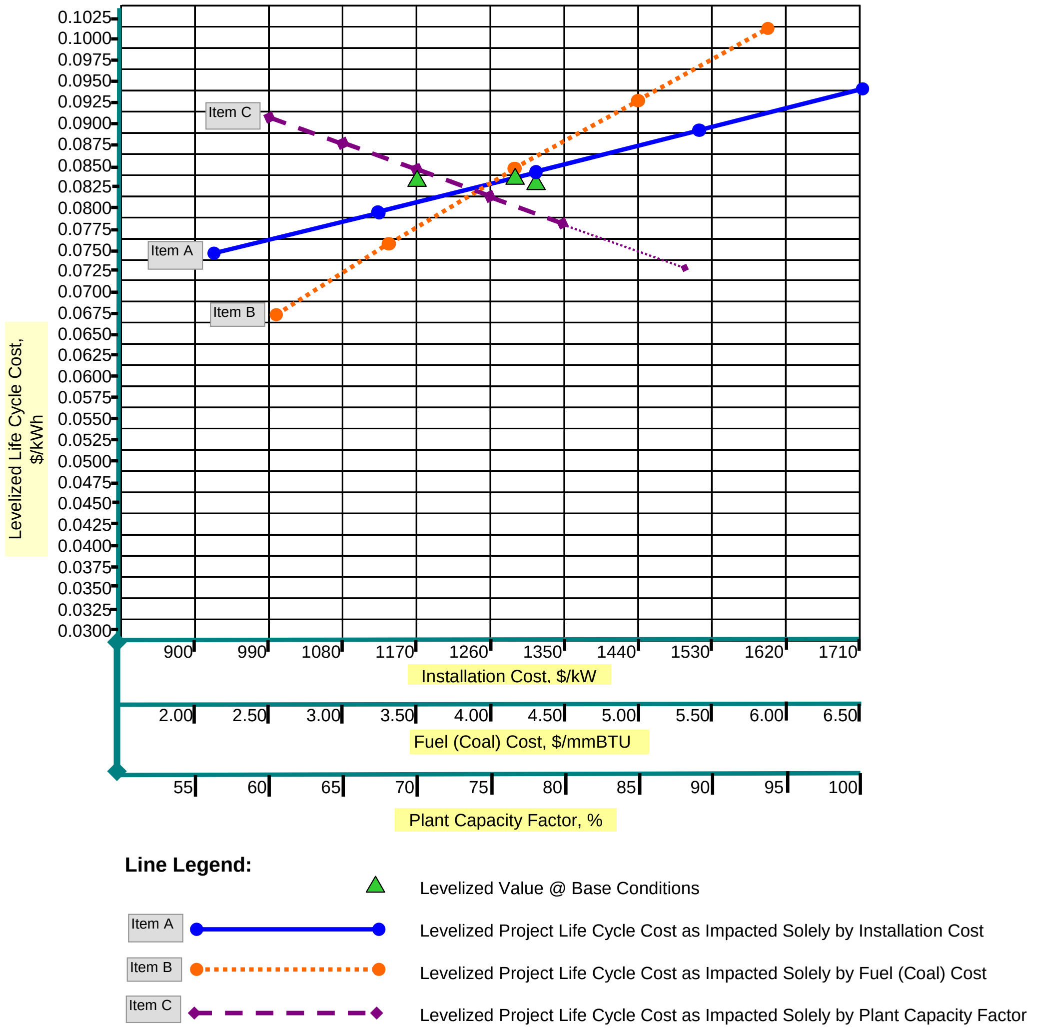


Figure 25 Case 3 (IGCC – Banshan Power Plant) One-Way Sensitivity Analysis



Case 3: IGCC (Banshan Power Plant) IMPACT OF MAJOR PROJEC COST PARAMETERS ON LEVELIZED LIFE CYCLE COSTS OF POWER PLANT

6 CONCLUSIONS

The use of coal as a primary source of fuel for power generation remains a key factor for APEC developing member economies, especially the ‘emerging ones,’ in sustaining their economic growth and developments. However, an equally important concern for these economies is the matter of coal-related emissions mitigation.

Evidently, the advanced coal-based power generation technologies are gaining greater mainstream acceptance by the electric power generation industry in these APEC developing economies. The degree of acceptance of these advanced technologies by the power industry relies on the economic and energy strategies of each APEC member economy. Of course, the general attitude of the public towards environmental issues also plays a vital role in defining the future direction of power generation make-up in each economy.

