Asia-Pacific
Economic Cooperation

Lessons Learned in Upgrading and Refurbishing Older Coal-Fired Power Plants
A Best Practices Guide for Developing APEC Economies

APEC Energy Working Group
Expert Group on Clean Fossil Energy

October 2008

Energy Working Group Project EWG 05/2007

This report was prepared and printed by:

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WorleyParsons Report No: PCS-APEC-0-LI-011-0003.R1
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APEC#208-RE-03.1

Notice

In preparing this Study Report, WorleyParsons has relied on information supplied by and gathered from a number of sources including public domain and proprietary data services, internet sites, news services as well as parties involved in the industry. WorleyParsons has not used any data which has been provided to the APEC-EGCFE/EWG under a confidentiality agreement or that which has been deemed “confidential” by the owner of the information. Any projections are estimates only and may not be realized in the future. WorleyParsons should not be blamed or be held responsible for any factual errors or misinterpretation of data in this Report. WorleyParsons has not independently verified the accuracy of this information and has not audited any financial information presented in this Report.

This Study Report is based on the facts known to WorleyParsons at the time of its preparation. This report does not purport to contain complete and encompassing information pertaining to the subject matter in review. WorleyParsons has made a number of assumptions throughout the Technical Report, and it is accordingly subject to and qualified by those assumptions. This report provides a review of previously investigated cases and is based on the information available in the public domain and other sources from previous studies and investigations of specific sites/cases and the facts known to WorleyParsons at the time of the preparation of this report.

EXECUTIVE SUMMARY

This "Lessons Learned in Upgrading and Refurbishing Older Coal-Fired Power Plants — A Best Practices Guide for Developing APEC Economies" project, contract number PCS-APEC-0-LI-011-0003, examines various refurbishments and upgrades implemented by coal-based power plants located in the developing economies of the Asia-Pacific Economic Cooperation (APEC) region. Now known to the international community by its acronym APEC, the Asia-Pacific Economic Cooperation is a forum for 21 Pacific Rim economies which organized themselves to regularly meet and exchange ideas about the regional economy, trade and investment and other matters involving mutual cooperation among its members. 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.

All the 21 member economies regularly meet to discuss issues related to common interests and concerns. There are key areas that APEC works to meet its goals of free and open trade and investment in the Asia-Pacific region, namely:

(1) Trade and Investment Liberalization

(2) Business Facilitation, and

(3) Economic and Technical Cooperation.

The APEC Member Economies are looking forward to utilize the outcomes of these three areas of common interest in strengthening 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.

To proceed with this effort, the study group used a number of methodologies of collecting and retrieving information from various sources, such as the Internet, the APEC ECGFE and WorleyParsons databases. One other vital source of information is the visiting delegation electric power industry officials from the People's Republic of China (PRC), which has contributed a great deal in giving the study group an up-to-date perspective of the current trends in PRC's approach to aging power plant upgrades and refurbishments. The study group realizes that among the developing APEC economies, the PRC will have the highest growth of electric power demand for many years to come. For this reason, data collection was pursued with Chinese electric power utility companies, which are identified to have recently upgraded and refurbished their cola-fired power plants.

While the main focus of this report is to draw lessons from actual cases of coal-fired power plant upgrades and refurbishments, it also explores the processes, which lead to decisions of power utilities to upgrade or refurbish their generating units. For instance, Section 3 of this report discusses the ways of assessing major power plant component degradation. The same section of this report also mentions the effect of aging on plant efficiency, safety, availability and reliability and presents ways to countercheck plant equipment aging degradation. The latest approaches in the industry to assess the remaining service life of power generating units are discussed. These approaches include non-destructive testing methods, which are part of a thorough evaluation, inspection and review of all critical components of the power plant. The use of plant performance testing and trending is also discussed as part of the basis for decisions to implement upgrade and refurbishment activities.

Towards the later part of this report, six study cases are presented. Only those power plants, which provided sufficient response information to the questionnaires sent to them earlier, are included in the study cases. The case study Section 4 deals with study cases involving upgrades and refurbishments of air heaters, boiler burners, sot blowers, steam turbines, condensers, instrumentation and control systems induced draft fans and coal pulverizers. These plants are listed in Table 4 which shows the cost incurred in the upgrades and the corresponding benefits derived. As a yardstick to measure economic viability of the upgrade projects, the Discounted Cash Flow Rates of Return (DCFROR), Net Present Values (NPV's) and payback periods are calculated in each study case. At the end of the Case Study Section (Section 4) the cases were ranked, where the economic evaluation indicators are all shown in one single tabulated presentation (Table 5).

Lastly, the lessons learned from these coal-fired electric power generation plant upgrades, as documented during this APEC-sponsored study, are compiled into a Best Practices Guide for Developing APEC Economies. This best practices guide can serve as a reference document for electric power utility companies; those situated in developing APEC economies in particular, which intend to upgrade their older coal-fired electric power generation units.

Glossary

ACFB	Atmospheric Circulating Fluidized Bed
AH	Air Heater
APEC	Asia-Pacific Economic Cooperation
BB	Boiler Burner
BS	Boiler Sootblower(s)
BTU	British thermal unit
CCGT	Combined Cycle Gas Turbine
CCT	Clean Coal Technology
CFB	Circulating Fluidized Bed
CO_2	Carbon Dioxide
CO	Carbon Monoxide
CP	Coal Pulverizer
CRH	Cold Reheat
DEH	Digital Electro-Hydraulic
DAS	Data Acquisition System
DCFROR	Discounted Cash Flow Rate of Return
DCS	Digital Control System
DP	Desalination Plant(s)
EGCFE	Expert Group of Clean Fossil Energy
ESP	Electro Static Precipitator
EVN	Electricity of Viet Nam
EWG	Energy Working Group
FBC	Fluidized Bed Combustor
FGD	Flue Gas Desulfurization
FSSS	Flame Safety Supervisory System
GDP	Gross Domestic Product
GNP	Gross National Product
GV	Governor Valve
GW	Gigawatts (Thousand MW or Million kW)
GWh	Gigawatt-hours (Million kWh)
HP	High Pressure
IC / I &C	Instrumentation and Control
IDF	Induced Draft Fans
IGCC	Integrated Gasification Combined Cycle
IP	Intermediate Pressure
IPP	Independent Power Producer
IS	Ignition System
kJ	Kilojoules
kW	Kilowatts
kWh	Kilowatt-hour
LP	Low Pressure
MCS	Master Control System
MCR	Maximum Continuous Rate
MIS	Management Information System
MT	Magnetic-Particle Testing
MW/MWe	Megawatts (Thousand kW)
NOx	Nitrogen Oxides
NPV	Net Present Value
OEM	Original Equipment Manufacturer
OECD	Organization of Economic Cooperation and Development
PC	Pulverized-coal
PEP	Philippine Energy Plan

RH	Reheat(er)
RHDS	Reheat De-Superheater
RMB	Currency of the People's Republic of China
SC	Supercritical
SC	Surface Condenser
SCADA	Supervisory Control and Data Acquisition
SCAH	Steam Coil Air Heater
SCC	Stress-Corrosion Cracking
SCGT	Simple Cycle Gas Turbine
ST	Steam Turbine
T&I	Test and Inspection
TOFD	Time of Flight Diffraction
Tonne	One thousand kilograms
TPP	Thermal Power Plant
U.S. / U.S.A.	United States of America
USC	Ultra-Supercritical
WP	Worleyparsons Inc., Group
$	U.S. dollar

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1 INTRODUCTION

The worldwide availability of coal as a fuel resource for power generation coupled with its relatively lower cost and stable price has driven an upward trend in its demand that is likely to continue for many years. This demand primarily and largely will meet the huge consumption of coal-based power plants now spread all over the globe. It most especially will serve that need in countries that are expected to have steep economic growth in the coming years. Many of these coal-based power generation facilities are located in the Asia-Pacific Economic Cooperation (APEC) region, which at present is a presently 21-member organization of diverse economies located around the Pacific Rim. This study is focused on those coal-based power plant units, which are located in a number of APEC developing economies are the focus of this study.

1.1 Background

In parallel with strong economic performance, rapid industrialization, and rising personal incomes, energy consumption in the APEC region has grown strongly since the 1980s. Total primary energy consumption in APEC has increased by almost 50 percent since 1980 to reach more than 5 billion tonnes of oil equivalent in 2002. Growth in APEC energy consumption has been driven to a large extent by the developing member economies. In these economies, rapid economic and population growth, together with industrial expansion, urbanization and the transition from noncommercial biomass to commercial energy sources have been key factors underlying energy consumption patterns. Fossil fuels (coal, oil and natural gas) account for approximately 90 percent of total primary energy consumption in APEC. Oil has remained the dominant fuel since 1980. Nonetheless, oil's share of the primary energy mix fell from 48 percent to 38 percent between 1980 and 2002, largely as a result of energy supply diversification strategies and high oil cost throughout the region. In contrast, the shares of coal and natural gas in primary energy consumption have increased over the period since 1980. In 2002, coal and gas accounted for 30 percent and 22 percent of the region's primary energy consumption respectively.

The most rapidly growing component of energy consumption has been the demand for electricity by the industrial, commercial and residential sectors since 1980, expanding at an average annual rate of 4 percent over that period. In low income APEC economies, electricity use has expanded by an average of 8 percent per year.

While the mix of fuels used to generate electricity varies significantly across APEC economies, coal has remained the primary energy source over the past 20 years, with a share of around 45 percent in 2002, followed by natural gas (18 percent), nuclear (16 percent), hydropower (14 percent) and oil (6 percent). A summary of power generation in APEC economies is presented in Table 1. The data in the table is based on year 2001. Most of the newly built power plants in recent years are super-critical or ultra-super-critical units, which contribute significant growth for the total coal-generation capacity in APEC developing economies since 20001. Increasing energy consumption and heavy reliance on fossil fuels for power generation is expected to continue in many APEC economies over the medium to longer term, a trend that will have implications for the environment, both at the local level and on a global scale. Subcritical PC technology dominates the power generation sector, accounting for more than a quarter of capacity from all sources in the APEC region in 2001. This translates to around three quarters of coal-fired power generating capacity in the region. Typically, this technology has relatively low conversion efficiencies compared with other coal and gas technologies. In addition, the variation in the average thermal efficiency of subcritical pulverized-coal units across the APEC region was estimated to be between 27 and 38 percent [*APEC 2001*]. Average thermal efficiency of subcritical PC fired power generation in developed economies is around 35 percent. The thermal efficiency of coal-fired power plants in some developing economies is relatively low, for instance approximately 30 percent in China [*New Energy Technologies, APEC 2005*], due to the fact hat there are still a good number of older small coal-fired units in the power generation sector. Improvements in the efficiency of coal-fired power generation plants can lead to significant reductions in fuel consumption and emissions of carbon dioxide and other pollutants such as SOx, NOx and Hg.

Against this background, plant upgrades and refurbishments, which are aimed at increasing designed to increasing the efficiency of coal as fuel utilization, offer a valuable option for enhancing the environmental performance of energy related activities among APEC member economies. Such activities are a direct means of reducing greenhouse gas emissions and pollutants arising from electricity generation by lowering coal consumption per unit of electricity output. At the same time, plant upgrades also enhance security of energy supply in APEC economies.

Table 1 APEC Electricity Generation Capacity (2001)

	Total Generation Capacity (MWe)	Coal-Fired Generation		Gas-Fired Generation		Oil Fired-Generation		Non Fossil Fuel Power		Subcritical Coal-Fired Generation	
		Total Capacity (MWe)	Percentage (%)	Total Capacity (MWe)	Percentage (%)	Total Capacity (MWe)	Percentage (%)	Total Capacity (MWe)	Percentage (%)	Total Capacity (MWe)	Percentage (%)
Australia	44,526	27,057	60.8	5,989	13.4	2,733	12	8,751	19.7	27003	60.7
Brunei Darussalam	818	0	0	806	98.5	12	1.5	0	0	0	0
Canada	110,601	17,818	16.1	9,991	9.0	4,684	4.2	78,108	70.6	17,657	16
Chile	9,700	1,947	20.1	1,713	17.7	1,304	13.4	4,735	48.8	1,824	18.8
China	231,038	160.413	69.4	1,231	0.5	13,767	6.0	55,627	24.1	152,965	66.2
Hong Kong, China	11,041	6,610	59.9	2,046	18.5	2,382	21.6	4	0	6,610	59.9
Indonesia	30,041	7,197	24.0	5,690	18.9	9.467	31.5	7,686	25.6	7,138	23.8
Japan	256,268	29,549	11.5	52,858	20.6	71,667	28.0	102,193	39	10,049	3.9
Korea, Rep. of	53,057	13,900	26.2	11,910	22.4	6,298	11.9	20,951	39.5	5,241	9.9
Malaysia	17,209	1,700	9.9	7,837	45.5	3,585	20.8	4,87	23.8	1,700	9.9
Mexico	39,352	2,600	6.6	4,872	12.4	17,850	45.4	14,029	35.7	2,600	6.6
New Zealand	9,269	1,021	11.0	1,592	17.2	433	4.7	6,222	67.1	1,011	10.9
Papua New Guinea	780	0	0	121	15.5	438	56.1	221	28.4	0	0
Peru	4,863	270	5.6	222	4.6	1,719	35.3	2,652	54.5	270	5.6
Philippines	17,385	4,258	24.5	683	3.9	7,862	45.2	4,581	26.4	4,258	24.5
Russian Federation	217,256	50,782	23.4	87,946	40.5	11,706	5.4	66,822	30.8	39,806	18.3
Singapore	7,115	0	0	1,299	18.3	5,331	74.9	485	6.8	0	0
Chinese Taipei	34,307	9,218	26.9	4,279	12.5	7,970	23.2	12,840	37.4	9,218	26.9
Thailand	23,513	3,467	14.7	12,154	51.7	1,142	4.9	6,750	28.7	409	11.8
United States	832,875	333,528	40.0	188,343	22.6	79,202	9.5	231,802	27.8	218,213	26.2
Viet Nam	6,391	693	10.8	898	14.1	1,506	23.6	3,294	51.5	523	8.2

Source: "*New Energy Technologies*", APEC # 205-RE-01.1, APEC Energy Working Group, 2005

1.2 Project Objectives

This project study is primarily aimed at the following objectives:

(a) To assess the outcomes on a number of refurbishment and upgrade cases of coal-based power plants located in any one of the Asia-Pacific Economic Cooperation (APEC) - member developing economies.

(b) To record, collate, and draw lessons from these plant upgrades and refurbishments and, consequently, produce a document that can be used as a reference for similar applications in the future. This document shall be called: "***A Best Practices Guide for Developing APEC Economies as Derived from Lessons Learned in Refurbishing Coal-fired Power Plants***".

1.3 Scope

A breakdown of the scope of work components for this study is listed below:

(a) A number of suitable candidate projects located in developing APEC economies were identified as case studies. This step was done in cooperation with the APEC Expert Group of Clean Fossil Energy (EGCFE). The selected study cases have capacities of no less than 100 MW and have been in operation for more than 12 years. Other protocols of case selection, such as efficiency range, were exercised by getting the EGCFE approval before any in-depth effort was dedicated into a particular candidate case for study.

(b) A framework was developed for reporting the elements of the case study projects that were identified or selected by the project team in consultation with designated member economy experts.

(c) Information and data relevant to the project were collected. Data collection came from multiple sources: consultant's own contacts and experts from industry and government, with the latter having the support in terms of introduction/endorsements from EGCFE representatives.

(d) The case study results were synthesized in a preliminary draft report, including an outline or strategy to complete the work, for the review and approval of the Project Steering Committee representatives.

(e) The implications of the case study results were assessed. Consequently valuable lessons were drawn from each case study and vital information was consolidated, so that this information database can be used as reference in preparing the Best Practices Guidelines to aid future plant upgrade decision making. These guidelines now become part of the report after consulting with and getting the approval of the EGCFE Project Steering Committee.

(f) This final report is hereby prepared, including the Best Practices Guidelines, as an integral part of it. This report will be published following the review and approval of the EGCFE Project Steering Committee.

(g) A feedback mechanism will be established to enable interested recipients of the report to raise questions or present their own ideas. This proposed feedback mechanism can be done online through the assistance of EGCFE or other alternative means.

(h) This study will be presented at the first EGCFE Clean Fossil Energy Technical and Policy Seminar following completion of the project, scheduled to take place in November 2008. This said presentation in November 2008 is part of the planned dissemination effort to assist in disseminating the results of the study results.

2 STUDY METHODOLOGY

The main focus of this study is to directly obtain as much relevant information on recent upgrades as possible directly from coal-fired power the source plants. At the onset of this While actual travel and plant visits were not accomplished, the project team was able to gather vital data with the use of telephones, emails and Internet link-up. In addition, the WorleyParsons Study Team was successful in organizing organized a dialogue with a visiting Chinese delegation, which represented various power plants in the People's Republic of China (PRC). Scott Smouse, who is the APEC Expert Group Chair on Clean Fossil Energy, also participated in this meeting. These discussions, which were held at the WorleyParsons' offices in Reading, Pennsylvania, USA, in December, 2007, turned out to be one among are considered as some of the most reliable sources of information in this project study. A synopsis of the dialogue is included in Appendix 1 (Section 8.1) of this report.

After the meeting with the Chinese delegation, the study team prepared a questionnaire, copies of which were sent to various APEC member developing economies. These questionnaires were targeted primarily to APEC developing member-economies that have a large amount of current and projected coal consumption for electric power generation.

In addition to the information, which was obtained directly from power plants, other information sources were also were tapped. These alternative sources of survey inputs include:

(1) EGCFE Reference Documents - Several articles recommended by the APEC Expert Group on Clean Fossil Energy (EGCFE) served as a good source of information for this study.

(2) Information was sought from numerous sources and was received from many of them. These include:

- Power Utility Companies
- Governmental Institutions
- Organized Groups
- Domestic/Local Media
- International Bodies/Organizations
- Internet
- Visiting Technocrats from APEC Economies
- WorleyParsons Database

3 DECISION-MAKING AND RANKING OF OPTIONS

Performance analyses and evaluations on implemented power plant upgrade projects are discussed in the succeeding pages of this report. As an introduction, this section of the report discusses the usual management approach in arriving at thought process that leads to a decision to refurbish or upgrade a power plant's major component. This discussion portion of the report will take into consideration points to areas in the power utility organization that monitor conditions, review performance, and maketrigger decisions to upgrade (or retire) a power generation unit. To widen the perspective of this report, the coverage of the study is carriedset back much earlier on the service life of a plant component, further detailing the processes that compel plants to consider decisions to upgrade their older units. Additionally, the levels of management in a power plant owner's organization that may be involved in the decision-making process to upgrade older units are noted, according to their respective roles in the process.

In any economy, whether it is an APEC member economy or one which does not belong to the APEC group, the main drivers to refurbish old units or build new power plants are either or both of the following:

(1) To meet additional electricity demand

(2) To replace capacity or regain efficiency that is lost due to plant aging

The rise in electric energy demand is a function of economic expansion, greater electrification of daily functions, and population growth. On the other hand, aging degradation of power plants creates obstacles to effectively meet rising electricity power demands. The impact of increasing public concern on the rise of emission levels from coal-based power generating units in recent times has also gained careful consideration in planning for coal-based power plant upgrades and refurbishments.

3.1 Power Plant Aging Degradation

All materials comprising a power plant deteriorate over time. Aging degradation rates of building materials vary, depending on exposure to aggressive environment, method of use and maintenance practices. Systems, structures and components in industrial facilities are subject to aging degradation. Aging degradation is defined as the cumulative degradation that occurs with the passage of time in systems, structures and components that can, if unchecked, lead to a loss of function and an impairment of safety [U.S. Nuclear Regulatory Commission, 1991]. Aging degradation can be observed in a variety of changes in physical properties of metals, concrete, and other materials in a power plant. These materials may undergo changes in their dimensions, ductility, and fatigue capacity, mechanical or dielectric strength. Aging degradation results from a variety of aging mechanisms, which are physical or chemical processes such as fatigue, cracking, embrittlement, wear, erosion, corrosion, and oxidation. These aging mechanisms act on plant systems, structures and components due to challenging environments associated with high heat and pressure, radiation, reactive chemicals, and synergistic affects of any combination of these mechanisms. Some operating policies such as power plant cycling or varying power outputs and equipment testing, can also create stress for power plant components. In reality there is far less number of component failure types as compared with the vast array of plant components that could undergo such failures. However, although plants operate in fairly similar operating conditions, due to diversity in plant designs, histories, and operating and maintenance practices, the specific effects of aging are quite unique for each plant. Even near-twin units at the same site can have substantial differences in the remaining economic/service lives of the major plant components.

Some of the major power plant systems that experience aging degradation are:

- Air heaters
- Boiler Burners
- Soot-blowers
- Steam Turbine Steam Path
- Coal Pulverizers
- Condensers

3.1.1 How to Countercheck Aging Degradation

There are a number of ways to mitigate or counter the effects of aging degradation. One way is proper operating practice, where equipment is run within design limits at all times, if possible. Operating transients can be minimized by a combination of good operating practice and well designed instrumentation and control. Protective materials and coatings can be applied to minimize the effect of the natural elements. However, crucial among these factors to manage aging degradation is a well-conceived, regularly implemented, effective maintenance program. Maintenance involves a variety of methods to predict or detect aging degradation and other causes of plant equipment/component failure.

3.1.2 Effect of Aging on Plant Efficiency, Availability and Reliability

As plant components degrade due to age, clearances of rotating parts like turbines, fans and pumps widen, causing efficiencies to fall way below design values. Likewise, wall thicknesses of high-pressure and -temperature containing parts thin due to erosion and corrosion, and over longer periods of time, fatigue and creep stress can become problems. In surface condensers, for instance, where by design due to incompatibility of tube and tubesheet materials, standard practice requires that tubes be merely rolled to tube sheets. Frequent leaks can develop at the tube-to-tube sheet interfaces, thus causing more frequent shutdowns. Such operating interruptions affect availability, while decline in material integrity of high-pressure, high-temperature containing parts can ultimately effect the reliability of the plant itself.

3.1.3 Effect of Aging on Safety

Any high energy conversion unit poses a safety threat to operators if not properly operated or not well-maintained. At times, an unexpected failure of equipment could occur either due to overload or cyclic transients; but at times equipment could fail suddenly while running at sustained/continuous load condition. For parts containing high-pressure or high-temperature fluids, a sudden part failure, as what could happen on a pipe or header, could be hazardous to plant personnel. The same case is true to plenums and pipes containing toxic and corrosive materials that could fail suddenly due to aging deterioration. Therefore, telltale signs of failure must be closely monitored. These signs can manifest as very high amplitude vibrations, as in the case of rotating equipment, leaks on flanges and threaded connections, or discoloration of material surfaces, and bulging of thinned overheated walls of pressure-containing vessels. Predicting occurrence of failures due to aging degradation is a highly challenging task. Yet, there is a compelling need to have such events predicted or anticipated in order to avoid catastrophic failure or accidents in the plant. Corrective actions of these signs of failure can be done by either parts replacement or complete replacement of the entire assembly or the equipment itself.

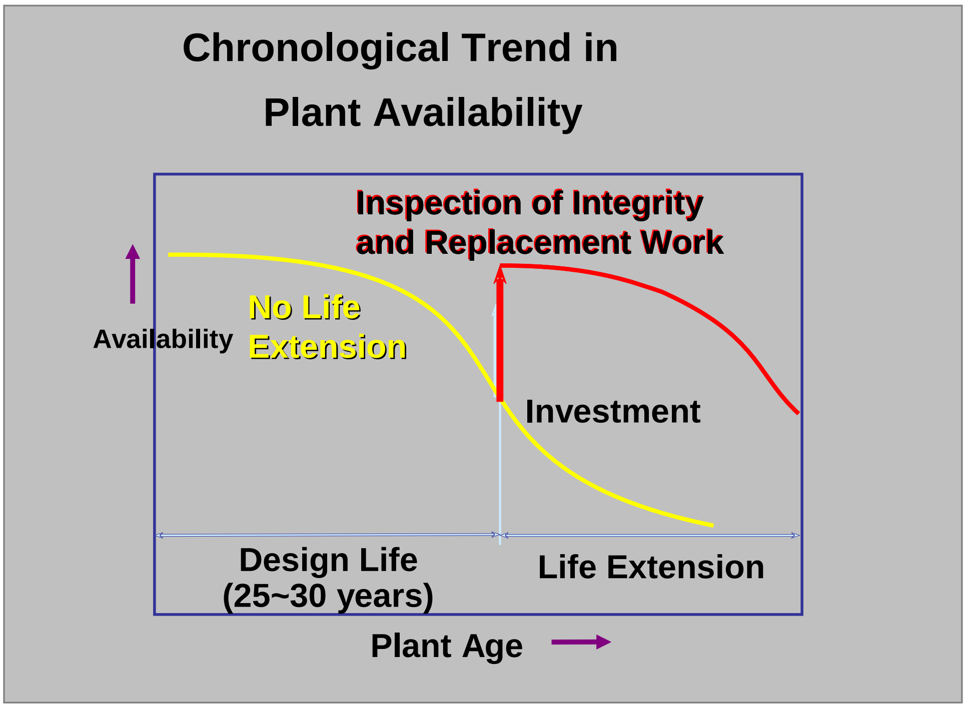
3.2 Assessing Major Power Plant Component Degradation

3.2.1 Life Extension and Remaining Life Assessment

Life Extension (LE) and Remaining Life Assessment (RLA) for an aging power plant involve a thorough evaluation, inspection and review of the critical plant components. This evaluation and assessment is required in order to enable the plant owners to obtain a fairly accurate prediction of the remaining service lives of the various plant components subjected to the review. From the assessment result, counter-measures can be implemented. These preventive maintenance measures can facilitate early detection of defective equipment design, help prolong the equipment service life, raise the level of reliability and improve the individual equipment efficiency, and possibly the efficiency of the over-all plant.

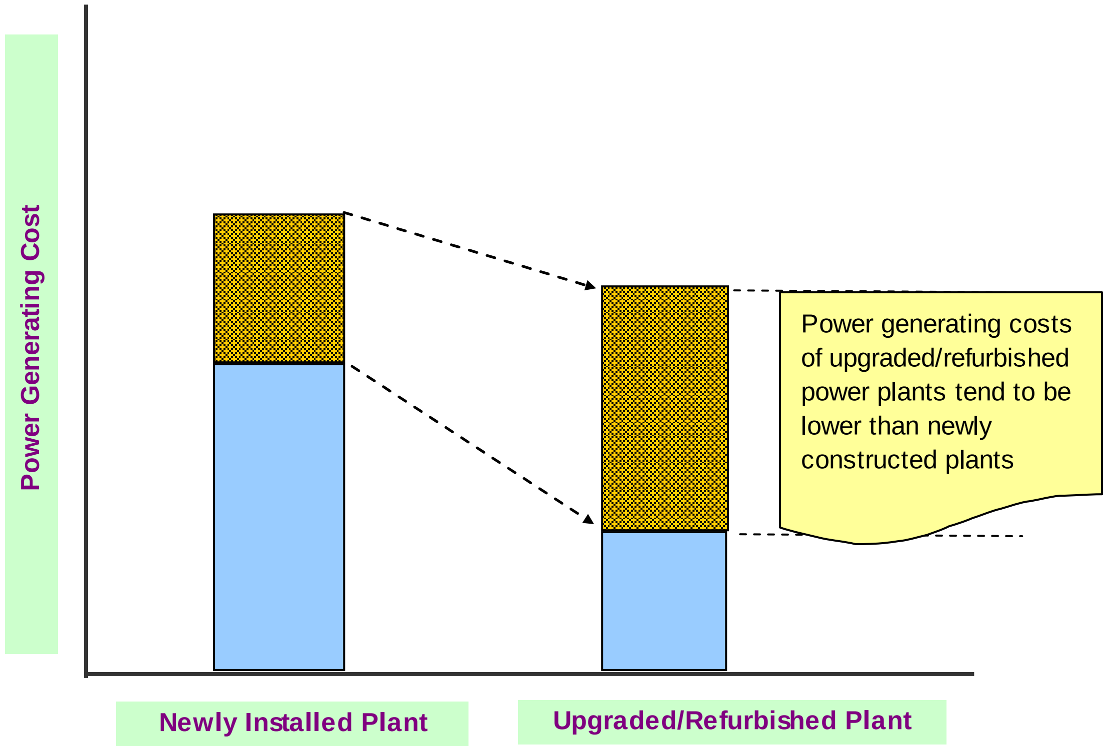
Power plant life extension and plant refurbishment/upgrade programs are driven by the scarcity of new plant construction in some APEC economies. In many cases, it is caused by the much steeper rise in power demand as compared to the pace of building new generation capacity. Experience now gained in such refurbishment efforts will be very useful to the world in general and the APEC member economies in particular. Older and less efficient power plants are often relegated to cyclical operation due to their diminishing performance; hence their need for refurbishment for more flexible roles within the generation fleet. Upgrade and refurbishment result in (a) increasing reliability and longevity of the plant, and (b) improving efficiency to bring the old plant back to economic usefulness and oftentimes environmental compliance. Figure 1 illustrates the impact of refurbishment and upgrade to power plant availability and longevity.

Figure 1 Impact of Refurbishment and Upgrade to Plant Availability and Longevity



What makes refurbishment and upgrade options more attractive is that in a number of situations the results of upgrade efforts produced more economically feasible options than if the same amount of generating capacity were obtained from newly built power plants. Shown below in Figure 2 is the likely result of a refurbishment/upgrade as compared with a newly built generation plant:

Figure 2 Comparisons of Power Generating Cost between Newly Installed and Upgraded/Refurbished Generation Units



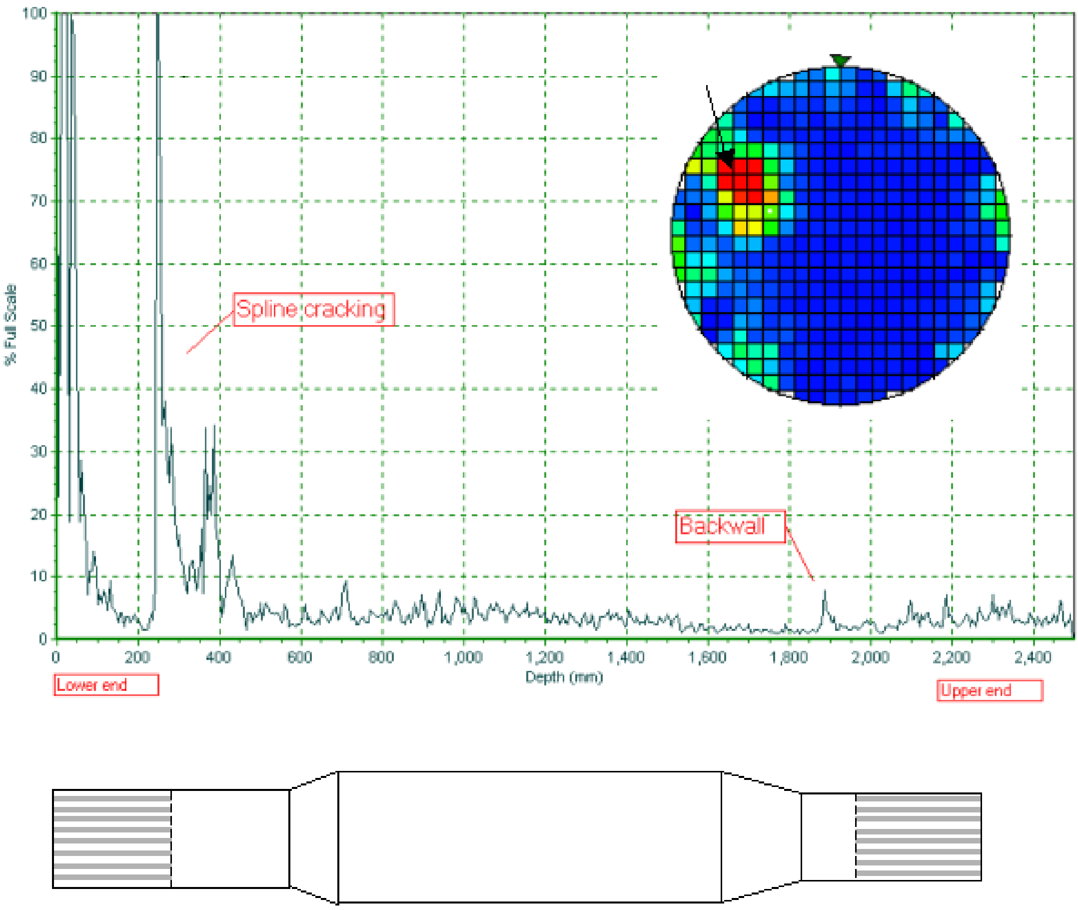
As examples of methods to assess plant component degradation, shown below are types of inspection and life assessment efforts usually done prior to a major refurbishment or upgrade.

Creep Test – This test determines the toughness of highly critical materials in the plant, such as turbine rotors and high energy piping. In coal-based power plants, creep in high-pressure and high-temperature piping and headers can likely occur near the end of the plant's service life.

Crack Detection using Magnetic-particle Testing (MT) – If iron particles are sprinkled on a cracked magnet, the particles will be attracted together in clusters, not only at the poles at the ends of the magnet, but also at the poles at the edges of the crack. This cluster of particles is much easier to see than the actual crack, and is the basis for magnetic particle inspection. Figure 7 shows a mechanical part being tested by MT. This is another common test available in coal-based power plants. It is very useful not only in life assessments, but also during the normal course of a plant's economic life.

Ultrasonic Testing (UT) - In ultrasonic testing, very short ultrasonic pulse-waves with center frequencies ranging from 0.1-15 MHz and occasionally up to 50 MHz are launched into materials to detect internal flaws or to characterize materials. The technique is also commonly used to determine the thickness of the test object, for example, to monitor corrosion rates in pipes. A sample of an ultrasonic test application is shown in Figure 3. Ultrasonic testing is often performed on steel and other metals and alloys, though it can also be used on concrete, wood and composites, albeit with less resolution.

Figure 3 Ultrasonic Test of a Mechanical Part



Ultrasonic Testing (UT) is a Non-Destructive method to detect material flaws or early indication of failure and the procedure employs the application of sound waves having frequencies usually in the mega-hertz range. There are two basic methods in UT, namely: *pulse echo* and *through transmission*. While the former method makes use of a single transducer, the later makes use of two. In the pulse echo method a transducer, made of piezoelectric material, transmits a pulse of mechanical energy into the material. The energy passes into the material, reflects from the back surface, and is detected by the same transducer, yielding a signal on an oscilloscope with a time base. The oscilloscope normally shows the original pulse of the ultrasonic transducer (front surface echo), the back reflection and any extra blip indicating a reflection from a defect in the material. From the oscilloscope timing, the depth of the defect below the surface can be determined. Alternatively, in the transmission method, two transducers are placed on opposite sides of the material and any reduced intensity sensed by the receiving transducer indicates defect shadowing part of the ultrasonic energy. The location of defect can not be obtained. Both pulse echo reflection and transmission methods are in use and their selection depends on the accessibility of the component.

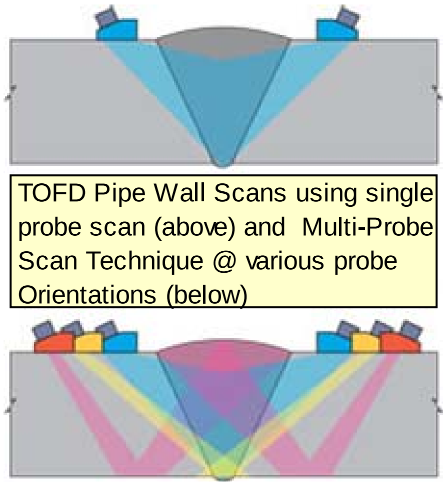
Figure 5 includes ways to predict component integrity degradation using various inspection methods. The diagram lists the commonly used methods in life assessment activities, including:

(a) Time of Flight Diffraction (TOFD) – This is an advanced and automated weld examination technique that assists in Fitness for Purpose (FFP) inspections. TOFD is a fast and efficient way to scan a lot of weld area in a very short time period. It has been reported by the current practitioners of this technique (TCR-Arabia) that dead zones near the front and back surfaces can be enhanced using combined TOFD and conventional pulse echo techniques.

According to the TCR-Arabia website, TOFD is an advanced and automated weld examination technique that assists in Fitness For Purpose (FFP) inspections. Using TOFD, the expert NDT team members can perform amplitude-independent accurate flaw sizing on a wide coverage area in Saudi Arabia. Obviously, this technique can be used both for old power plants that need NDT inspections for remnant life assessment as well as for new plants which are still under construction.

TOFD is a fast and efficient way to scan a lot of weld area in a very short time period. Dead zones near the front and back surface can be enhanced using combined TOFD and conventional pulse echo techniques. Figure 4 shows a case of TOFD use on pipe wall weld inspection.

Figure 4 TOFD Application Technique



The Time of Flight Diffraction (TOFD) technique is based on ultrasound, which, in contrast to manual pulse-echo examination, uses received diffraction signals instead of received reflected signals. TOFD is very sensitive to detecting all kinds of defects, irrespective of its orientation. Using this advanced technique gas and binding defects, porosity, slag inclusions and cracks can be detected independent of defect orientation with very accurate sizing of the defects (±0.5-1.0 mm).

In service validation and FPP projects TOFD has proved itself to be an acceptable technique, combining the high detection rate with a very high reliability in pre-service and in-service inspections. The ability to have digital storage of all inspection data, TOFD enables future evaluation of the same weld at any time and ensures high reproducibility.