Among the advanced coal power technology options under study in this paper, the supercritical pulverized-coal type has been identified as the most readily chosen option by many utilities. The ultra-supercritical design is closely following SCPC in terms of potential as the power plant of choice. This observation of the bright promise of the USCPC is supported by the fact that the USCPC model resulted in the lowest levelized life cycle cost when compared against the SCPC and IGCC.

However, this comparison is based on a couple of projects recently implemented in one APEC emerging economy. It is not an assurance that this same levelized life cycle cost picture will repeat when similar technologies are implemented in other APEC developing member economies. More cases must be reviewed, documented and analyzed before any firm conclusions can be drawn as to which of these technologies are economically superior to the others.

Another study observation is that there is no longer a clear threshold of distinction between the SCPC and the USCPC in economic modeling. Essentially, these two pulverized-coal designs are operating under the same thermodynamic Rankine-based cycle. They only differ in the extent of pressures and temperatures attainable during operation. It is therefore perceived that these two models, i.e., SCPC and USCPC, have essentially the same economic model features. On the other hand, the IGCC possesses a different feature both technologically and economically versus the pulverized-coal models and should be treated separately in all economic reviews and comparisons. Although the IGCC is not yet as mature in development as its PC counterpart, it has contributed remarkably to the greater promise in making coal a sustainable, reliable and less polluting fuel for many years to come.

7 RECOMMENDATIONS

It is recommended that developing APEC member economies develop policies and strategies along the following key areas in order to encourage power utilities to adopt advanced coal power generation technologies:

(1) Tariff discount grants or outright exemptions on customs duties for imported advanced technology coal power generation plant components, such as coal gasifier components for IGCC's, and high-alloy steel tubing for supercritical and ultrasupercritical steam generation plants. This move will bring down the installation cost of the plant.

(2) Provision of tax credits to electricity utilities that build new plants using advanced coal-based power generating technologies, such as SCPC, USCPC, and IGCC. Legislation of new tax laws may be required to provide such credits and tax breaks.

(3) Establishment of licensing agreements with foreign suppliers or original equipment manufacturers (OEMs), in order to facilitate the local manufacture of major power plant components, thereby cutting installation cost of new coal power generating plants.

(4) Government support in the creation of an advanced technology coal power generation demonstration project, which can also provide a solid base for international exchanges and cooperation in the field of clean coal technology.

(5) Improvement in coal handling and transport infrastructure to bring down the coal cost to power plants in the long run. A stable and competitive coal price is a very strong incentive for power utilities to build new power generating units, which are coal.

(6) Provision of funds for research, promotion, development and diffusion of knowledge and ideas pertinent to these advanced coal IGCC, SCPC and USCPC power generation technologies. Such spread of information can be channeled through government departments and agencies, which are dealing with energy and electric power generation. It can be more effective if done in coordination with the academic community and business sector.

(7) Development of IGCC test base and plan for the deployment of IGCC technology in APEC developing economies. The test base will make use of the IGCC demonstration plant and will rely on existing research, equipment, and installations to be located in a developing APEC-member economy, which could meet the requirements to host such a facility.

(8) Provision to key participants in advanced coal power generation technology projects the much needed support in the actual installation and operations of an advanced coal-based power plant that will be built using maximum possible local content, i.e., to reduce overall construction cost and to boost local industry. [Note: This effort is now ongoing within the 'emerging among the developing' APEC economies such as China and Korea.]

(9) Establishment of a monitoring program related to advanced coal-based power generation technology. This technology monitoring program could be accomplished by a leading group at state or national level and could be incorporated into expert group(s) in the advanced coal power generation technology field. Such a combined, multi-disciplinary group could then conduct advanced technology project evaluations. The group can

organize and coordinate the work of relevant research institutes, universities, manufacturers, and utilities. The group can also develop a plan:

(a) for importing IGCC/SCPC and USCPC equipment and technology;

(b) for applying research and development of advanced technology projects in APEC-member economies;

(c) for the manufacturing of equipment, for demonstrations and tests, and for the commercial identification and diffusion of IGCC/SCPC and USCPC.

(10) Establishment of a state-level group of high-level experts from both the APEC member economies and technology provider economies. This will be another group distinct from the previous one. The responsibility of this group will be to make technical decisions and consultancy regarding such matters as the import of technology, the evaluation, and identification of relevant plans, the development of implementation schemes and feasibility reports, including the development proposals related to advanced coal technologies for consideration by the government and concerned sectors of industry.

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Appendix 1: Case Study Calculations – Base Data

Case 1: Supercritical Pulverized-Coal Technology (SCPC)
Name of Plant: Kemen Power Plant
APEC Economy: People's Republic of China

Item	Calculation Input Data	Unit	Value	Remarks
1	Project Projected Economic Life	Years	25	
2	Plant Electric Generation Capacity	MW	2400	4 x 600-MW Units
3		kW	2,400,000	
4	Installation Cost (EPC) per kW	US$/kW	500	
5	Total Installation Cost (EPC)	US$	1,200,000,000	Item 3 x Item 4
6	Capacity Factor	%	0.80	
7	One Year Calendar Time Period	hours	8760	
8a	Projected Annual Generation/Output	MWh/yr	16,819,200	Item 2 x Item 6 x Item 7
8b		kWh/yr	16,819,200,000	Item 3 x Item 6 x Item 7
9	Plant Heat Rate (HHV)	BTU/kWh	9210	
10	Annual Plant Heat Input (from fuel)	mmBTU/ yr	154,904,832	Item 8b x Item 9
11	Coal Price	US$/mmBTU	4.18	Based on RMB730/Ton
12	Plant Annual Fuel Cost	KUS$/yr	647,502	Item 10 x Item 11
13	Operating & Maintenance Cost (Annual)	KUS$/yr	92,384	Item 13b + Item 13d
13a	O&M Fixed Cost per kW	US$/kW	17.89	
13b	O&M Annual Fixed Cost	US$/yr	42,936,000	(Item 2b x Item 13a)/1000
13c	O&M Variable Cost	US$/MWh	2.94	
13d	O&M Annual Variable Cost	US$/yr	49,448,448	Item 8a x Item 13c
14	By-product Credit (Sulfur and Slag Sales)	KUS$/yr	-	N/A
14a	Sulfur/Slag Production Rate	Lbs/MWh	-	N/A
14b	Combined Annual Sulfur/Slag Production	Tons/yr	-	N/A
14c	Annual Sulfur Production	Tons/yr	-	N/A
14d	Price of Sulfur	US$/Ton	-	N/A
14e	Projected Annual Sulfur Sales	US$/yr	-	N/A
14f	Annual Slag Production	tons/yr	-	N/A
14g	Price of Slag	US$/Ton	-	N/A
14h	Projected Annual Slag Sales	KUS$/yr	-	N/A
15	Adjusted Operating & Maintenance Cost	KUS$/yr	-	N/A
Other Inputs Required in EXCEL (Bicycle-IV) Levelized Life-Cycle Cost Calculations:				
16	Fraction of Capital from Bonds	%	40	
17	Nominal Bond Interest Rate	%	8	
18	Bond Term	years	25	
19	Debt-Repayment Method	Proportional		
20	Nominal Equity Rate of Return	%	15	
21	Inflation Rate	%	2	
22	Income Tax Rate	%	30	
Item	Calculation Input Data	Unit	Value	Remarks
23	Gross Revenue Tax Rate	%	2	

24	Salvage Value	US$	0	
25	Depreciation Allowance Method	Sum-of-the –Year -Digits		
26	Depreciation Term for Initial Capital	years	25	= plant economic life
LEVELIZED LIFE CYCLE COST				
27	Capital	US$/kWh	0.00862	
28	O&M	US$/kWh	0.00636	
29	Fuel	US$/kWh	0.04458	
30	Income Tax	US$/kWh	0.00200	
31	Gross Revenue Tax	US$/kWh	0.00126	
32	Levelized Life Cycle Cost	US$/kWh	**0.06282**	

Case 2: Ultra-supercritical Pulverized-Coal Technology (USCPC)
Name of Plant: Laizhou Power Plant
APEC Economy: People's Republic of China