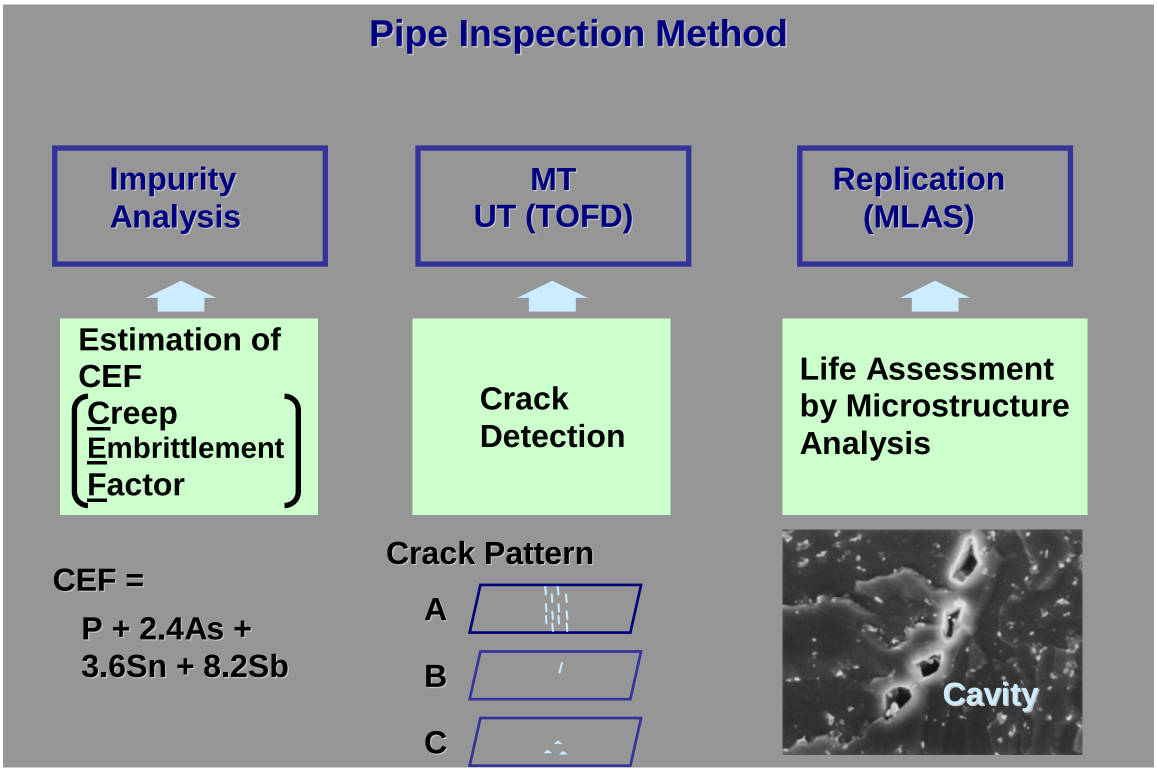
As far as industry acceptance is concerned, TCR-Arabia has reported that ASME Boiler and Pressure Vessel Standard Section VIII Code Case 2235-9 states that it is acceptable to use the TOFD for Ultrasonic examination in accordance with ASME Section V, Article 4. ASME Code Case 2235-9 mentions about replacing RT with UT and has resulted in incorporating TOFD into pressure vessel work for both detection and sizing of flaws. This now allows TOFD to be used on all Section VIII pressure vessels. On the other hand, the American Petroleum Institute Standard API 579 in its current draft form states the Recommended Practice for Fitness-for-Service (The crack depth, length, angle and distance to other surface breaking or embedded cracks is typically determined using UT examination techniques, either TOFD or angle beam.

Draft-API 580 states the Risk Based Inspection Recommended Practice (Base Resource Document recommends automated ultrasonic shear wave testing as a highly effective inspection technique for crack detection and sizing. The capability of the Automated UT technique/type is evaluated using probability of detection (POD) curves from round-robins in the past where TOFD showed the best performance).

British Standards Institute's welding standards policy committee has created the BS 7706 as a guide for the calibration and setting-up of the TOFD technique for defect detection, location and sizing of flaws. Another well documented guide is the Pr EN 583-6.

(b) Replication Technique – This technique takes a replica of the microstructure on specific and highly critical area of the boiler, such as the superheater headers, and then subjecting the replica under microscopic analysis to predict the condition and estimate the remaining life of the component.

Figure 5 Inspection Methods in Determining Remaining Life of Plant Materials

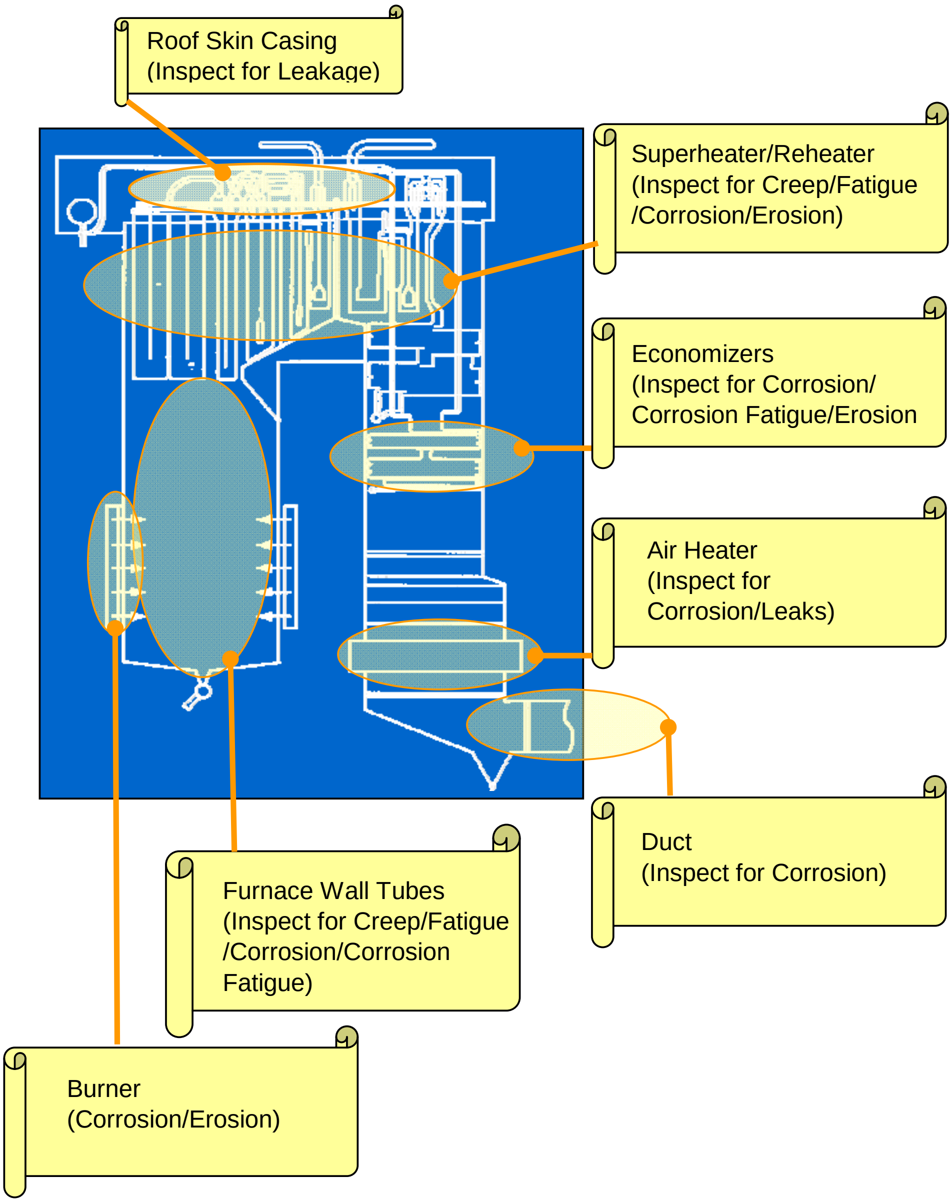


Note: Meanings of above acronyms—(1) CEF = Creep Embrittlement Factor; (2) MT = Magnetic-Particle Testing; (3) UT = Ultrasonic Testing; (4); TOFD = Time of Flight Diffraction; (5) MLAS=Microstructure Life Assessment System

The presentation shown above in

Figure 5 is what may be considered a summary of approaches. Actual extensive field effort in the area of condition and remnant (an inspection industry term) or remaining life assessment is comprised of several other evaluation and inspection methods undertaken at various points in the system. Essentially, this list points to areas generally located within the boiler envelop as shown in the succeeding Figure 6.

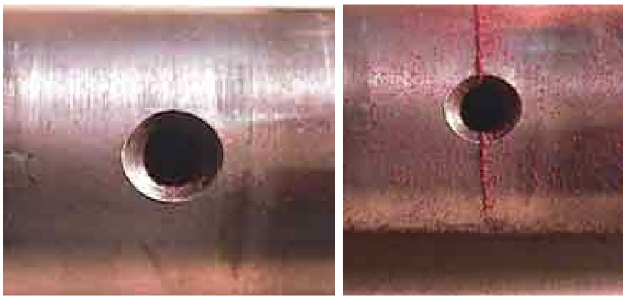
Figure 6 Areas Regularly Inspected for Life Assessment within the Boiler



Note: Since above illustrated sections of the boiler are the usual targets for remanent life assessments, these are also the sections which readily get upgraded or refurbished.

There are several ways of conducting inspections within and outside of boiler parts. Of course, the most extensively used method is the visual technique performed by Non-Destructive Test inspectors who are duly qualified to conduct such inspections. Where metals are involved, the usual technique to verify suspected cracks and discontinuities in metallic structures is the liquid penetrant test (PT) usually called visual and the Magnetic-Particle Testing. The photos taken on the same inspection specimen are shown in Figure 7. The photo on the left shows a mere visual inspection approach (with liquid penetrant application), while the photo on the right on the same specimen shows a more pronounced crack, this being aided by applying the magnetic-particle method.

Figure 7 Visual and Magnetic-Particle Test (MT) of crack originating at hole



Courtesy of MHI

It should be noted that above applications of Non-Destructive Testing are methods used by most American standards such as ASME, AWS and API. A lot of APEC member economies follow a separate and distinct set of standards in their own areas like foe example the JIS Std. in Japan, Canadian Standards, a separate standards in Australia, although one set of standards gaining recognition apart from those mentioned are the ISO standards. Several APEC economies have now adopted these set of standards together with other European (British and German) standards as well.

3.2.2 Performance Testing

Another good way of assessing the actual condition of an old power plant prior to considering it for major refurbishment or upgrade is to conduct a series of power plant Performance Test runs. The tabulated list below contains various performance testing codes as examples that are required when the plant will be subjected to such a test:

Table 2 Examples of Performance Test Codes

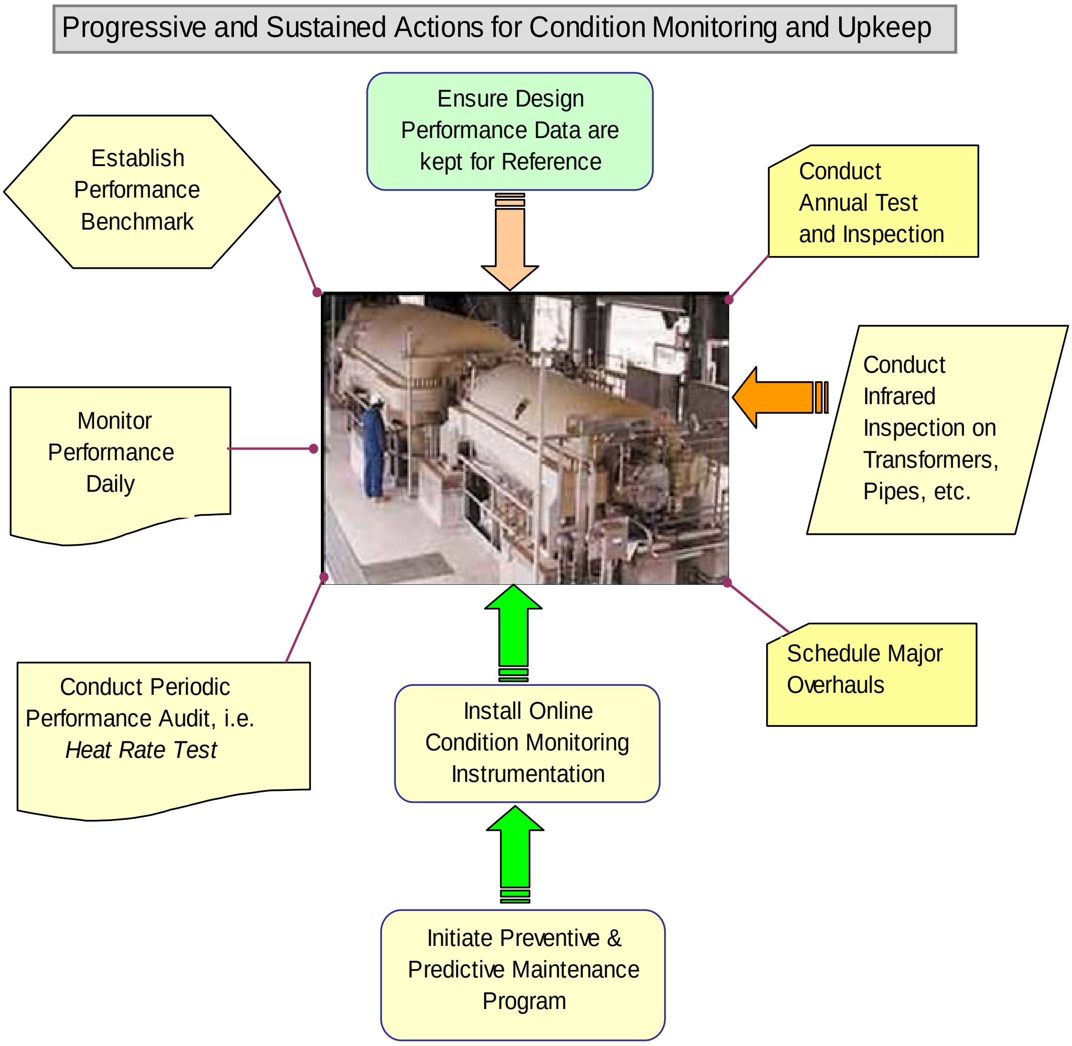
ASME Performance Test Codes	
PTC 4	Fired Steam Generators
PTC 4.3	Air Heaters
PTC 6	Steam Turbines
PTC 11	Fans
PTC 12.1	Feedwater Heaters
PTC 12.2	Steam Surface Condensers
PTC 12.3	Deaerators
PTC 40	Flue Gas Desulphurization
Note: The design Heat Balance is required as reference in the analysis of deterioration in any of above plant component	

By subjecting all major equipment in a plant to Performance Tests and thereafter compare the performance test results obtained with that of the design values or with those which were obtained during the commissioning of the old power plant, the owner(s) of the plant can then see how far the performance of the old unit has drifted away from economically (and/or environmentally) acceptable limit. For this purpose, the original design heat balance values can be used as a benchmark to evaluate how much the power plant system drifted from the desired operating parameters.

3.2.3 Performance Trending

Periodic performance testing, as discussed in the preceding paragraph, can be expensive. Some companies or organizations maintain their own Performance or Results Engineering groups with trained personnel capable of conducting such an extensive test. The exercise involves sophisticated instrumentation and specific time duration dedicated to each identified unit that will undergo testing. These units may be disengaged from Automatic Dispatch Systems (ADS) mode. This exercise may also involve a select group of operating plant staff/personnel to witness such a test. It is, therefore, incumbent upon management to determine the optimum frequency of testing within a given year. One good method of justifying a less frequent performance testing schedule is to follow a strict performance trending and condition monitoring program to compensate for a longer gap between extensive performance tests. The following diagram illustrates the basic items covered in a continuous condition monitoring program and performance trending set-up in a power plant:

Figure 8 Monitoring Equipment Condition and Performance



There will be fewer surprises to plant operators if performance trending and monitoring programs are strictly followed. Modern Data Acquisition Systems (DAS) functions are integrated and incorporated into Distributed and Control Systems (DCS) functions and have now reached a stage of sophistication where practically all critical operating parameters are automatically monitored, and major plant equipment is fully outfitted with adequate permissive, interlocks, alarms and tripping mechanisms to ensure that the equipment is well protected from sudden and, much worse, catastrophic failures.

3.2.4 Statistical Records – Uptime and Downtime Profiles

While records on equipment vibrations, non-destructive tests, thermo-imaging, heat rate testing and so forth, are usually the works of special groups within a power plant organization, there is one important aspect that is normally maintained by the plant operators, shift engineers and operations foremen. It is the monitoring and record keeping of all the events occurring in the unit every second of the day. The modern Supervisory Control and Data Acquisition Systems (SCADA) used in most power plants today records a plant's operations as historical information, storing the information into electronic archives for future retrieval.

The operator-machine interface remains important in controlling the plant, and also in recording data and analyzing facts. It is essential that operators are always mindful of operating parameters that signal the worsening condition of their plants. For example, as machines get older, their uptimes (operating hours) tend to shrink while their downtimes tend to increase. Frequencies of forced outages and interruptions increase as time passes. Aborts or unsuccessful return to smooth operation from a shutdown can increase, as well. Finally, turnaround times for annual test and inspections of power generating units could grow longer per year as more and more components need to be fixed.

This phenomenon is a natural occurrence, but it is best to be anticipated and observed closely. The following daily time monitor sheet, Figure 9, as illustrated below, provides a simple format from which operators can monitor changes daily, as they transfer data from electronic log sheets to their own hard copy files. Furthermore, this type of recording can be the source data sheet for calculating plant availability, forced outage rates, reliability profiles and so forth.

Figure 9 Power Plant Status Time Report Format

DATE:

24-hour Plant Status Time Report

UNIT NO	STATUS	Unit Status HRS	Unit Status MIN	DECIMAL VALUE	Time and Reason when status changed
UNIT - 1	RH	24	0	24.00	
	SH	0	0	0.00	
	FOH	0	0	0.00	
	SMOH	0	0	0.00	
	TIOH	0	0	0.00	
	FDH	0	0	0.00	
	SDH	0	0	0.00	
	RR	0	0	0.00	
		HRS	MIN		NOTE: Use small letter case with short description
UNIT - 2	RH	0	0	0.00	
	SH	0	0	0.00	
	FOH	0	0	0.00	
	SMOH	0	0	0.00	
	TIOH	24	0	24.00	
	FDH	0	0	0.00	
	SDH	0	0	0.00	
	RR	0	0	0.00	
		HRS	MIN		
UNIT - 3	RH	0	0	0.00	
	SH	0	0	0.00	
	FOH	0	0	0.00	
	SMOH	0	0	0.00	
	TIOH	24	0	24.00	
	FDH	0	0	0.00	
	SDH	0	0	0.00	
	RR			0.00	
		HRS	MIN		
UNIT - 4	RH	0	0	0.00	
	SH	0	0	0.00	
	FOH	0	0	0.00	
	SMOH	0	0	0.00	
	TIOH	24	0	24.00	
	FDH	0	0	0.00	
	SDH	0	0	0.00	
	RR			0.00	
	STATUS	HRS	MIN		

Symbols

RH	Running Hours	FOH	Forced Outage Hours	FDH	Forced derated Hrs
SH	Standby Hours	SMOH	Sched Maint Outage Hrs	SDH	Scheduled derated Hrs
		TIOH	T & I Outage Hours	RR	Rerated to full load

Shift Foreman:

Note: If this form is accomplished DAILY, each Electric Power Generating Unit can have very good STATISTICAL data base and Plant Availability and Reliability Factors can be readily derived from it for future Unit Evaluations.

4.3 Beyond Degradation and the Role of the Government and Organized Bodies

There will come a time when a spare part, single equipment or a major plant component in a power plant reaches a point or condition beyond economic repair. Sometimes obsolescence occurs faster than the physical breakdown of a part, which leaves no other options, but to replace or retire the unit or part in question. When that point is reached, it is time to decide the next course of action. In the power generation business, the *status quo* or inaction is not an option. Components will continue to degrade if no remedies are taken. In order to meet the system electric load demand, the electricity utility owners have several options. Additionally, a case faced by one utility owner in an economy where private ownership is widespread may not be unique. It is possible that there are a number of utility owners simultaneously facing a similar dilemma regarding which way to proceed with their aging power plants.