Item	Calculation Input Data	Unit	Value	Remarks
1	Project Projected Economic Life	Years	25	
2	Plant Electric Generation Capacity	MW	2000	2 x 1000 MW Units
3		kW	2,000,000	
4	Installation Cost (EPC) per kW	US$/kW	560	
5	Total Installation Cost (EPC)	US$	1,120,000,000	Item 3 x Item 4
6	Capacity Factor	%	80	
7	One Year Calendar Time Period	hours	8760	
8a	Projected Annual Generation/Output	MWh/yr	14,016,000	Item 2 x Item 6 x Item 7
8b		kWh/yr	14,016,000,000	Item 3 x Item 6 x Item 7
9	Plant Heat Rate (HHV)	BTU/kWh	8660	
10	Annual Plant Heat Input (from fuel)	mmBTU/yr	121,378,560	Item 8b x Item 9
11	Coal Price	US$/mmBTU	4.18	Based on RMB730/Ton
12	Plant Annual Fuel Cost	KUS$/yr	507,362	Item 10 x Item 11
13	Operating & Maintenance Cost (Annual)	KUS$/yr	68,146	Item 13b + Item 13d
13a	O&M Fixed Cost per kW	US$/kW	14.03	
13b	O&M Annual Fixed Cost	US$/yr	28,060,000	(Item 2b x Item 13a)/1000
13c	O&M Variable Cost	US$/MWh	2.86	
13d	O&M Annual Variable Cost	KUS$/yr	40,085,760	Item 8a x Item 13c
14	By-product Credit (Sulfur and Slag Sales)	KUS$/yr	-	N/A
14a	Sulfur/Slag Production Rate	Lbs/MWh	-	N/A
14b	Combined Annual Sulfur/Slag Production	Tons/yr	-	N/A
14c	Annual Sulfur Production	Tons/yr	-	N/A
14d	Price of Sulfur	US$/Ton	-	N/A
14e	Projected Annual Sulfur Sales	US$/yr	-	N/A
14f	Annual Slag Production	Tons/yr	-	N/A
14g	Price of Slag	US$/Ton	-	N/A
14h	Projected Annual Slag Sales	KUS$/yr	-	N/A

15	Adjusted Operating & Maintenance Cost	KUS$/yr	-	N/A
Other Inputs Required in EXCEL (Bicycle-IV) Levelized Life-Cycle Cost Calculations:				
16	Fraction of Capital from Bonds	%	40	
17	Nominal Bond Interest Rate	%	8	
18	Bond Term	years	25	
19	Debt-Repayment Method	Proportional		
20	Nominal Equity Rate of Return	%	15	
21	Inflation Rate	%	2	
22	Income Tax Rate	%	25	
Item	**Calculation Input Data**	**Unit**	**Value**	**Remarks**
23	Gross Revenue Tax Rate	%	2	
24	Salvage Value	US$	0	
25	Depreciation Allowance Method	Sum-of-the –Year -Digits		
26	Depreciation Term for Initial Capital	years	25	= plant economic life
LEVELIZED LIFE CYCLE COST				
27	Capital	US$/kWh	0.00966	
28	O&M	US$/kWh	0.00563	
29	Fuel	US$/kWh	0.04192	
30	Income Tax	US$/kWh	0.00224	
31	Gross Revenue Tax	US$/kWh	0.00121	
32	Levelized Life Cycle Cost	US$/kWh	**0.06066**	

Case 3: Integrated Gasification Combined Cycle Technology (IGCC)

Name of Plant: Banshan Power Plant

APEC Economy: People’s Republic of China

Item	Calculation Input Data	Unit	Value	Remarks
1	Project Projected Economic Life	Years	25	
2	Plant Electric Generation Capacity	MW	200	1 x 200 MW
3		kW	200,000	
4	Installation Cost (EPC) per kW	US$/kW	1320	
5	Total Installation Cost (EPC)	US$	264,000,000	Item 3 x Item 4
6	Capacity Factor	%	70	
7	One Year Calendar Time Period	hours	8760	
8a	Projected Annual Generation/Output	MWh/yr	1,226,400	Item 2 x Item 6 x Item 7
8b		kWh/yr	1,226,400,000	Item 3 x Item 6 x Item 7
9	Plant Heat Rate (HHV)	BTU/kWh	8681	Based on Wabash River Plant Study (projected)
10	Annual Plant Heat Input (from fuel)	mmBTU/yr	10,646,378	Item 8b x Item 9
11	Coal Price	US$/mmBTU	4.18	Based on RMB730/Ton
12	Plant Annual Fuel Cost	KUS$/yr	44,502	Item 10 x Item 11
13	Operating & Maintenance Cost (Annual)	KUS$/yr	9,030	Item 13b + Item 13d
13a	O&M Fixed Cost per kW	US$/kW	34.21	
13b	O&M Annual Fixed Cost	US$/yr	6,842,000	(Item 2b x Item

				13a)/1000
13c	O&M Variable Cost	US$/MWh	2.58	
13d	O&M Annual Variable Cost	US$/yr	3,164,112	Item 8a x Item 13c
14	By-product Credit (Sulfur and Slag Sales)	KUS$/yr		Item 14e + Item 14h
14a	Sulfur/Slag Production Rate	lbs/MWh	175	
14b	Combined Annual Sulfur/Slag Production	tons/yr	95,555	
14c	Annual Sulfur Production	tons/yr	17,433	Based on 17.87% share of sulfur /slag (WP data)
14d	Price of Sulfur	US$/Ton	33	
14e	Projected Annual Sulfur Sales	US$/yr	575,289	
14f	Annual Slag Production	tons/yr	80,122	Based on 82.13% share of sulfur /slag (WP data)
14g	Price of Slag	US$/ton	5	
14h	Projected Annual Slag Sales	KUS$/yr	400,608	
15	Adjusted Operating & Maintenance Cost	KUS$/yr	976	Item 13 - Item 14
Other Inputs Required in EXCEL (Bicycle-IV) Levelized Life-Cycle Cost Calculations:				
16	Fraction of Capital from Bonds	%	40	
17	Nominal Bond Interest Rate	%	8	
18	Bond Term	years	25	
19	Debt-Repayment Method	Proportional		
20	Nominal Equity Rate of Return	%	15	
21	Inflation Rate	%	2	
22	Income Tax Rate	%	30	
Item	**Calculation Input Data**	**Unit**	**Value**	**Remarks**
23	Gross Revenue Tax Rate	%	2	
24	Salvage Value	US$	0	
25	Depreciation Allowance Method	Sum-of-the –Year –Digits		
26	Depreciation Term for Initial Capital	years		= plant economic life
LEVELIZED LIFE CYCLE COST				
27	Capital	US$/kWh	0.02601	
28	O&M	US$/kWh	0.00853	
29	Fuel	US$/kWh	0.04202	
30	Income Tax	US$/kWh	0.00604	
31	Gross Revenue Tax	US$/kWh	0.00169	
32	Levelized Life Cycle Cost	US$/kWh	**0.08429**	

SUMMARY COMPARATIVE LEVELIZED LIFE CYCLE COST (Plant Location: APEC Developing Economy)				
Cost Items	Unit	Value		
		Case 1	Case 2	Case 3
		SCPC	USCPC	IGCC
Capital	US$/kWh	0.00862	0.00966	0.02601
O&M	US$/kWh	0.00636	0.00563	0.00853

Fuel	US$/kWh	0.04458	0.04192	0.04202
Income Tax	US$/kWh	0.00200	0.00224	0.00604
Gross Revenue Tax	US$/kWh	0.00126	0.00121	0.00169
Levelized Life Cycle Cost	US$/kWh	0.06282	0.06066	0.08429

Appendix 2: Chinese Delegation Dialogue

DIALOGUE
with Members of
HeNan Electric Power Survey & Design Institute (HEPSDI)
ShanXi Electric Power Design Institute (SXED)
ShangDong Electric Power Engineering Consulting Institute (SDEPCI)
Chair, APEC Expert Group on Clean Fossil Energy
and
WorleyParsons Group, Inc.
Reading, PA, USA

December 6, 2007

QUESTIONNAIRE RESPONSE:

(1) Are both cost effectiveness, which would include raising thermal efficiencies and emissions reduction, given the same attention on all coal-fired power plant refurbishment and upgrade in China today?

Response: *In China, more attention is given to emissions control than to efficiency improvements when considering the refurbishment of older coal-fired power plants.*

(2) If a particular power plant has changed ownership from the government to a privately owned corporation, how much would it affect the operating strategy of the plant?

Response: *As of today, there is really no transfer of ownership yet from the government to private hands when it comes to power utilities.* [**Note**: Since the government remains a major stakeholder in these electric utility companies, profit-driven policies that private ownership is prone to adapt remain less likely to dominate.]

(3) What particular plant sub-systems are given greatest priority for upgrades or refurbishments in China today: burners, air preheaters, pulverizers, reheaters/superheaters, turbine flow path, condenser, or control systems?