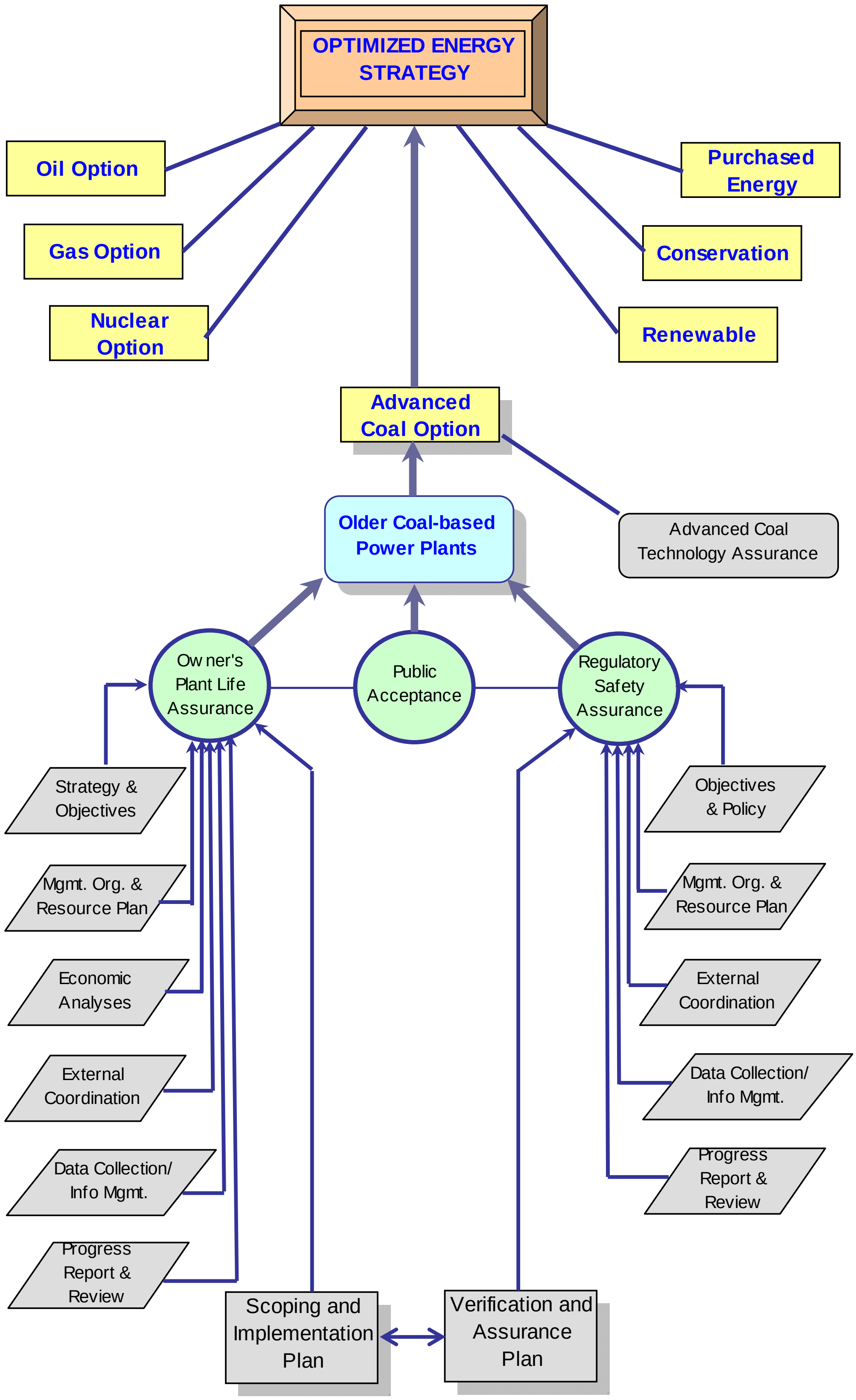
Whatever and wherever the case may be, the government usually has an influence on the decisions made by utility owners with regard to the direction of the electricity generation fleet. The degree of government participation and influence varies from one country to another. In fact, it may not be the government that intervenes directly in the power sector planning, but other organized bodies, sanctioned by the government, whose purposes are to foster national goals. This situation is good for the utility owner(s) in the sense that these organized bodies help ensure that the whole power industry is kept viable and well directed at the macroeconomic level. Based on this, a decision-making tool in a form of a Strategy Guideline for coal-based power utility fleet replenishment, configured to be used as a guideline at the macro level is presented in the form of a diagram, as illustrated in Figure 10. This guideline is adopted from the Organization of Economic Cooperation and Development (OECD). As suggested by this international body, it is an international framework for life management of nuclear plants. In the OECD paper entitled, "*Nuclear Power Plant Aging and Life Management: A Model Approach, Current Status and Country Comparisons*", the strategy presented has logically placed the nuclear option at the heart of the whole spectrum of power plant matrix. In this particular case, the coal option is positioned at the focal point, in the same manner that the gas option or renewable option could take in the framework if it were used for such purpose.

An advantage of organized bodies such as APEC, OECD, the World Bank, EPRI, etc., which are networks in and of themselves, is their strategic ability to link with other networks. For that matter alone, information in their databases is huge and easily accessible. Hence, strategic guidelines offered by such groups are of greater valuable than the individual efforts of a given power utility firm.

There now is a number of Independent Power Producers (IPP's) operating in APEC member developing economies. These companies are either locally based or have overseas headquarters. It is anticipated that these companies coordinate with organized bodies such as APEC, for instance, in crafting their strategies and producing both their short and long-tem plans. PEC is interested in the power generation sector and willing to share its information and expertise gained from its continuous program of research in various fields of interest. One of these is the efficient utilization of coal as fuel and concomitant mitigated emissions through the aid of new technologies.

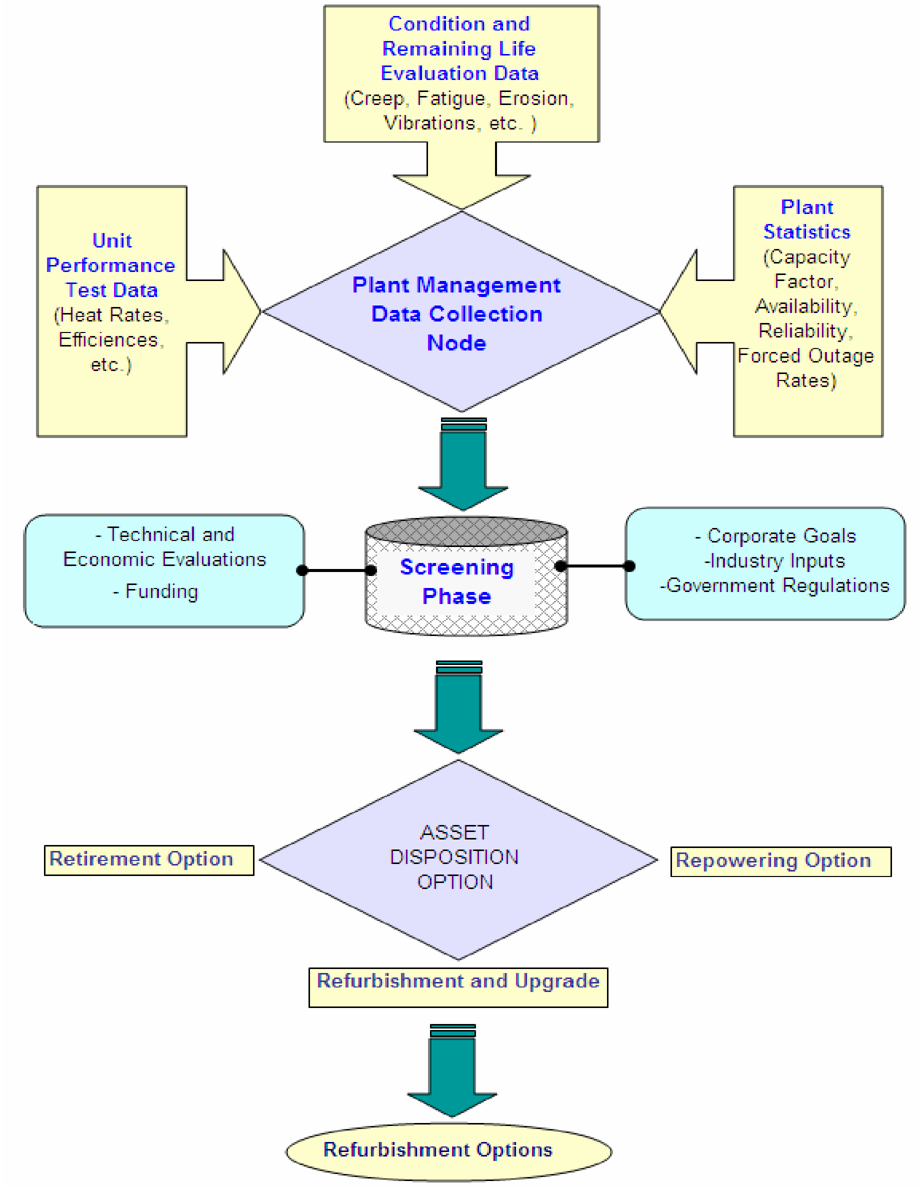
The following diagram is a strategy roadmap, which any power utility company may adopt for its own using. This diagram is intended for a coal-based power utility, but it can be used for other types of energy sources, as well.

Figure 10 Proposed Strategy Guideline for Coal-Based Power Generation Plant



If applied to any APEC member developing economy situation, the above *Macro-Analytic Approach* in deciding the Refurbishment and Upgrade of Power generating units should be paired with a *Micro-Analytic Approach* component at the power plant management level. Logically, initiatives for refurbishments or upgrades should originate from the power plant level, since the plant manager is closest to the on-site situation and knows the plant's equipment status and staff abilities. Corporate leaders are involved with a wider scope of operations, probably covering all sites in the system. Thus, the plant manager should be a key participant in the decision making process to upgrade or refurbish or implement some other option to the assets under his or her control. Figure 11 presents a logical, decision-making road map that identifies the steps leading to a decision to refurbish or upgrade a power plant.

Figure 11 Power Plant Decision-Making Road Map for Refurbishments and Upgrades



4 CASE STUDY

This section presents actual cases of older coal-based power generation plant upgrades and refurbishments. These projects are reported as actual cases and are representative of the current trend of extending the service lives of older, conventional coal-based power plants. Most of the cases reported are from the People's Republic of China, which among the APEC developing economies has the greatest number of power plants built in the last decade. Additionally, a couple of cases are from the Philippines.

4.1 Case Study Methodology

At the start of the project, a study base document was issued and approved by APEC Experts' Group on Clean Fossil Energy (EGCFE) Energy Working Group. In that study base document, the approach to the study was outlined in detail. It included reaching out to sources of information within and outside APEC and WorleyParsons Group, Inc. Much of the information was obtained from the public domain through the worldwide web (Internet). In addition to the data collected from the survey and reference materials, the authors of this report are contributing information from actual cases and situations derived from their professional experiences that are relevant to the current study.

The study team was privileged to meet with a Chinese delegation at WorleyParsons offices in Reading, Pennsylvania, USA. Among the group of dignitaries were leaders and technocrats in the Chinese electric power industry. A dialogue was held on December 6, 2007. A synopsis of the discussions is attached in this report as Appendix 1.

The team also issued a survey questionnaire to various power plants in the APEC region, and the information provided in the responses was very helpful to this work. Most of the materials obtained during the survey came from the People's Republic of China, with a couple of cases from the Philippines. These cases are listed as they are identified from the survey responses. However, given the incompleteness of several of the forms, only those that contained all the required inputs suitable for economic analysis are considered for that aspect of the work. All of the statements contained in all of the responses became sources of information for the *Lessons Learned* and *Best Practices Guide* sections in this report. Each response is technologically unique and is site specific, and therefore, was addressed individually in the best practice recommendations.

The following table summarizes the distribution of plant equipment that was refurbished as covered in the survey of this study:

Table 3 Summary Matrix of Refurbishment and Upgrade Projects

Plant Component Refurbished	Number of Cases	Remarks
Coal Pulverizers	3	Worn edges / table liner wear and loading problems
Air Heaters	8	Most of the problems were high air leakages
Boiler Burners	5	Flexibility problems in operating ESP/ unstable combustion / deformation/loss of baffle synchronization
Ignition Systems	1	High fuel oil consumption (Note: Fuel oil is ignition fuel)
Induced Draft Fans	3	Broken blades / capacity adjustment / lack of coupling flexibility
Boiler Sootblowers	6	Erosion / poor performance /
Steam Turbines	6	Turbine Stage deteriorating performance / blade upgrades / back-end loading limitations

Surface Condensers	2	Insufficient heat transfer area; tube deterioration
Instrumentation and Control	5	Obsolescence / reliability issues
Flue Gas Desulfurizers	2	Emission regulation / permitting requirement
Reheater Coils	1	Sagging assembly / deterioration
Steam Coil Air Heaters	1	Loss of effective supports / bent tubes
Reheat Desuperheaters	1	Eroded cold reheat walls
Electro-hydraulic Control Fluid Polishing	1	Deteriorated portable polishers
Desalination Plant (Brine Recirculation Pump)	1	Stress corrosion cracking of pump casing.

4.2 Identified Cases for Study

The following tabular listing comprises the power plants/companies that responded to the study group questionnaires. There is a more comprehensive version of this list in Appendix 8.2. In that list, all the details pertaining to the refurbishments and upgrade, as provided by the power plants are listed. The responses from the Chinese Power Plants, which were originally written in Chinese, were translated to English and catalogued accordingly.

Table 4 List of Surveyed Coal-Based Power Generation Plants

Plant Name (Economy) /Capacity Rating (MW)	Refurbishe/ Upgraded Plant Component	Investment Cost U.S. Dollars or RMB	Benefit due to Upgrade	Remarks
1)Hangzhou Banshan Power Plant (China) Capacity (MCR)= 125 MW Date Refurbished: Year 2000 Unit No. 4	***Air Heater***	$428,571 or RMB 3,000,000	Leak reduction from 12% to 6% **Net Unit Efficiency Gain= 2%**	
	Boiler Burner	$214,286 or RMB 1,500,000	Boiler efficiency after upgrade = 91.02%	Efficiency data prior to upgrade is not given
	Boiler Soot blowers	$285,714 or RMB 2,000,000	Improved unit efficiency and reliability	Only stated as such; no numbers on efficiency and reliability given
	Steam Turbine	$2,657,143 or RMB 18,600,000	Turbine heat rate improved by 1021.3 kJ/kWh (968 BTU/kWh)	This case is good candidate for study
	Instrumentation and Control	$428,571 or RMB 3,000,000	Increased the operating reliability of equipment and reduced the operations and maint. workload	No actual benefit values given like, for example, % reliability increase
2)HuBei Hanxin Power Plant (China) Capacity	***Air Heater***	$542,857 or RMB 3,800,000	Leak reduction from 20% to 10%	(assume efficiency gain of 3% based on Hangzhou Banshan Case)
	Boiler Burner	$285,714 or RMB 2,000,000	No data	
	Boiler Soot blowers	$571,428 or RMB 4,000,000	Boiler Efficiency was improved	Response did not show actual boiler efficiency improvement in %

(MCR)= 326 MW Date Refurbished: Year 2004 Unit No. 2	***Steam Turbine***	$757,143 or RMB 5,300,000	Turbine heat rate improved by 189 kJ/kWh (199.4 BTU/kWh)	This case is good candidate for study
	Condenser	$1,542,857 or RMB 10,800,000		
	Instrumentation and Control	$2,142,857 or RMB 15,000,000	No data on benefits available	
3) NanChang Power Plant (China) Capacity (MCR)= 125 MW Date Refurbished: Year 2004(AH); 2006 (Burners) Units No. 10 & 11	***Air Heater***	Each Unit: $ 214,286 or RMB 500,000	Leak reduction from 28% to 12%	assume efficiency gain of 5% based on Hangzhou Banshan Case
	Boiler Burner	Each Unit: $51,429 or RMB 360,000	Boiler Efficiency increased by 2%	This case is good candidate for study
	Boiler Soot-blowers	Each Unit: $85,714 or RMB 600,000		
	Induced Draft Fan	Each Unit: $ 85,714 or RMB 600,000		
	Condenser	Each Unit: $171,429 or RMB 1,200,000	Turbine Heat Rate has improved by 0.37 kJ/kWh (0.35 BTU/kWh)	This case is good candidate for study
	Steam Turbine	Unit No. 11 $2,857,143 or RMB 20,000,000	Turbine Heat Rate has improved by 777.89 kJ/kWh (737.3 BTU/kWh)	This case is good candidate for study
	Instrumentation and Control	$285,714 or RMB 2,000,000 (each unit)	No specific claim of monetary improvement	The improved control must have contributed to improved heat rate of the unit
	Addition: **New FGD to each unit** (added on May 2007)	$3,571,429 or RMB 25,000,000 (total both units)	Mitigated emission pollution	This effort is to mitigate pollution which is necessary in permitting regulations
4) Taizhou Power Plant (China) Capacity (MCR)= 125 MW Date Refurbished: Year 1999	***Air Heater***	$885,714 or RMB 6,200,000	Air leakage rate decreased from 19.5% to 6.0% (13.5% reduction) ID Fan power drop= 92 kW; FD Fan power drop= 98 kW	Assume efficiency gain of 4.5 % based on Hangzhou Banshan Case

5) Power Plant "A" Huadian Power Int'l. (China) Capacity (MCR)= 330 MW	***Air Heater***	$371,429 or RMB 2,600,000	Boiler Efficiency Increased	No actual boiler efficiency % value given
	Boiler Burner	$700,000 or RMB 4,900,000		
	Boiler Soot-blowers	$157,143 or RMB 1,100,000	boiler tube failures decreased	No actual numbers given
	Steam Turbine	Not available	No data on benefits available	
6) Guangzhou Zhujiang Power Plant (China) Capacity (MCR)= 300 MW Date Units No. 1 to 4	***Air Heater***	$35,714 or RMB 250,000	Air leakage rate decreased from 20% to 10~12% (8 -10% reduction)	Assume efficiency gain of 3 % based on Hangzhou Banshan Case
	Coal Pulverizer	$25,714 or RMB 180,000	Stone coal discharge decreased by 356 Tonne/month	
	Boiler Burner	$114,286 or RMB 800,000	Operational improvement noted after upgrade	No improvement data figures given
	Boiler Soot-blowers	Not Available	Improvement Data not given	
	Induced Draft Fans	Not Available	Reliability increased significantly	No reliability improvement numbers provided in the response to questionnaire
	Steam Turbine	Not Available	Not Available	
	FGD System	Not Available	Not Available	
	Plasma Ignition System	$714,286 or RMB 5,000,000 (per Unit)	Saved the plant 600 tonnes of oil until date of response	
7) Power Plant "B" (Unit #1) Huadian Power Int'l. (China) Capacity (MCR)= 335 MW	***Air Heater***	$ 214,286 or RMB 1,500,000	Air leakage rate decreased from 15% to 7% (8 % reduction)	Assume efficiency gain of 2.7 % based on Hangzhou Banshan Case
	Boiler Burner	Not Available	Not Available	
	Boiler Soot-blowers	$214,286 or RMB 1,500,000	Overheating of pipe walls resolved; boiler exit gas temperature reduced	No numbers on benefit given
	Steam Turbine	$1,428,52 or RMB 10,000,000	Turbine Heat Rate has improved by 330 kJ/kWh (312.78 BTU/kWh)	This case is good candidate for study
	Instrumentation and Control	$1,428,52 or RMB 10,000,000	Plant coordinated control target achieved	No numbers on benefit given

8) Power Plant "B" (Unit #1) Huadian Power Int'l. (China) Capacity (MCR)= 648 MW	***Air Heater***	$214,286 or RMB 1,500,000	Reliability increased but leakage rate was the same	No numbers on benefit given
	Instrumentation and Control	$428,572 or RMB 1,000,000	Coordinated control was achieved	No numbers on benefit give
9) Fengzheng Power Plant (Unit # 1,2,3,4,5 &6) North United Power	***Air Heater***:	$180,000 or RMB 1,260,000 (each)	Air leakage rate decreased from 30.2% down to 10.2 %(Unit # 1=20% reduction) and 39.8% down to 9.8% (Unit #2 =30 % reduction)	Due to these large air leak reduction percentages, unit efficiency improvements may not be accurately predicted
	Induced Draft Fans	$214,286 or RMB 1,500,000	Not Available	
	Boiler Burner	$171,429 or RMB 1,200,000 each	Excess air decreased from 1.67% to 1.54%	
	Steam Turbine	$2,828,571 or RMB 19,800,000 (Total)	Not Available	No actual numbers on benefit given on the response sheet
	Electrostatic Replacement with Baghouses (Units 1,3&5)	U#1=RMB 14,960,000 ($2137143) U#3=RMB 14,980,000 ($2140000) U#5=RMB 14,960,000 ($2137143)	Solid removal efficiency improved	No actual numbers on benefit given on the response sheet
10) Power Plant "C"	***Instrumentation and Control (Unit # 1)***	$7,142,857 or RMB 50,000,000	Faster response achieved; easier to be modularized	
	Instrumentation and Control (Unit #2)	$7,142,857 or RMB 50,000,000	Faster response achieved; easier to be modified	
	DEH System of Unit # 1 was Upgraded		No data on benefits available	
	Boiler Soot-blowers	$71,429 or RMB 500,000 (each)	No data on benefits available	
	Air Heater (Unit # 2)	$2,857,143 or RMB 20,000,000	Excess air decreased from 11% to 7% (4% improvement); reliability increased	Assume efficiency gain of 1.33 % based on Hangzhou Banshan Case

	Pulverizer (Unit # 2)	Data Not Available	Pulverizer capacity increased by 20%	
	Boiler Burner (U# 2)	Data Not Available	Excess air decreased; NOx emission reduced by 10 ppmv@4% O_2; Average Annual Maint. Cost reduced by Y100,000 ($14,286)	
	Steam Turbine (Unit # 2)	$8,571,428 or RMB 60,000,000	Turbine Heat rate improved by 180 kJ/kWh (170.61 BTU/kWh)	This case is good candidate for study
11) Pagbilao Power Plant, the Philippines (Unit # 1)	***Air Heater (Unit #1& 2)***	No Project Cost Data	No measured performance variable	No comment made by plant
	Pulverizer (Unit #1& 2)	No Project Cost Data	No data on benefits available	No comment made by plant
	Boiler Burner (U# 1&2)	No Project Cost Data	No data on benefits available	No comment made by plant
	Instrumentation and Control (Unit #1&2	No Project Cost Data	Payback Period = 20 months	As claimed by plant personnel working on the project.
Notes:	(1) The study team did not pursue missing information, as it was understood to be not readily available at the plant or was controlled information; The same applies to cases when a plant is only labeled as "A", "B" or "C," which means the plant is not ready to have its name released for the study publication. (2) A more comprehensive version of this table is available in Appendix 8.2.			