Response: *Seldom are older power plants undergoing upgrades of reheaters/superheaters, and pulverizers. However, on older turbine units, they do retrofits to improve steam flow path efficiency via OEMs. FGDs and ESPs get more attention than pressure part and combustion system upgrades on the boiler side.*

(4) Are there current plans to extend operating life of plants which are now at 25-30 years of operation by moving from base-loaded to 2-shift operations?

Response: *There are no such plans considering it has now become a general government policy or program to retire older generating units within the next 5 years. These are mostly small capacity units. The new coal-fired power plants and those still planned to be built are usually rated 300 MW or larger.*

[**Note**: Art Baldwin added a question regarding the approximate number of power plants in China that are likely to be retired soon. The answer to his query was that *about 10,000 MW of old generating capacities shall be replaced with new ones annually for five years resulting in a total of 50,000 MWe's of capacity scheduled to be retired.*]

(5) Have organizational changes in China involving splitting up of big utility companies into competing companies created strong drivers or motivations for the existing power plants to look for greater plant competitiveness, increased availability, and improved emissions control? **Response**: *The delegation response to this query was that the power plant managers somehow still managed to be competitive, considering that the major utility companies, though government-owned, remain distinctly identifiable as unique performers and can still be gauged among them from the top.*

(6) How often are major steam turbine overhauls in the coal-fired power plants being done in China? Is this being done every four years, which most OEMs do, and do these overhauls include retrofits or the introduction of better designed turbine parts as well?

Response: *Four years or more was the old practice for the older units. With the newer ones, they expect overhauls to be fewer and less frequent due to improved control and reliability as a result of design improvement of the newer units and more operating experiences gained.*

(7) In major power plant upgrades or refurbishment, is payback time given much more emphasis than environmental regulations?

Response: [*Note*: This question was not specifically made, as it was addressed in the response to Question No. 1, which related to this topic, given the earlier statement from the Chinese delegation that environmental control now takes precedence over efficiency.]

(8) What is the usual basis for a major power plant upgrade? Are there lifetime monitoring systems in place in most plants now?

Response: *Power plant lifetime monitoring systems (or life assessment programs) are now being carried out in a few plants depending on some guidelines followed by plant management.*

(9) Are emission control systems such as FGDs, NO_x reduction systems and Electrostatic Precipitators (ESPs) now introduced to older coal-fired power plants as part of refurbishment efforts? Normally, how old are the plants receiving such improvements in China today?

Response: *No, since there is now an ongoing program to phase-out older units. (Refer to Query No. 4)*

(10) Is the Distributed Control System (DCS) now being introduced to older coal-fired plants in China? How old are these plants that are converted to DCS, normally?

Response: *No, since there is now an ongoing program to phase-out older units. (Refer to Query No. 4). However, DCS has now become a standard feature in newly built coal-fired power plants.*

(11) Is China making stricter (more stringent) environmental laws, and how do they impact on older coal-fired power generators?

Response: *The older power plants shall certainly meet related environmental laws and local emissions requirement for operation. However, government policies may have more impacts than environmental laws on the older coal-fired power generators.*

(12) How widely used are Continuous Emission Monitoring Systems (CEMS) in China today? Are these systems now being introduced to older power plants?

Response: *The use of CEMS on all new power plants has become standard; for older power plants, CEMS installation depends on utility company policy decision.*

(13) Are records now available in China about coal-fired power plants that underwent refurbishment/upgrade several years back and are now getting back the value of their investments?

Response: *The Chinese delegation was unable to name a specific organized official body that collects information of this nature, although a certain Chinese publication/website, such as China State Power Information Network, was mentioned as a good lead to this kind of information.*

(14) There are now Chinese plants which were built with entirely foreign capital under the Build-Operate-Transfer (BOT) arrangement. Were these plants built and operated under the same guidelines and regulation as the other Chinese power plants?

Response: *The answer was yes; few coal-fired power plants built under the Build-Operate-Transfer (BOT) arrangement were built and are being operated under the same guidelines and regulations as the other Chinese power plants.*

(15) Could you possibly cite cases in China where new coal fuel technology using IGCC, as an example, are being developed?

Response: *An IGCC project is ongoing in Shandong province. It was also mentioned that water source is one of the obstacles for applying IGCC in some of the northern provinces in China.*

(16) How many of the newly-built coal-fired power plants in China today (approximate in terms of percentage to total number of plants being built) are designed with supercritical or ultra-supercritical steam pressures in order to attain greater operating efficiencies?

Response: *In China today, all new 600-MW power plants are of the supercritical or ultra-supercritical design. The same applies to 300-MW cogeneration plants.*

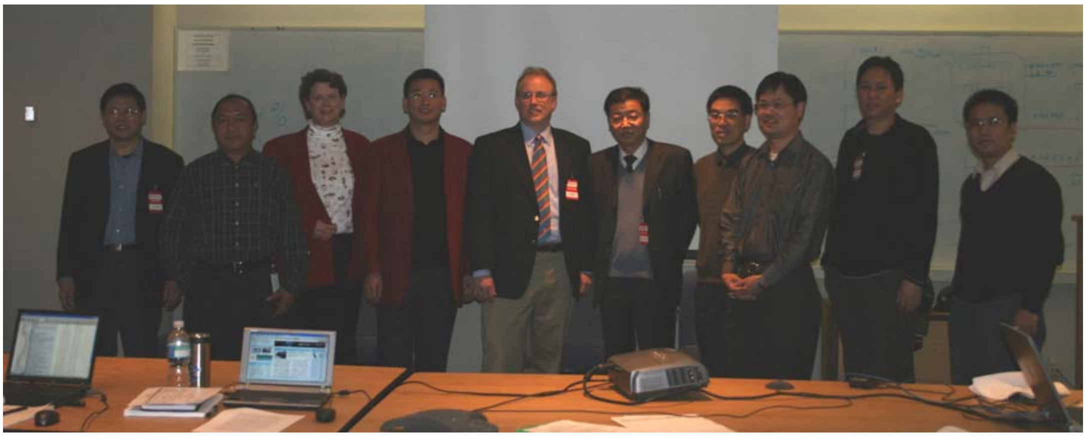
After the question and answer session, Scott Smouse, Chair, Asia Pacific Economic Cooperation – Expert Group on Clean Fossil Energy, spoke about the ongoing APEC ECFMG projects, several of which include China. He also discussed future activities where China can be an active participant, especially in the area of coal utilization and emission control, and noted upcoming conferences in the region that will be sponsored by APEC and others.

Before the meeting, an IEA study report "Case Studies of Recently Constructed Coal and Gas-Fired Power Plants," was provided by Scott Smouse of the US Department of Energy's National Energy Technology Labs for WorleyParsons' reference.

It was suggested that this Chinese delegation be utilized as a source of expertise to identify Chinese power plant refurbishment studies/publications that have been completed. During the course of the discussion, the Chinese delegates thought that it would be best to contact the officials of the five major utilities directly and review available published articles to obtain the information. They stated that they could, however, help to identify the correct utility contacts.

Participants:

Wang Chengil, Vice President, HEPSDI
Zhang Changbin, Vice President, SXED
Zhao, Jiamin, Vice Chief Engineer, SDEPCI
Zhang Yonghong, Director, SXED
Song Wenfeng, Project Department Director, SXED
Wang Xinping, Mechanical Department Director, SXED
Scott Smouse, APEC Expert Group Chair on Clean Fossil Energy, USDOE/NETL,
Arthur Baldwin (by teleconference), Project Manager, USDOE/NETL
James Van Laar, Director, Power Consulting Group, WorleyParsons Group, Inc.
Qinghua Xie, Senior Mechanical Engineer, WorleyParsons Group, Inc.
Napoleon Lusica, Project Manger, WorleyParsons Group, Inc.
Jacqueline Bird, Director of Government & Advanced Energy Projects, WorleyParsons Group, Inc.



This photo above was taken during the dialogue between the APEC/EGCFE (EWG) – WorleyParsons Study Group and the Chinese Delegation of electric power managers and technocrats. Photo was taken at the WorleyParsons Reading, PA, U.S.A. headquarters on December 6, 2007.

Appendix 3: Sensitivity Analysis

Sensitivity Analysis: Impact on Project Levelized Life Cycle Cost by Major Factors Acting Individually

Case 1: SCPC (Kemen Power Plant)