4.3 Case Study

The following are selected study cases which were taken from those listed in the preceding table. Only those plants that provided data on both project costs and quantifiable benefits are included in these case studies.

4.3.1 Case study 1

(1) Name of Power Plant: Hangzhou Banshan Power Station

(2) Location: Hangzhou Zhejiang Province, People's Republic of China

(3) Unit: No. 4

(4) Capacity Rating (MCR): 125 MW

(5) Owner: China Huadian Corporation

(6) Component(s) Refurbished/Upgraded:

- Air Heater
- Boiler Burner

- Sootblower
- Turbine

(7) Year of Upgraded/Refurbishment: Year 2000

(8) Plant Background:

Hangzhou Banshan Power Company Limited is located in Hangzhou, Zhejiang, and was founded in March 1959. The company has five coal-fired units (Unit 1,2,3,4 & 5) and three combined cycle units with total capacity of 1530 MWe. Unit 1 (12-MWe), 2 and 3 (50-MWe for each) were retired recently. Units 4 and 5 (both 125-MWe) were put into operation in the 1980s and 1990s and presently are still running. In 2001, three natural gas-fired combined cycle generating units, each rated to be 390 MWe, were put in operation. Currently, a 200-MWe class IGCC unit is being built and is scheduled to be online in 2010.

(9) Problem Statement (Basis for Upgrade):

- Air Heater – Air heater had high air leakage and serious ash clogging
- Oil Burners – Boiler could not be easily started at cold starts; it needed an upgrade, including addition of new oil-saving ignition burners.
- Sootblowers – The original set of blowers was rarely used as most of the mechanical parts were not functioning; erosion of those original blowers was severe.
- Steam Turbine – The original turbine had a declining performance since it was first started up. Before the upgrade turbine efficiency had declined severely.

(10) Installation Cost:

- Air Heater - $428,571 (RMB 3,000,000)
- Boil Burner - $214,286 (RMB 1,500,000)
- Sootblowers - $285,714 (RMB 2,000,000)
- Steam Turbine - $2,657,143 (RMB 18,600,000)

  Total = $3,585,714 (RMB 25,100,000)

  Source of Funding – Self-funded

(11) Age of Plant when Upgraded/Refurbished: 16 years (start of plant commercial operation was in 1984)

(12) Savings/Benefits from Upgrade/Refurbishment:

$723,917 base year 2000 (from 2000 – 2007) inflated at 2% per year

$1,516,605 base year 2008, inflated at 2% per year thereafter

Savings/Benefits derived from:

Turbine Heat Rate Improvement of 425 BTU/kWh (as stated in the Questionnaire Response Form)

<u>Assumptions:</u>

(a) A yearly escalation factor (inflation rate) of 2% is assumed on all cost related items.

(b) A Plant Capacity Factor of 70% is assumed. Capacity factor in this case is equal to the average annual operating time that the Unit is running @ 100% Load (Note: *based on sample given in APEC Report EWG 04-2003T , Page 52*)

Basis:

(a) Reference point of Economic Analysis is year 2000.

(b) Dollar values is based at year 2000

(c) Coal Price basis:

- $2.00 /mmBTU (year 2000 inflated @ 2% per annum till price surge in 2008 due to Chinese coal industry deregulation
- $4.19/mmBTU (year 2008 price upward shift which is higher than the 2% annual increase projection as reckoned from year 2000; partly due to coal industry deregulation
- 15 years of economic life for the new upgrades/refurbishment.

Economic Evaluation Tool(s) Used in Project Performance Assessment:

The economic tools used in evaluating this case are the Discounted Cash Flow Rate of Return (DCFROR), otherwise known as the Internal Rate of Return (IRR), the Net Present Value Method and the calculations for Payback Period for the project initial capital.

Discounted Cash Flow Rate or Return is defined as the discount rate that makes the present value of future cash flows equal to the initial capital outlay. It may be defined as "that discount rate which makes Net Present Value (NPV) equal to zero".

Another good method to assess the economic feasibility of a project is the Net Present Value method. This method of assessment is applied in five of the following six case studies, all of which are based on a guideline discount rate of 20%, which is the cost of money or rate of return in China where these projects were implemented. There were two values from which the guideline rate was chosen from and these are: 10% discount rate, which is the usual cost of money for a power system owner and includes the weighted cost of capital for each class of debt and equity *[Reference: Babcock & Wilcox, Steam, at page 37-5]*. However, all the cases presented in this study took place in the People's Republic of China; therefore, the return of capital in the PRC at the time of project implementation is used. The funds used to implement the projects were not borrowed from banks but were self-generated extra funds from the utility owners; hence there were more chances that those funds could have higher rate of returns when used somewhere else. For this reason, the cost of money used for the NPV assessment of the upgrade/refurbishment projects was 20%. This value of 20% is based from the outcome of a study titled: "*The Return to Capital in China*" written by Chang-Tai Hsieh and Yingyi Qian in their working Paper 12755 (Year 2004).

As a reinforcing indicator of the economic feasibility of the projects reviewed, the payback period is also calculated. In these cases, the payback period is obtained by simply dividing the total initial investment cost (outflow) by the annual income in terms of fuel savings (inflow).

Economic Feasibility Calculations: With the basic input cost data, and other supporting basis and assumptions, the DCFROR is calculated by projecting the fuel savings as derived from the heat rate improvement attributable to the upgraded/refurbished project. The NPV was obtained by equating to zero all present values of cash outflows (investments in capital) and present values of all projected savings in terms of avoided fuel expenses. Several values of discount rates were used in the iteration of the expression as presented below:

Present Value of Cash Flow = Cash Flow during year 'y'/ (1 +discount rate)^{y}, where 'y' is the year the particular cash flow occurred. In effect, the spreadsheet has two columns of annual cash streams, i.e., one column for the initial investment and expenses for project upkeep and another column for the benefits gained in terms of avoided fuel costs. A sample presentation of a DCFRO Excel calculation sheet is shown in Appendix 4. In Case 1, for example, the DCFROR value of 19.75% is determined by making several iterations, using different values of discount rates, until the Net Present Value (difference of present values of the Cash Outflow and Cash Inflow columns) have settled at or near zero. The usual viable Rate of Return on Investments is 10% or more. However, in the People's Republic of China where these cases occurred, 20% is considered as the guideline rate of return. On the other hand, Payback Period is a straightforward process of determining the recovery of capital over a period of time. It is calculated by dividing the Total Installed Cost of Upgrade (Investment) divided by the Annual Benefit (Savings) or Income derived from the same. Since the income is inflated at a rate of 2%, the average value of the first 5-year savings is used instead of the first year savings value only.

Another good assessment is to determine the impact of these investments on plant upgrades on the levelized life cycle cost of the plant. However, *levelized life cycle cost* is not used since the initial cost of the power plant itself is not known.

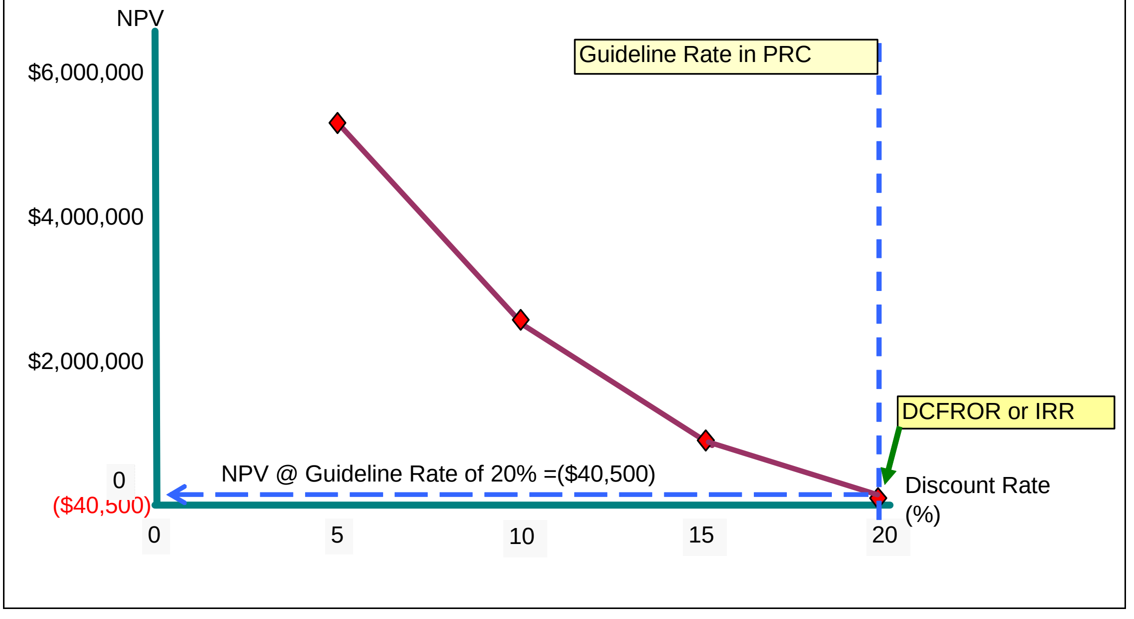
The Project Feasibility Indicators for Case No. 1:

- Discounted Cash Flow Rate of Return (DCFROR) = 19.75%
- NPV @ 20% Guideline Rate (Base Year 2000) = ($40,500)
- Pay back Period = 4.76 years

The result of this evaluation should be noted, where it revealed that as contrasted to a prevailing return to investment in the Chinese market of 20% of self-generated capital, the project return projection was short of $40,500 to match an opportunity investment somewhere else which could have yielded 20%. This being said, there are other intangible aspects of the project which are not readily quantified, such as reduced pollution, improved reliability, etc. which could not be gained by the plant if the funds were not used for these upgrades.

The Net Present Value Profile for the project is shown in Figure 12.

Figure 12 Case 1 Net Present Value Profile



4.3.2 Case study 2

(1) Name of Power Plant: HuBei Hanxin Power Station

(2) Location: Hanchuan, Hubei Province, People's Republic of China

(3) Unit: No. 2

(4) Capacity Rating (MCR): 326 MW

(5) Owner: China GuoDian Group

(6) Component(s) Refurbished/Upgraded:

- Air Heater
- Boiler Burner
- Sootblower
- Turbine
- Condenser

(7) Year of Upgraded/Refurbishment: 2004

(8) Plant Background:

Hanxin Group is located in Hanchuan, Hubei province. The company has total installed capacity of 4 × 300-MWe. All four units are pulverized coal-fired subcritical type. Original commercial operation of Unit No. 2 started in June 1996 (Unit No. 1 started earlier), and Units 3 & 4 were started in 1998.

(9) Problem Statement (Basis for Upgrade):

- Air Heater – Air heater had high air leakage and poor heat transfer
- Oil Burners – Poor combustion efficiency and stability
- Sootblowers – Sootblower performance deteriorated to a very low level
- Steam Turbine – Seal needed retrofit. Governing stage nozzles required replacement.
- Condenser – Steam turbine back pressure consistently high due to insufficient heat transfer surface area.

(10) Installation Cost:

- Air Heater - $542,857 (RMB 3,800,000)
- Boil Burner - $285,714 (RMB 2,000,000)
- Sootblowers - $571,429 (RMB 4,000,000)
- Steam Turbine - $757,143 (RMB 5,300,000)
- Condenser - S1,542,857 (RMB 10,800,000)

Total = $3,700,000 (RMB 25,900,000)

Source of Funding – Self-funded

(11) Age of Plant when Upgraded/Refurbished: 4.5 years (start of plant commercial operation was on June 28, 1996)

(12) Savings/Benefits from Upgrade/Refurbishment:

$795,171 base year 2000 (from 2004 – 2007) inflated at 2% per year

$1,665,882 base year 2008, inflated at 2% per year thereafter

Savings/Benefits derived from:

Turbine Heat Rate Improvement of 179 BTU/kWh (as stated in the Questionnaire Response Form)

Assumptions:

(a) A yearly escalation factor (inflation rate) of 2% is assumed on all cost related items.

(b) A Plant Capacity Factor of 70% is assumed. Capacity factor in this case, is equal to the average annual operating time that the Unit is running @ 100% Load (Note: based on sample given in APEC Report EWG 04-2003T, Page 52)

Basis:

(a) Reference point of Economic Analysis is year 2004.

(b) Dollar values is based at year 2004

(c) Coal Price basis:

- $2.00 /mmBTU (year 2000 inflated @ 2% per annum till price surge in 2008 due to Chinese coal industry deregulation
- $4.19/mmBTU (year 2008 price upward shift which is higher than the 2% annual increase projection as reckoned from year 2004; partly due to coal industry deregulation
- 15 years of economic life for the new upgrades/refurbishment.

Economic Evaluation Tool(s) Used in Project Performance Assessment:

The economic tools used in evaluating this case are DCFROR or IRR, the Net Present Value @ a guideline rate of 20% and calculation for the Payback Period. The generally accepted definition of a project's discounted cash flow rate of return is that it is the discount rate which makes the present value of future cash flows equal to the initial capital outlay. It may be defined as that discount rate which makes NPV equal to zero. As reinforcing indicator of the economic feasibility of the project, payback period is also calculated. In this case, payback period is obtained by simply dividing the total initial investment cost (outflow) by the annual income in terms of fuel savings (Inflow).

Calculating for the levelized life cycle cost of the plant, another approach to see the impact of investments on plant upgrades is not used in this case, since the initial cost of the power plant is not known.

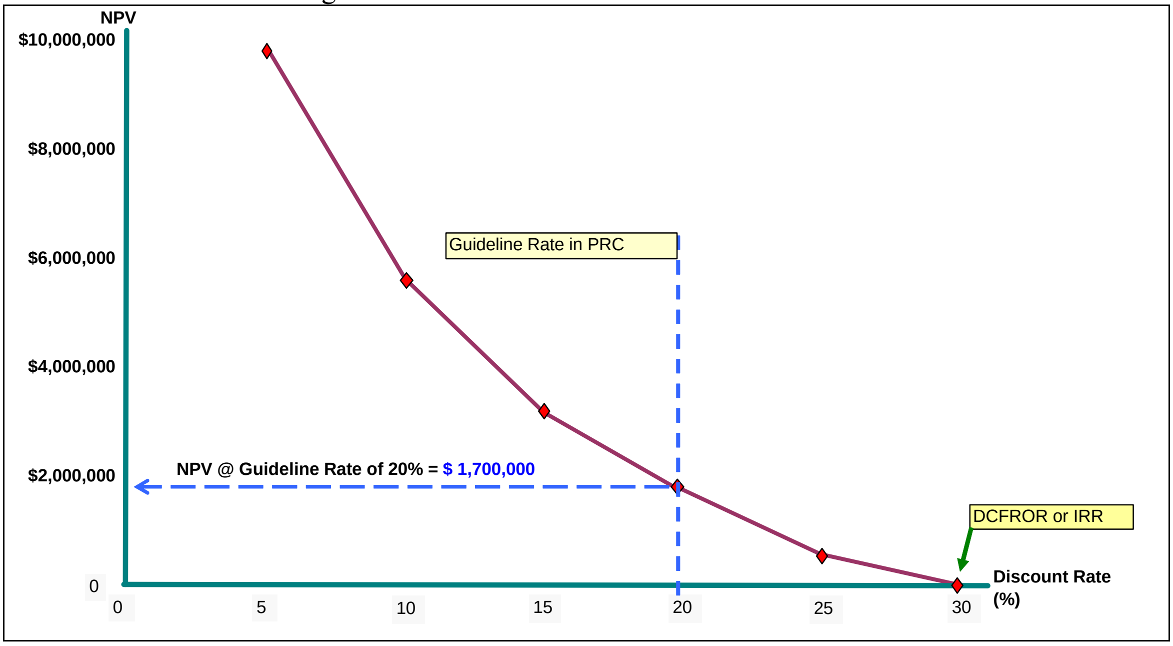
Economic Feasibility Calculations: The economic analysis and feasibility calculation is similar to that used in the preceding case (Case No. 1)

Project Feasibility Indicator for this case is as follows:

- Discounted Cash Flow Rate of Return (DCFROR) = 29.54%
- NPV @ 20% Guideline Rate (Base Year 2004) = $1,700,000
- Payback Period = 3.74 years

The Net Present Value Profile for the project is shown below.

Figure 13 Case 2 Net Present Value Profile



4.3.3 Case Study 3

(1) Name of Power Plant: NanChang Power Station

(2) Location: NanChang, Jiangxi Province, People's Republic of China

(3) Unit: No. 11

(4) Capacity Rating (MCR): 125 MW

(5) Owner: China Power Investment Group Co.

(6) Component(s) Refurbished/Upgraded:

- Air Heater
- Boiler Burner
- Sootblower
- Turbine
- Condenser

(7) Year of Upgraded/Refurbishment: 2004

(8) Plant Background:

Nanchang Power plant is located Nanchang, Jiangxi. Currently, the plant has total installed generating capacity of 250 MWe (2 x 125-MWe). All the units are pulverized coal-fired and were started in 1988 and 1989 respectively. The China government is shutting down some of the aged, smaller power generating units in National 11th Five Year Plan (2006-2010). The two units are planed to be phased out by the end of year 2010, and a green-field coal-fired power plant (4 x 600-MWe) is being planned in a different location, away from the Nanchang urban area. The first two units are scheduled to be online in 2010.

(9) Problem Statement (Basis for Upgrade):

- Air Heater – Air heater had high air leakage.
- Oil Burners – Unstable combustion issue
- Sootblowers – Poor sootblowing performance; replaced with compressed air sootblowers
- Steam Turbine – Degraded performance; steam path modified (HP, IP, & LP)
- Condenser – Tubes needed replacement; changed to stainless steel.