Item	Major Cost Factors (Note 1)	Unit	Adverse Trend		Base Case (Ref.=1.0)	Favorable Trend	
			Worse	Bad		Good	Better
A	Installation Cost per kW	US$/kW	Up by 30%	Up by 15%	500	Down by 15%	Down by 30%
			650	575		425	350
	Installation Cost (Total)	KUS$	1560000	1380000	1200000	1020000	840000
	Levelized Life-Cycle Cost	US$/kWh	0.06607	0.06445	0.06282	0.06120	0.05957
B	Fuel (Coal) Cost	US$/mmBTU	Up by 40%	Up by 20%	4.18	Down by 20%	Down by 40%
			5.852	5.016		3.344	2.508
	Fuel (Coal) Cost for 1 year	KUS$	906503	777003	647502	518002	388501
	Levelized Life-Cycle Cost	US$/kWh	0.08102	0.07192	0.06282	0.05372	0.04463
C	Plant Capacity Factor (Note 2)	%	Down by 10%	Down by 5%	80	Up by 5%	Up by 10%
			70	75		85	90
	Impacted Plant Output	MWh/year	14716800	15768000	16819200	17870400	18921600
	Impacted O&M	KUS$/year	566564	607033	647502	687971	728440
	Impacted Fuel Cost	KUS$/year	86203	89294	92384	95475	98566
	Levelized Life-Cycle Cost	US$/kWh	0.06480	0.06375	0.06282	0.06201	0.06128

Notes:

(1) The Levelized Life Cycle Costs presented in these tables indicate the sensitivities of the case project viabilities as subjected to swings in major life cycle cost factors; these values are calculated to see the effects of these major cost factors, i.e., Items A, B, and C, as each vary individually and not in concert with one another.

(2) Varying the Plant Capacity Factor will have an impact on Fuel Cost and Plant Maintenance and Operations Costs as well

(3) This notes apply to all the tables and cases shown in this Appendix.

Case 2: USCPC (Laizhou Power Plant)

Item	Major Cost Factors	Unit	Adverse Trend		Base Case (Ref.=1.0)	Favorable Trend	
			Worse	Bad		Good	Better
A	Installation Cost per kW	US$/kW	Up by 30%	Up by 15%	560	Down by 15%	Down by 30%
			728	644		476	392
	Installation Cost (Total)	KUS$	1456000	1288000	1120000	952000	784000
	Levelized Life-Cycle Cost	US$/kWh	0.06430	0.06248	0.06066	0.05884	0.05702
B	Fuel (Coal) Cost	US$/mmBTU	Up by 40%	Up by 20%	4.18	Down by 20%	Down by 40%
			5.852	5.016		3.344	2.508
	Fuel (Coal) Cost for 1 year	KUS$	710307	608834	507362	405890	304417
	Levelized Life-Cycle Cost	US$/kWh	0.07777	0.06922	0.06066	0.05211	0.04355
C	Plant Capacity Factor	%	Down by 10%	Down by 5%	80	Up by 5%	Up by 10%
			70	75		85	90
	Impacted Plant Output	MWh/year	12264000	13140000	14016000	14892000	15768000
	Impacted O&M	KUS$/year	63135	65640	68146	70651	73156
	Impacted Fuel Cost	KUS$/year	443942	475652	507362	539073	570783
	Levelized Life-Cycle Cost	US$/kWh	0.06273	0.06133	0.06066	0.05981	0.05905

Case 3: IGCC (Banshan Power Plant)

Item	Major Cost Factors	Unit	Adverse Trend		Base Case (Ref.=1.0)	Favorable Trend	
			Worse	Bad		Good	Better
A	Installation Cost per kW	US$/kW	Up by 30%	Up by 15%	1320	Down by 15%	Down by 30%
			1716	1518		1122	924
	Installation Cost (Total)	KUS$	343200	303600	264000	224400	184800
	Levelized Life-Cycle Cost	US$/kWh	0.09410	0.08919	0.08429	0.07938	0.07447
B	Fuel (Coal) Cost	US$/mmBTU	Up by 40%	Up by 20%	4.18	Down by 20%	Down by 40%
			5.852	5.016		3.344	2.508
	Fuel (Coal) Cost for 1 year	KUS$	62303	53402	44502	35601	26701
	Levelized Life-Cycle Cost	US$/kWh	0.10144	0.09286	0.08429	0.07571	0.06714
C	Plant Capacity Factor	%	Down by 10%	Down by 5%	70	Up by 5%	Up by 10%
			60	65		75	80
	Impacted Plant Output	MWh/year	1051200	1138800	1226400	1314000	1401600
	Impacted O&M	KUS$/year	8718	8874	9030	9187	9343
	Impacted Fuel Cost	KUS$/year	38144	41323	44502	47681	50859
	Levelized Life-Cycle Cost	US$/kWh	0.09084	0.08731	0.08429	0.08167	0.07937