(10) Installation Cost:

- Air Heater – $214,286 (RMB 1,500,000)
- Boil Burner – $51,429 (RMB 360,000)
- Soot blowers – $85714 (RMB 600,000)
- Steam Turbine – $3,714,286 (RMB 26,000,000)
- Condenser – $171,429 (RMB 1,200,000)

Total = $4,237,144 (RMB 29, 660,000)

Source of Funding – Self-funded

(11) Age of Plant when Upgraded/Refurbished: 15.5 years (start of plant commercial operation was on May, 1988)

(12) Savings/Benefits from Upgrade/Refurbishment:

$1,255,357 base year 2000 (from 2004 – 2007) inflated at 2% per year

$2,629,972 base year 2008, inflated at 2% per year thereafter

Savings/Benefits derived from:

Turbine Heat Rate Improvement of 737 BTU/kWh (as stated in the Questionnaire Response Form)

<u>Assumptions:</u>

(a) A yearly escalation factor (inflation rate) of 2% is assumed on all cost related items.

(b) A Plant Capacity Factor of 70% is assumed. Capacity factor in this case, is equal to the average annual operating time that the Unit is running @ 100% Load (Note: *based on sample given in APEC Report EWG 04-2003T, Page 52*)

<u>Basis:</u>

(a) Reference point of Economic Analysis is year 2004.

(b) Dollar values is based at year 2004

(c) Coal Price basis:

- $2.00 /mmBTU (year 2000 inflated @ 2% per annum till price surge in 2008 due to Chinese coal industry deregulation
- $4.19/mmBTU (year 2008 price upward shift which is higher than the 2% annual increase projection as reckoned from year 2004; partly due to coal industry deregulation
- 15 years of economic life for the new upgrades/refurbishment.

<u>Economic Evaluation Tool(s) Used in Project Performance Assessment:</u>

The economic tool used in evaluating this case is DCFROR. The generally accepted definition of a project's discounted cash flow rate of return is that it is the discount rate which makes the present value of future cash flows equal to the initial capital outlay. It may be defined as that discount rate which makes NPV equal to zero. As a reinforcing indicator of the economic feasibility of the project, the payback period is also calculated. In this case, the payback period is obtained by simply dividing the total initial investment cost (outflow) by the annual income in terms of fuel savings (inflow).

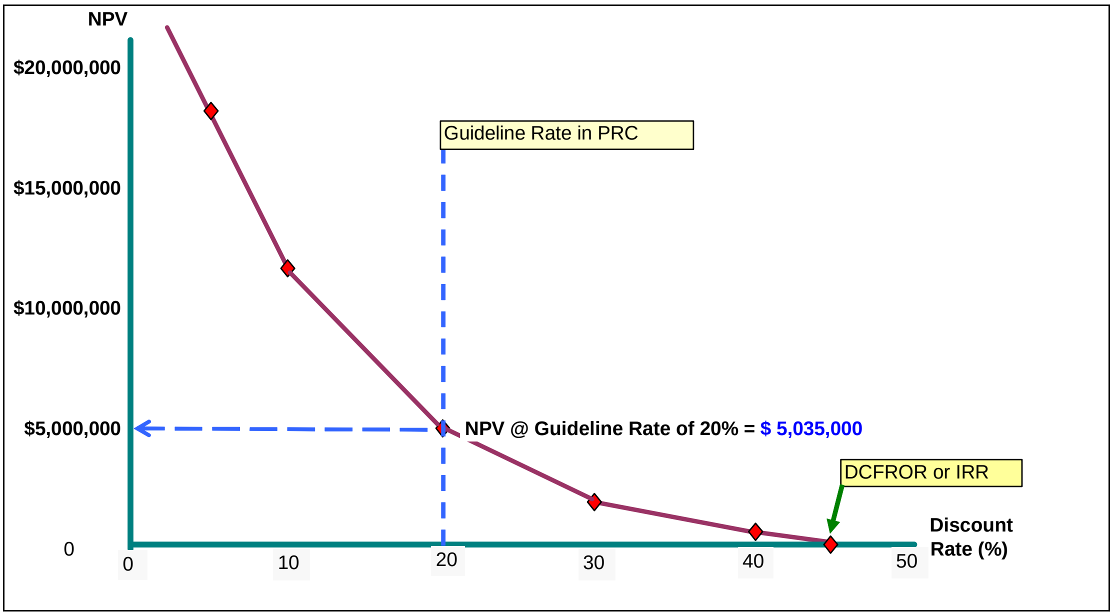
Calculating for the levelized life cycle cost of the plant, another approach to see the impact of investments on plant upgrades, is not used in this case since the initial cost of the power plant is not known.

Project Feasibility Indicators for this case (Study Case No. 3) are as follows:

- Discounted Cash Flow Rate of Return (DCFROR) = 44.98%
- NPV @ 20% Guideline Rate (Base Year 2004) = $5,035,000
- Pay back Period = 2.71 years

The Net Present Value Profile for the project is shown below.

Figure 14 Case 3 Net Present Value Profile



4.3.4 Case study 4

(1) Name of Power Plant: Power Plant ‘B’

(2) Location: Zouxian, Shandong Province, People’s Republic of China

(3) Unit: No. 1

(4) Capacity Rating (MCR): 335 MW

(5) Owner: Huadian Power International Corporation Ltd

(6) Component(s) Refurbished/Upgraded:

- Air Heater
- Boiler Burner
- Sootblower
- Turbine
- Instrumentation & Control

(7) Year of Upgraded/Refurbishment: Year 2002

(8) Plant Background:

Huadian International Zouxian Power Plant is a large pulverized coal-fired power plant, located in Zoucheng City, Shandong Province. At present, the plant has four 335-MWe, two 600-MWe and two 1000-MWe generating units with a total installed capacity of 454-MWe. The plant is one of the largest coal-fired power plants in the nation, and is a subordinate enterprise of China Huadian Corporation.

(9) Problem Statement (Basis for Upgrade):

- Air Heater – Air heater had high air leakage.
- Oil Burners – Needed improvement at partial load operation; replaced with rich-lean burners
- Sootblowers – The original infrasonic sootblowers were replaced with steam sootblowers
- Steam Turbine – Degraded performance; steam path modified (HP, IP, & LP); shaft seals and blade and stationary vane sealing were modified.
- Instrument and Control – The plant original control system was upgraded to a DCS system to increase the automation and control level.

(10) Installation Cost:

- Air Heater - $214,286 (RMB 1,500,000)
- Boil Burner - $285,714(RMB 2,000,000)
- Sootblowers - $214,286 (RMB 1,500,000)
- Steam Turbine - $1,428,571 (RMB 10,000,000)
- Inst. & Control - $1,428,571 (RMB 10,000,000)

Total = $3,571,428 (RMB 25,000,000)

Source of Funding – Self-funded

(11) Age of Plant when Upgraded/Refurbished: 17 years (start of plant commercial operation was in 1985)

(12) Savings/Benefits from Upgrade/Refurbishment:

$1,427,911 base year 2000 (from 2002 – 2007) inflated at 2% per year

$2,991,474 base year 2008, inflated at 2% per year thereafter

Savings/Benefits derived from:

Turbine Heat Rate Improvement of 312.8 BTU/kWh (as stated in the Questionnaire Response Form)

Assumptions:

(a) A yearly escalation factor (inflation rate) of 2% is assumed on all cost related items.
(b) A Plant Capacity Factor of 70% is assumed. Capacity factor in this case, is equal to the average annual operating time that the Unit is running @ 100% Load (Note: *based on sample given in APEC Report EWG 04-2003T, Page 52*)

Basis:

(a) Reference point of Economic Analysis is year 2004.

(b) Dollar value is based at year 2004.

(c) Coal Price basis:

- $2.00 /mmBTU (year 2000 inflated @ 2% per annum till price surge in 2008 due to Chinese coal industry deregulation
- $4.19/mmBTU (year 2008 price upward shift which is higher than the 2% annual increase projection as reckoned from year 2004; partly due to coal industry deregulation
- 15 years of economic life for the new upgrades/refurbishment.

Economic Evaluation Tool(s) Used in Project Performance Assessment:

The economic tool used in evaluating this case is DCFROR. The generally accepted definition of a project's discounted cash flow rate of return is that it is the discount rate which makes the present value of future cash flows equal to the initial capital outlay. It may be defined as that discount rate which makes NPV equal to zero. As reinforcing indicator of the economic feasibility of the project, payback period is also calculated. In this case, payback period is obtained by simply dividing the total initial investment cost (outflow) by the annual income in terms of fuel savings (Inflow).

Calculating for the levelized life cycle cost of the plant, another approach to see the impact of investments on plant upgrades is not used in this case, since the initial cost of the power plant is not known.

Case Study No. 4 Project Feasibility Indicators:

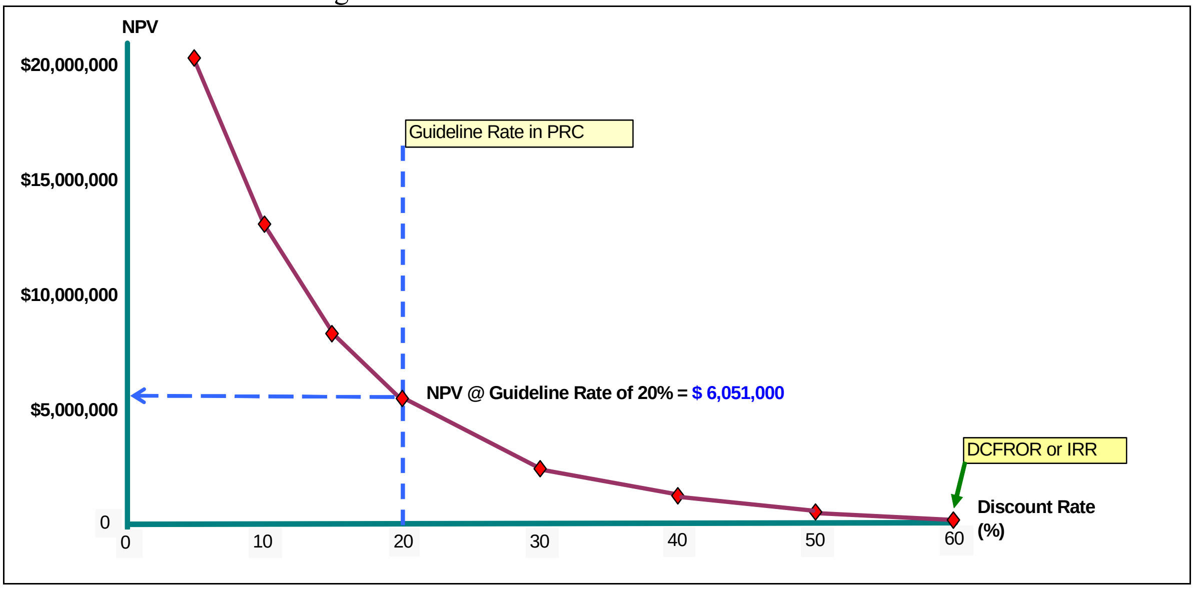
- Discounted Cash Flow Rate of Return (DCFROR) = 59.89%
- NPV @ 20% Guideline Rate (Base Year 2004) = $6,051,000

- Pay back Period = 2.40 years

Note: This power plant has been in commercial operation since the 1980s. The refurbishment, after a period of steady decline on performance, had definitely given a substantial improvement on the plant heat rate. On the other hand, the cost of refurbishment was not as high as those of the other plants; hence, the higher rate of return on this particular project investment. Net present Value of investment is obviously high given that the plant has been given a second lease of life with a relatively low capital infusion.

The Net Present Value Profile for the project is shown in Figure 15.

Figure 15 Case 4 Net Present Value Profile



4.3.5 Case study 5

(1) Name of Power Plant: Power Plant ‘C’

(2) Location: Pingwei, Anhui Province, People’s Republic of China

(3) Unit: No. 2

(4) Capacity Rating (MCR): 600 MW

(5) Owner: China Power Investment Group Co.

(6) Component(s) Refurbished/Upgraded:

- Air Heater
- Turbine

(7) Year of Upgraded/Refurbishment: 2002

(8) Plant Background:

Pingwei Power Plant is located in Huainan City, Anhui Province. The plant is owned by China Power Investment Group Co. The plant currently has two 600-MWe pulverized-coal-fired power generating units. The two units were put in operation in 1989 and 1992 respectively. Two 1000-MWe ultra-supercritical pulverized-coal-fired power generating units are planned to be put in operation before 2011.

(9) Problem Statement (Basis for Upgrade):

- Air Heater – The original air heater was replaced by a new Howden air heater due to high air leakage.
- Steam Turbine – Degraded performance; the flow paths of HP, IP, & LP turbines, the blade and stationary vane sealing, shaft seal and 1st stage blade were all modified.

(10) Installation Cost:

- Air Heater – $2,857,143 (RMB 20,000,000)
- Steam Turbine – $8,571,428 (RMB 60,000,000)

Total = $11,428,571(RMB 80,000,000)

Source of Funding – Self-funded

(11) Age of Plant when Upgraded/Refurbished: 12 years (start of plant commercial operation was in 1993).

(12) Savings/Benefits from Upgrade/Refurbishment:

$1,394,989 base year 2000 (from 2005 – 2007) inflated at 2% per year

$2,922,502 base year 2008, inflated at 2% per year thereafter

Savings/Benefits derived from:

Turbine Heat Rate Improvement of 172.62 BTU/kWh (as stated in the Questionnaire Response Form).

<u>Assumptions:</u>

(a) A yearly escalation factor (inflation rate) of 2% is assumed on all cost related items.

(b) A Plant Capacity Factor of 70% is assumed. Capacity factor in this case, is equal to the average annual operating time that the unit is running @ 100% load (Note: *based on sample given in APEC Report EWG 04-2003T, Page 52*)

<u>Basis:</u> Similar to those of the preceding case studies (Case Study No.1 – 4).

<u>Economic Evaluation Tool(s) Used in Project Performance Assessment:</u>

Economic analysis and calculations are similar with those of the preceding Case Study No. 1 to 4. Due to the relatively high cost of steam turbine upgrade/refurbishment the rate of return as calculated is below 15%.

Case Study No. 4 Project Feasibility Indicators:

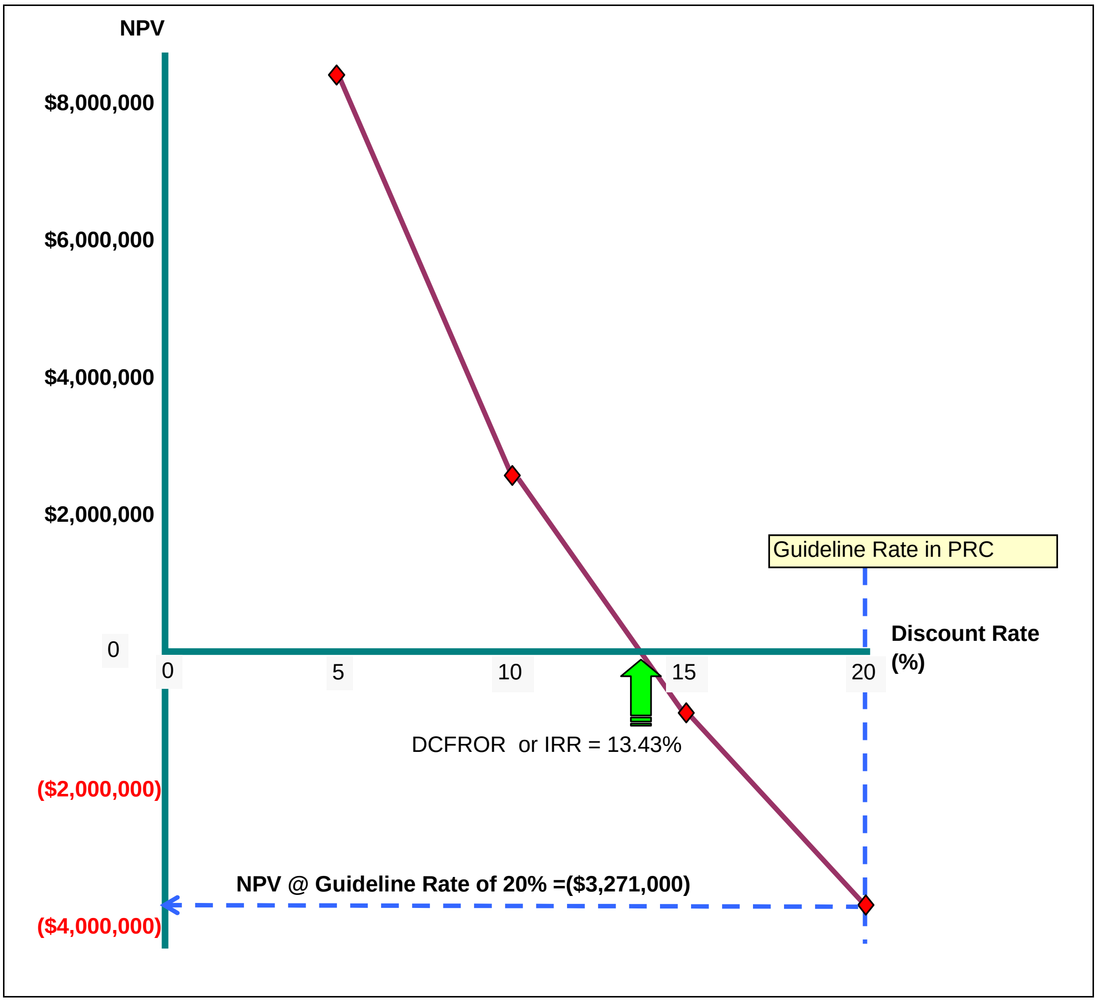
- Discounted Cash Flow Rate of Return (DCFROR) = 13.43%

- NPV @ 20% Guideline Rate (Base Year 2000) = ($3.271,000)*
- Pay back Period = 5.62 years

*Note: The NPV @20% discount rate of $3,271,000 is the difference between the projected net present values of the project cash flows as contrasted to an alternative scenario where the company-owned funds could have been diverted in a 20% yielding investment somewhere else in the PRC. However, as explained in Case 1, there are other not readily quantifiable benefits that can be derived by the company (China Power Investment Group Co.) having invested the money in this particular project.

The Net Present Value Profile for the project is shown in Figure 16.

Figure 16 Case 5 Net Present Value Profile



4.3.6 Case study 6

(1) Name of Power Plant: Pagbilao, Power Plant

(2) Location: Quezon, Province, Luzon Island, Philippines

(3) Unit: No. 1 & 2

(4) Capacity Rating (MCR): 385 MW

(5) Owner: Team Energy Corp.

(7) Component(s) Refurbished/Upgraded:

- Air Heater
- Coal Pulverizer
- Burners
- Instrumentation and Control

(8) Year of Upgraded/Refurbishment: 2006

(9) Plant Background:

Pagbilao Power Plant is a subcritical coal power plant located in the province of Quezon, in the island of Luzon, the Philippines. It has 2 x 385 MW units using sub-bituminous coal as fuel. The original mode of operation for this plant was base loaded. Now, both Units No. 1 & 2 are shift load units.

- (10) Problem Statement (Basis for Upgrade):
- Air Heater – The air heater had been encountering frequent high differential pressure (clogging).
- Coal Pulverizers – The table liner was hard surface overlaid in 2006 due to wear.
- Burners – The burners were replaced to improve air flow.
- Instrumentation and Control – The old system became obsolete and had to be replaced by a state-of-the-art Ovation Expert Control system in 2004 & 2006 respectively.

(11) Installation Cost: (not reported)

Source of Funding – Self-funded

Age of Plant when Upgraded/Refurbished: 8 & 10 years (start of plant commercial operation was in 1993 & 1996)

(12) Savings/Benefits from Upgrade/Refurbishment: Not reported by the plants

Pay back Period = slightly over 2 years on the Instrumentation and Control investment. (Note: This information was indicated in a related report coming from the power plant)

4.4 Ranking of Case Study Results and Discussion

The ranking of the cases as presented in this section can be seen in the following table of comparison:

Table 5 Ranking of Study Cases

Case	Plant Name	Indicators			Remarks
		DCFROR or IRR (%)	NPV @ 20% (in PRC)	Payback (years)	
1	Hangzhou Banshan Power Station	19.75	($40,500)	4.76	Unit No. 4; plant commercial start date: 1984
2	HuBei Hanxin Power Station	29.54	$1,700,000	3.74	Unit No. 2; plant commercial start date: 1996
3	NanChang Power Station	44.98	$5,035,000	2.71	Unit No. 11; plant commercial start date: 1988
4	Zouxian, Shandong	59.89	$6,051,000	2.4	Unit No. 1; plant commercial start date: 1985 [*Ranked as most attractive Upgrade*]
5	Power Plant 'C' (Pingwei, Anhui Province)	13.43	($3,271,000)	5.62	Unit No. 2; plant commercial start date: 1993;[*Ranked as least attractive Upgrade*]
6	Pagbilao Power Plant	N/A	N/A	2.5	For I & C Upgrade on Units 1 & 2; Payback is obtained from a report related to particular I& C upgrade.

4.4.1 Clarification of Ranking Approach

The preceding table displays a matrix of economic assessment indicators relative to a number of case studies presented in this report. While several names of power plants appeared in the list of survey respondents, not all of them have given all the information required to evaluate the economic feasibility of their upgrade projects. Unlike the usual project feasibility studies, where all events still have to unfold in the future, all the cases presented in this report are now running in their upgraded conditions. Moreover, the amount of information obtained by the study team renders impractical and imprecise the evaluation of an individual component's distinct contribution to the entire upgrade improvement. As a case in point, we wish to cite the case of the simultaneous upgrades of the surface condenser, air heaters, sootblowers and steam turbine, which resulted in a significant unit heat rate improvement. In these cases, individual components of any single plant's upgrade cannot be segregated from each other and be treated separately for ranking purposes.

For example, the various improvements implemented in Case Study No. 1 (Hangzhou Banshan Unit No. 4), which are those of the air heater, sootblower, boiler burner and steam turbine upgrades, just can not be treated individually to enable comparing one component upgrade against each other for the following reasons:

(1) All these upgrades were installed simultaneously during a single outage for this purpose; hence it would be difficult to identify the exact share of one upgrade to the benefit gained in terms of improved plant performance, after the simultaneous refurbishment work.

(2) There was only one significant benefit indicator reported by the plant and that was the improvement of the turbine heat rate after the upgrade. This improvement of 425 BTU/kWh cannot be credited to the turbine upgrade alone, since the air heaters, burners and sootblowers were also upgraded at the same time and therefore have all contributed to the overall plant performance improvement.

As a matter of course, the ranking approach was done by taking the upgrade/refurbishment activities of each plant as a single combined upgrade project; the simultaneous upgrade projects of the other power plants are treated the same way and then all these plants with refurbishments were compared or ranked against each other which resulted in the matrix shown above. Of course, each of the plants in the six case studies presented in this paper has unique circumstances. Their commonality is that five of the six are located in a single APEC member economy, i.e., the People's Republic of China. As shown in the table, the DCFROR/IRR, the Net Present Value @ 20% guideline discount rate, and Payback Period values indicate which of the projects yielded the best promise of economic success. We wish to remind the reader that care must be taken in interpreting the NPV values, because NPV is a relative indicator between the project IRR and an arbitrary discount rate which is 20%. In other words, if the guideline rates in these NPV calculations were set at 10% (instead of 20%), then there would have been no negative NPVs in any of the cases presented in this study.

4.4.2 Forward – Looking Statements

The last sentence in the preceding paragraph states the phrase 'best promise.' Usually in all economic assessments forward-looking statements like *promise*, *anticipate*, *potential*, *estimate*, and similar words just cannot be avoided. In reality, actual results may differ materially due to many different variables, such as the speed and nature of increased competition and deregulation in the electric utility industry, economic and meteorological conditions (i.e., *force majeure*), changes in markets for energy services, changing energy and commodity market prices, etc. Of course, frequency and speed of change in these factors vary from one APEC economy to another, as is true with the rest of the world. Therefore, economic indicators do not guarantee a precise future outcome; however, they do help stake holders avoid blind or random choices.

4.4.3 Sensitivity Analysis

While there can be many possible outcomes that can be expected due to uncertainties during the life of a project, a specific critical project variable must be selected to demonstrate uncertainty impact by Sensitivity Analysis. The Plant Capacity Factor is the variable selected in this study for the Sensitivity Analysis of one project, Case-1. The *Plant Capacity Factor* is one of the most critical variables that can impact on a project's outcome. Table 6 shows the impact of *Plant Capacity Factor* on the DCFROR and Payback numbers of Case No. 1.

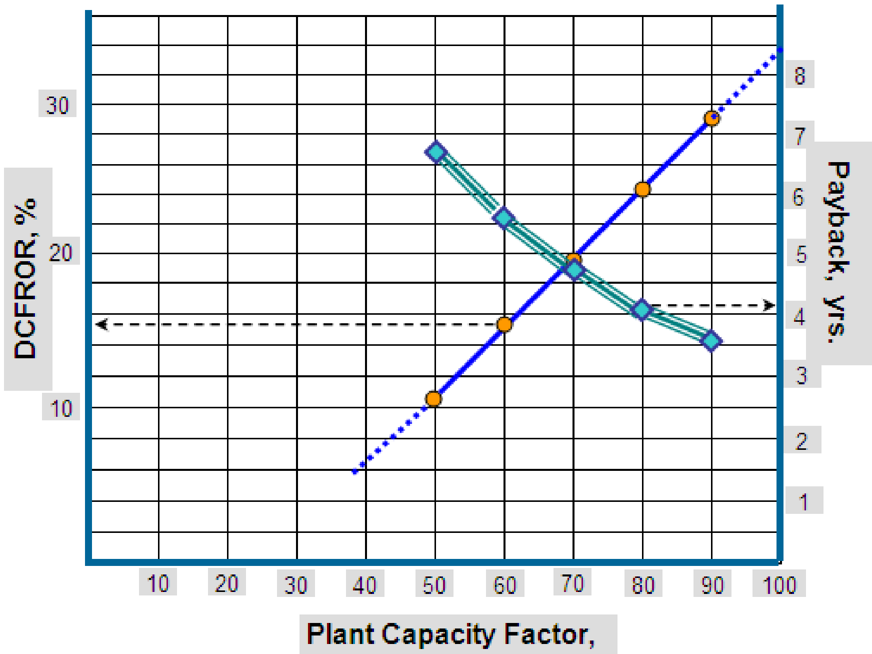
Table 6 Sensitivity of Case No. 1 to Plant Capacity Factor

	Plant Cap. Factor	DCFROR or IRR (%)	Payback (years)
TRIAL 1	50%	10.25	6.66
TRIAL 2	60%	15.12	5.55
TRIAL 3	70%	19.75	4.76
TRIAL 4	80%	24.34	4.16
TRIAL 5	90%	29.01	3.7

The power plant net capacity factor is the ratio of the actual output of a power plant over a period of time and its output if it had operated at full nameplate capacity during the entire time. Capacity factor is calculated by dividing the total energy the plant produced (for example, in kilowatt-hours) during a period of time by the energy the plant would have produced at full capacity. For a better interpretation of this Table 6, and the economic analysis of this section, the capacity factor should not be confused with the availability factor, which does not consider a full capacity rating in the *hours* that the machine is calculated to be running.

The impact of plant capacity factor on the economic indicators of a project, i.e. DCFROR or IRR and payback period can be more easily assessed if graphically shown. Figure 17 illustrates the rising trend in Discounted Cash Flow Rate of Return towards higher values of Plant Capacity Factor. Consequently, the payback time to recover investment funds shortens as capacity factor improves.

Figure 17 Sensitivity Chart of DCFROR and Payback Trend Lines



4.4.4 Timing of Investments and Emission Control Opportunities

The timing of a decision to proceed greatly impacts on the outcome of an upgrade project. A good decision delayed may not turn out as well if it had been accomplished in a timely fashion. This is particularly true in the case of a major plant component, the surface condenser for instance, which when an upgrade decision were delayed, could affect seriously the capacity factor of the plant in terms of constant tube leak repair, or the efficiency of the unit in terms of higher heat rate caused by a poor vacuum. Time-based lost opportunities abound in any industry, such as the electric power industry where the ‘hour’ is linked with the product itself, i.e., kW-hour. Therefore, delaying the implementation of a decision that has passed all the feasibility screening criteria can diminish the value of the project as time moves on.

5 CONCLUSIONS

The Asia-Pacific Economic Cooperation (APEC) region is home to developed and developing economies with a rapidly growing demand for electricity. At the same time, it is a host to a growing number of aging power plants, coal-based power plants especially. To this end, there are strong incentives for the electric utilities in the region to extend the service lives of these older coal-based power plants. It has been proven that major power plant components, steam turbines especially, can remain in service for as long as 50 years. However, maintaining the *status quo* on these aging units is not a preferable option for the stakeholders in particular and the public or society in general. In reality, plant status or conditions do not plateau or remain constant. The older a power plant gets, the faster will it decline in performance and reliability. This decline can be manifested in worsening heat rates, dropping numbers in plant availability/reliability, and loss of mechanical and structural integrity in various components of the entire power generating system affecting the general well-being and safety of plant operators.

The key to prolonged power plant economic life is the right timing and adequate degree of upgrades and refurbishments on major and critical plant components. Basically, these upgrade efforts are aimed at the following objectives: (1) improved overall plant efficiency, (2) plant reliability and availability recovery, (3) restored capacity rating, (4) enhanced safety, and (5) emission mitigation.

Upgrades, refurbishments, retrofits and repowering are decisions geared towards recovering diminishing economic values of power plant assets. These recovered values are realized by the sustained generation of electric power to meet the growing demands for it. While it is an important business decision on the part of power plant owners to keep older coal-based units running for several years more by refurbishing them, keeping the level of emissions low while burning coal as fuel, with or without regulation, is an equally important mission.

Refurbishment and upgrades are management decisions that require serious consideration. Once funds are committed and spent for an upgrade project, the installation and completion of the project may not net as much return as originally forecast. A refurbishment project requires a thorough analysis, both technical and economic. Screening out multiple options to determine a single course of action sometimes requires multiple decision-making tools. There are a number of quantitative means to evaluate projects, such as standard economic analysis indicators, which are supported with qualitative screening methods. However, good assessment calculations at the beginning of a project do not fully guarantee that same figures would be realized during the life of a project. There are many possible deviations occurring in real time that could possibly not be anticipated in projected time.

Actual implementation of projects may produce either good or undesirable results. Either way, it is always a good practice to monitor and keep record of these results as they unfold. This survey of older coal-based power plants within the APEC developing member economies is an effort to collect valuable information for future reference. Subsequently, the list of lessons learned from the collected information will be synthesized into a best practices guide.

Due to the strained economic climate that the world is presently experiencing, this time in our history being characterized with prices for petroleum products hitting record highs, it would be highly unlikely that we will be seeing the last of the older coal-based electric power generating plants any time soon. These older power generators will continue to deliver much needed electricity, if their conditions are upgraded and refurbished. These refurbished power plants will continue to supply power to their respective grids, and these plants include those located within both the developing and developed member economies in the APEC region, as well as in other regions of the world.

Particular mention needs to be made for those old coal-fired power plants located within China. it's the Chinese government has a special policy regarding older coal-based power plants. In the previously-referenced dialogue with the Chinese delegation, it was stated that fewer and fewer older coal-based power plants will undergo upgrades in the near future. The exception is for upgrades involving steam flow path refurbishments to improve efficiency and the addition of emission control components, such as flue gas desulphurizers (FGDs) and electrostatic precipitators (ESPs). Please refer to the synopsis of the conversations, found in Appendix 2.

It is understandable that upgrade and refurbishment of older coal-fired units have not attracted as strong an interest in the Chinese power industry today, as does the building of new and much higher capacity coal-based power generation units. The People's Republic of China, as a fast-emerging APEC member economy, is facing tremendous growth in electricity and energy demand. From China's vantage point, the best way to meet this surging demand is by building big-capacity, more efficient and less polluting power generating units. It is perceived that the economies of scale of the larger, newer units can best serve the increasing electric power demand at the magnitude that China faces today.

6 RECOMMENDATIONS

The following are recommendations pertaining to Plant Refurbishments and Upgrades:

(1) Maintain good upkeep practices and preventive/predictive programs in the power plant in order to extend the economical service life of the plant to the maximum possible duration.

(2) Conduct a thorough technical and economic feasibility study on all upgrade and refurbishment project proposals. If possible, depending on the scope of refurbishment required, enhance quantitative screening analysis, such as economic indicators: *Levelized Cost of Electricity*, *Internal Rate of Return, Payback Period*, etc., with qualitative screening tools such as *Decision Trees*, *KT –Decision Making Process*, and others.

(3) Refer to reports about lessons learned and best practice guide recommendations applicable to actual refurbishments and upgrades of coal-based power plants.

(4) Finally, the following sections are recommended for reference.

6.1 Lessons Learned from Upgrades and Refurbishments

The following paragraphs enumerate lessons learned from upgrades and refurbishments in various coal-based power plants in the APEC developing economies. Additional lessons are drawn by the authors of this report from their experience in dealing with actual power plant refurbishments and upgrades. For purposes of quicker reference, the cases reported are categorized or grouped by plant major component or operating area.

(1) Coal Pulverizer

Lesson Learned No.1

Plant Area/Component: Coal Pulverizer

Specific Case / Reason for Upgrade: The original pulverizer was Model RP783 bowl-Type medium speed mill having rated capacity of 33.1 tons/hour. After years of operation the edges of the milling bowls were worn off by approximately 10-15 mm. The wind ring gap was enlarged beyond its normal range. The large gap caused air speed to decrease and air movement direction to change at the wind ring. The air carrying capability of coal powder decreased and the coal-air separation efficiency dropped; hence, overall mill performance dropped. Consequently, coal discharge quantity increased and a certain amount of coal was wasted. The mill bowls were modified and 6 pieces of detachable extension ring were added to each bowl to adjust the wind ring gaps to 6~10 mm.

Lesson(s) Learned from the Experience: After this upgrade, the stone-coal discharge decreased by 356.4 tons /month.

Best Practice Guide: The action done by the plant is considered as best practice by itself.

Source of Survey Information: Guangzhou Zhujiang Power Plant

Lesson Learned No.2

Plant Area/Component: Coal Pulverizer

Specific Case / Reason for Upgrade: The original pulverizer spring loading systems were replaced by hydraulic loading systems. The mills were not modified.

Lesson(s) Learned from the Experience: The pulverizer capacity increased by 20%, but hydraulic system oil leakage occurred.

Best Practice Guide: (a) Calculate the loading capacity of each component of a new hydraulic system and compare each component's capacity to expected maximum loads at specific points in the support system. (b) Additionally, new pulverizer support specifications need to be reviewed thoroughly before actual installation, including hydraulic oil chemical and mechanical properties, especially hydraulic oil stability over time and under constant stress. (c) Pressure-test (using same hydraulic oil) the support system components, including connecting tubing and valves under a test pressure which is 150% of rated load at its support. (d) Lastly, in cases where a hydraulic support system replaces a spring support system, a hydraulic relief mechanism should be provided to allow for thermal expansion of both system oil and supported load. The original spring supports, apart from its main function of supporting the pulverizer, did have dual extra functions, which is partly absorbing structural vibration and thermal expansion (minimal it may be) of the pulverizer unit.

Source of Survey Information: Power Plant 'C'

Lesson Learned No.3

Plant Area/Component: Coal Pulverizer

Specific Case / Reason for Upgrade: In 2006, a table liner hard surface overlay was applied to minimize table liner wear. Additionally, MHI Tire roller was replaced with Firth Rixson Cast roller.

Lesson(s) Learned from the Experience: The plant did not report any undesirable outcome of the pulverizer roller modification.

Best Practice Guide: Hard surface overlay as pulverizer table fix can be the typical if not best approach under site specific circumstances.

Source of Survey Information: Pagbilao Power Plant (Units 1 & 2)

(2) Air Heater

Lesson Learned No.1

Plant Area/Component: Air Heater

Specific Case / Reason for Upgrade: A completely new design of air heater was used to replace a previous design which had high air leakage and serious ash clogging. The result of the change in type is a 6% drop in air leakage

Lesson(s) Learned from the Experience: It has been proven that using a different type of air heater can indeed result to effective control of a recurring problem.

Best Practice Guide: It is acceptable to resort to a different make or model of plant major equipment in refurbish/upgrade work, if original equipment make/design does not possess the desired features identified by the plant owner to resolve the problem. However, plant owner should first verify the performance of the new replacement units (in this particular case, the air heater), through research or from inquiry from those who are identified as earlier users of said component.

Source of Survey Information: Hangzhou Banshan Generation Co. Ltd. (Unit # 4)

Lesson Learned No.2

Plant Area/Component: Air Heater

Specific Case / Reason for Upgrade: High air leakage and poor heat transfer requiring the original sealing structure to be changed and the heat transfer elements were replaced.

Lesson(s) Learned from the Experience: Initially after the upgrade, the air leakage decreased by 20% before the upgrade. However, it was only short-lived. Soon after, the leakage has increased with operation time.

Best Practice Guide: The root cause of the problem must be identified first prior to deciding an upgrade. Perhaps the inherent position, location, thermal expansion provisions or support system is inadequate. Another issue is a thorough review of the material specifications to be used in the replacement unit.

Source of Survey Information: Hubei Hanxin Power Generating Co.

Lesson Learned No.3

Plant Area/Component: Air Heater

Specific Case / Reason for Upgrade: One layer of air heater was replaced

Lesson(s) Learned from the Experience: Because of insufficient funding, three more layers of air heater have not been retrofitted.

Best Practice Guide: As much as possible, a complete set of air heater assembly shall be installed at a single plant shutdown for that purpose. It would save both time and effort, if installation is well planned with proper logistics.

Source of Survey Information: NanChang Power Plant

Lesson Learned No.4

Plant Area/Component: Air Heater

Specific Case / Reason for Upgrade: Original air heater had a high rate of air leakage, severe corrosion, abrasion, and ash plugging. The exhaust gas temperature of the original air heater was high. The original air heater was replaced with a new HOWDEN 235vn1550 regenerative air heater.

Lesson(s) Learned from the Experience: After effects of this refurbishment indicate that (a) the system reliability improved, (b) air leakage rate decreased from 19.5% down to 6% after upgrade, (c) the induced draft fan shaft work decreased by 92 kW, (d) the forced draft fan shaft work dropped by 98 kW, and (e) the exhaust gas discharge temperature decreased by 40.1 ^{o}C**.** However, the plant observed later that it is difficult to disassemble the gear transmission system of the replacement air heater.

Best Practice Guide: Ensure that in-house plant maintenance personnel are well trained to handle newly acquired/installed plant components. During the process of buying the new equipment, vendor should be asked, and it should be stated in the purchase order contract, to provide the plant with special repair tools, necessary maintenance spare parts, technical, operating and maintenance manuals, etc. The plant should make sure that vendor provides a locally accessible after-sales field support.

Source of Survey Information: Taizhou Power Plant

Lesson Learned No.5

Plant Area/Component: Air Heater

Specific Case / Reason for Upgrade: Original air heater had a high air leakage rate. To correct the problem, 24 sealing pieces were added at the radial and axial directions of the air heater cold end, while the original heat transfer elements and sealing pieces were kept the same as before.

Lesson(s) Learned from the Experience: Doing this upgrade had yielded the following benefits – (a) the air leakage rate decreased from 20% before upgrade to 10~12% after upgrade and (b) the draft fan drive motors electric current dropped from 105~110A to below 100A.

Best Practice Guide: Keep close monitoring of leakages and motor loads and be mindful for the best timing to act on refurbishment of aging equipment, as was done by this particular plant.

Source of Survey Information: Guangzhou Zhujiang Power Plant

Lesson Learned No.6

Plant Area/Component: Air Heater

Specific Case / Reason for Upgrade: The original air heater had become unreliable (many breakdowns) and had developed a high leakage rate. In order to solve the leakage problem, the air heater was upgraded as follows: (a) the number of cells was increased from 24 to 48, (b) a top layer of regenerative surface was added, (c) the sealing gap was adjusted and modified to frame adjustment type.

Lesson(s) Learned from the Experience: The reliability of the component has improved. However, the following drawbacks are identified: (a) the leakage rate was the same as before, (b) the motor electrical load increased after retrofit [Note: Currently further modifications are being sought, considering that this is the plant's first 600-MW boiler retrofit.]

Best Practice Guide: The original equipment manufacturer (OEM) can be consulted to look at the situation and have the power plant in-house project engineering staff coordinate with the OEM. Otherwise, a separate engineering firm with the appropriate expertise to review the problem can be consulted. [Note: The increase in the air heater motor electrical load is a logical outcome to increasing the rotating mass of the air heater]

Source of Survey Information: Power Plant ‘B’ (Unit No. 5)

Lesson Learned No.7

Plant Area/Component: Air Heater

Specific Case / Reason for Upgrade: In 2005, after 12 years of operation, the original air heater was replaced by a new Howden Air Heater due to high air leakage.

Lesson(s) Learned from the Experience: The air leakage decreased from 11% before the upgrade to 7% after the upgrade. Temporarily, the thermal expansion was high at high unit load and once caused a unit trip because some portion of the air heater was cooled by the rain causing uneven expansion. Corrective measures were taken by the plant and the operation became normal.

Best Practice Guide: Ensure that high-temperature materials (especially metallic rotating parts) of operating plant equipment are protected from weather elements that can cause uneven thermal movements/distortion during operations. Insulate plant sections properly where needed.

Source of Survey Information: Power Plant ‘C’.

Lesson Learned No.8

Plant Area/Component: Air Heater

Specific Case / Reason for Upgrade: In 2004, after about 10 years of operation and due to frequent high differential pressure (clogging), the air heater hot element was changed from DU-MHI to DU-Korea. Intermediate element was changed from SNF-MHI to 50% Korea.

Lesson(s) Learned from the Experience: Result of upgrade was satisfactory.

Best Practice Guide: Action taken by the plant is considered a best practice approach. However, the response form sent back by the plant did not state whether the air heater element material change was in accordance with the OEM recommendations, or it was solely of the plant’s own choice of material.

Source of Survey Information: Pagbilao Power Plant (Unit No. 1).

(3) Boiler Burners

Lesson Learned No.1

Plant Area/Component: Boiler Burner

Specific Case / Reason for Upgrade: The original burners did not allow, by design constraints, the operation of electrostatic precipitators (ESPs); the upgrade allowed the operation of ESPs during the start-ups and part load operations by shifting 4 bottom burners to fuel oil during transient conditions.

This upgrade resolved the black smoke emission from the stack; hence, the emissions now meet the regulations.

Lesson(s) Learned from the Experience: Some original equipment manufacturers (OEM's) and suppliers of equipment or components only emphasize the steady-state capabilities of their products. Sometimes, on newly introduced models, drawbacks and weaknesses of designs could only be discovered during actual field runs under the responsibility of the buyers of equipment.

Best Practice Guide: It is best to include in the purchase/procurement requests that, if possible, testing for the integrity and performance of ordered equipment be accomplished in both bench scale (rig test) and full scale runs and must be witnessed by a representative of the buyer or a designated group to oversee the testing itself.

Source of Survey Information: Hangzhou Banshan Generation Co. Ltd. (Unit # 4)

Lesson Learned No.2

Plant Area/Component: Boiler Burner

Specific Case / Reason for Upgrade: To resolve unstable combustion issues in the boiler, the original boiler burners were replaced with shuttle-type burners.

Lesson(s) Learned from the Experience: Unstable combustion issues still remained after the upgrade.

Best Practice Guide: Ensure that during the acceptance test, results fully meet contract performance guarantees. Retraining the operators when tuning up the newly installed burners is an important step to take.

Source of Survey Information: NanChang Power Plant.

Lesson Learned No.3

Plant Area/Component: Boiler Burners

Specific Case / Reason for Upgrade: The original boiler burners were deformed due to the poor welding during assembly. Burner swing was not smooth and nozzles were prone to damage due to the high combustion temperature. The original burner nozzles were replaced with cast heat-resistant steel burner nozzles in 2002.

Lesson(s) Learned from the Experience: The benefit gained from the upgrade can be seen from the operational improvement attained. The whole-body casting steel burner nozzles were well formed and not prone to deforming under prevailing operating conditions, and burners can now be swung smoothly, unlike before the upgrade.

Best Practice Guide: Action taken by the plant was commendable. However, as best practice for brand new power plant installations, it would be good to take note of the lessons learned from this particular plant's experience, which is to specify early the burner parts and components that can withstand the severe conditions these parts will be subjected to in service.

Source of Survey Information: Guangzhou Zhujiang Power Plant.

Lesson Learned No.4

Plant Area/Component: Boiler Burners

Specific Case / Reason for Upgrade: Boiler combustion at partial load operation was poor. To solve the problem, the original burners were replaced with rich-lean burners.

Lesson(s) Learned from the Experience: The boiler combustion performance at partial load improved after the upgrade. However, after a while, the nozzles were observed to wear easily, a condition which impacts on the newly installed burner performance.

Best Practice Guide: Find the root cause of the accelerated nozzle erosion problem; refer the problem to the OEM, to an independent consultant or an in-house engineering staff, if in-house engineering is fully equipped and qualified to conduct such an investigation.

Source of Survey Information: Power Plant 'B' (Huadian Power Int'l Corp).

Lesson Learned No.5

Plant Area/Component: Boiler Burners

Specific Case / Reason for Upgrade: Secondary air baffles no longer synchronized during operation immediately before the upgrade. The original baffles were modified to achieve low-NOx combustion.

Lesson(s) Learned from the Experience: The boiler excess air ratio decreased. The NOx emission reduced by 10 ppmv @ 4% O_2. Additionally, average annual maintenance cost reduced by \$14,286 (Y100, 000 RMB).

Best Practice Guide: What was done is considered the best practice to deal with the problem.

Source of Survey Information: Power Plant 'C'.

(4) Burner Ignition System

Lesson Learned No.1

Plant Area/Component: Burner Ignition System

Specific Case / Reason for Upgrade: The ignition system was consuming a lot of fuel oil, which is the medium used for starting the burner. In lieu of the original ignitors, a plasma ignition system was installed in 2007.

Lesson(s) Learned from the Experience: As a result of the ignition system upgrade, 600 tons of fuel oil have been saved so far.

Best Practice Guide: Always make a bench or rig test trial before a new system or design is brought to mainstream use. In this case, it was not specifically stated in the questionnaire response material whether the plasma ignitors were rig/bench tested prior to installation. Nevertheless, the outcome is satisfactory.

Source of Survey Information: Guangzhou Zhujiang Power Plant.

(5) Induced Draft Fans

Lesson Learned No.1

Plant Area/Component: Induced Draft Fans

Specific Case / Reason for Upgrade: To improve existing induced draft fans' performance and decrease electricity consumption, hydraulic couplings were added to the existing IDFs.

Lesson(s) Learned from the Experience: The upgraded IDFs have been operated without any problems.

Best Practice Guide: Make use of less rigid fan-motor connection whenever possible.

Source of Survey Information: NanChang Power Plant.

Lesson Learned No.2

Plant Area/Component: Induced Draft Fans

Specific Case / Reason for Upgrade: The original Induced Draft Fan (IDF) blades were prone to breaking because the cast aluminum moving blades could not meet the strength requirements.

Lesson(s) Learned from the Experience: The IDF frequent blade failures was fixed by replacing the cast aluminum blades with forged aluminum blades resulting in increased reliability of the machine.

Best Practice Guide: Always use/specify materials that best match with service requirements. For example, given the same basic material chemical compositions and dimensions, tougher components such as forgings are preferable over castings, in applications that are prone to fatigue failure. In the same token, stainless steel should be selected vs. plain carbon steel for corrosive service application.

Source of Survey Information: Guangzhou Zhujiang Power Plant.

Lesson Learned No.3

Plant Area/Component: Induced Draft Fans

Specific Case / Reason for Upgrade: The induced draft fans were upgraded to meet the increased capacity demand of the boiler as the result of replacing the original electrostatic precipitators with new baghouses. The fan impellers were modified to suit to the new system characteristics. The impeller modification also required a corresponding drive motor upgrade.

Lesson(s) Learned from the Experience: Because the foundation of the machine (IDF & motor drive) was not modified, correspondingly, the machine vibration level increased.

Best Practice Guide: Whenever new and heavier weights (masses) are added into existing equipment, especially on one which has a rotating part such as a fan or pump, the foundation requirement should always be recalculated and modified if the existing foundation is found inadequate as shown by calculation results.

Source of Survey Information: Fengzheng Power Plant.

(6) Boiler Sootblowers

Lesson Learned No.1

Plant Area/Component: Boiler Sootblowers

Specific Case / Reason for Upgrade**:** All original sootblowers had never been used since after installation. The erosion of blowers was severe, mechanical devices were not functioning, and motors were broken. The blowers were damaged and could not be operated. They were replaced with 18 new IR-3 furnace blowers, 4 new IK-525 superheater blowers.

Lesson(s) Learned from the Experience: Sootblowers require continual use and exercise of its parts; non-use could sometimes lead to early failure and retirement of an assembly or part.

Best Practice Guide: All new equipment or parts must be exercised and utilized according to their design and purpose. Not using them could eventually lead to early failure.

Source of Survey Information: Hangzhou Banshan Generation Co. Ltd. (Unit # 4).

Lesson Learned No.2

Plant Area/Component: Boiler Sootblowers.

Specific Case / Reason for Upgrade: Original sootblowers were replaced due to the poor sootblowing performance. Original sootblowers were replaced with compressed air sootblowers.

Lesson(s) Learned from the Experience: On the upside, boiler efficiency increased as ash accumulation on the heating surface in the boiler was reduced. On the downside, compressed air valves were leaking.

Best Practice Guide: Piping handling compressed air, or any other gases or liquids at the plant, should preferably be subjected to pressure tests (hydro or pneumatic) to a test pressure of 150% of the system design working pressure.

Source of Survey Information: NanChang Power Plant.

(7) Steam Turbine

Lesson Learned No.1

Plant Area/Component: Steam Turbine

Specific Case / Reason for Upgrade: In this case, the turbine blades were of 1950s Soviet era Russian design, which has high losses and low efficiency. The blades have no shrouds at their tips or were with struts of rotating blades at some stages, which increased the leakage loss and blade trailing edge loss. Original flow path design caused low efficiencies of HP, IP and LP turbines. The velocity ratios and enthalpy drop distributions were unreasonable for some stages, which caused the thermodynamic characteristic parameters to be offset from the optimized values, so that stage efficiencies were low. Due to these reasons, the unit had a low overall efficiency causing high fuel consumption rate. Over a 10-year period, the heat rate increased from 8671 kJ/kWh to 9096 kJ/kWh.

Lesson(s) Learned from the Experience: Keeping track of plant performance has triggered the plant to decide on a major turbine upgrade. Major changes of this nature require and overall look at the turbine design. In this case, for example, in order to increase the supporting rigidity of the radial bearings after the retrofit, all the #1, #2 and #3 bearings with lining plates were changed to integrated ball bearings to improve the reliability of steam turbine operation. Due to a change in the rotor material, the expansion characteristic of the machine changed significantly. Hence, the cold start-up time and warm-up time, ramp rate, and sealing steam temperature were adjusted to avoid unit vibration. More specific details of the upgrade can be found in the Appendix 1.1.

Best Practice Guide: In major steam turbine upgrades, it is best to provide an overall approach in the work to be undertaken. Such was done in this refurbishment work, where practically all sections of the turbine from the governing stage of the HP turbine, the IP turbine stages and down to the LP stages, the critical parts were changed and retrofitted.

Source of Survey Information: Hangzhou Banshan Generation Co. Ltd. (Unit # 4).

Lesson Learned No.2

Plant Area/Component: Steam Turbine.

Specific Case / Reason for Upgrade: Turbine performance declined. Such condition led to the modification of the steam flow paths for HP, IP, and LP turbines. Shaft seals and blade and back pressure were optimized and the first stage blade was modified to reduce erosion.

Lesson(s) Learned from the Experience: Turbine heat rate improved substantially**.** However, the cooling system for the generator had to be modified accordingly. Likewise, the cooling time of the turbine cylinders increased after shutdown.

Best Practice Guide: Always refer to the nameplate rating of the generator before enhancing load generating capacity. Enhancement of capacity on one part of the assembly or system could shift the burden to the next weaker part of the system.

Source of Survey Information: NanChang Power Plant.

Lesson Learned No.3

Plant Area/Component: Steam Turbine

Specific Case / Reason for Upgrade**:** Turbine performance has fallen to a low level. In order to check the problem, the HP, IP, and LP turbines were upgraded; shat seals, blade and stationary vanes were modified. Estimated refurbishment cost was Y10,000,000 (RMB) or U.S. $1,428, 500.

Lesson(s) Learned from the Experience: The upgrade decision resulted in the turbine heat rate reduction (improvement) of 330 kJ/kWh. The company felt that the project was capital cost intensive considering that it used its own available funds without borrowing from outside sources. However, based on the achieved heat rate improvement the intensive capital funds could be recovered by the plant in a relatively short period.

Best Practice Guide: Prior to committing any funds for plant upgrade or refurbishment, a technical and economic study should be undertaken in order to justify the soundness of the decision.

Source of Survey Information: Power Plant 'B' (Unit No. 5).

Lesson Learned No.4

Plant Area/Component: Steam Turbine

Specific Case / Reason for Upgrade: After 12 years of operation, the steam turbine had to undergo the following upgrade to regain lost efficiency: (1) Refurbish HP, IP, and LP turbines. (2) Modified the blade and stationary vane sealing. (3) Shaft seal and 1^{st} stage blade were modified.

Lesson(s) Learned from the Experience: The turbine heat rate improved by 180 kJ/kWh after upgrade work. However, the bearing temperatures and vibrations increased.

Best Practice Guide: The plant could have done the following before start-up since these are standard practice procedures: (a) The turbine OEM should be consulted regarding the impact of replacing some components of the original turbine on the bearing capabilities, i.e., specs and so forth. (b) The new turbine rotor and casing/sealing clearances must be checked against original, as well as, turbine OEM recommended new values, if any. (c) The natural frequencies, including the 1^{st}, 2^{nd}, and 3^{rd} critical, need to be verified if affected by the steam flow path modification. (d) The new upgraded rotor needs to undergo thorough balancing, especially the dynamic balancing required during the commissioning phase after upgrade shutdown.

Source of Survey Information: Power Plant 'C'.

Lesson Learned No.5

Plant Area/Component: Steam Turbine

Specific Case / Reason for Upgrade: Upgrade of LP Stage turbine from hollow shaft to ruggedized rotor version. The purpose of the upgrade was to overcome the backend loading limit of the original LP rotor, which forced the 400 MW (Units 1 – 4) to runback at the threshold steam flow towards the condenser at or slightly over the turbine MW rating.

Lesson(s) Learned from the Experience: When the new ruggedized rotor was finally installed, it was found out that a 25-MW additional load was gained (from 400 MW to 425 MW). However, the next weaker part of the system surfaced, which is the reheat steam system that is limited to a maximum temperature of 965 ^{o}F. Reheat (RH) system desuperheating water flow is exceeded at a sustained 425-MW load. Consequently, so as not to lose the opportunity of being capable of generating more power, the plant has modified the spray water system to accommodate extra flow and prevent RH temperature to exceed design temperature limits.

Best Practice Guide: This is a case of an opportunity not missed by the host plant. This is a better than usual reaction by plant management, which could have decided not to use the extra capacity since first objective was only to obtain a higher backend loading limit for the LP rotor. The new backend loading limit of the ruggedized rotor is safely higher even at 425-MW load.

However, the best practice guide for this particular case is to go one extra mile by having the unit heat and mass balance reevaluated, given the fact that a shift in water flow quantities (for extra desuperheating) could impact on the MCR capability or heat rate of the plant.

Source of Survey Information: Actual power plant upgrade/refurbishment case as directly observed by a member of the Study Team.

Lesson Learned No.6

Plant Area/Component: Steam Turbine Valve Management

Specific Case / Reason for Upgrade: For several years the governor valve management systems of 4 x 400-MW steam turbines were not equipped to operate the governor valves (GVs) on partial arc admission mode, i.e., valves to open sequentially during start-up or during low load conditions. Thus operating the GVs in full arc mode (parallel or simultaneous opening) even at lower loads had caused a lot of steam friction, hence efficiency loss, through all the GVs at these low load conditions. To correct the situation, the governor valve management system was upgraded to allow the valves to open and close in partial arc mode at low load situations.

Lesson(s) Learned from the Experience: The governor valves will operate only on partial arc when set to do so; essentially at near valve-wide-open position, there is no longer significant difference between the two modes (full arc or partial arc).

Best Practice Guide: For older steam turbine-generators which are no longer assigned for base-load duties, partial-arc or sequential valve governing capability would be a good feature provided to them.

Source of Survey Information: Actual power plant upgrade/refurbishment case as directly observed by a member of the Study Team.

(8) Surface Condenser

Lesson Learned No.1

Plant Area/Component: Surface Condenser

Specific Case / Reason for Upgrade: Original condenser has insufficient heat transfer surface area resulting in high steam turbine back pressure and consequently, poor turbine performance. The upgrade involved adding surface area and replacing the original condenser tubes with stainless steel tubes. (Note: The survey response did not state the type of material used in the original tubes.)

Lesson(s) Learned from the Experience: The best practice calls for close evaluation of design specifications from the start of the procurement process. This applies to both original installations and replacement units. Good surface condenser design (per Heat Exchange Institute guidelines) normally allows a margin of 10% of the total number of tubes for plugging before any significant decline of performance will be evident.

Best Practice Guide: Carefully screen and evaluate specifications of all original (for new construction) and replacement units (for retrofits and upgrades). It is best to use reliable industry standards as guideline documents in specifying and ordering power plant equipment.

Source of Survey Information: Hubei Hanxin Power Generating Co.

Lesson Learned No.2

Plant Area/Component: Surface Condenser

Specific Case / Reason for Upgrade: The original condenser copper tubes were replaced with stainless steel tubes due to copper tube leakage.

Lesson(s) Learned from the Experience: *Condenser tube replacement is an effective way to keep heat rates down.*

Best Practice Guide: Conduct a life assessment inspection on the condenser to anticipate the remaining life of the condenser. The Heat Exchange Institute (HEI) in their earlier publications mentioned an upper limit of 10% of the total number of condenser tubes that can be plugged, below which the condenser can still continue to operate without impacting on the turbine performance.

Source of Survey Information: NanChang Power Plant

(9) Instrumentation and Control

Lesson Learned No.1

Plant Area/Component: Instrumentation and Control.

Specific Case / Reason for Upgrade: The original controls system installed in 1984 became obsolete and had to be replaced.

Lesson(s) Learned from the Experience: (a) The upgrade increased the operating reliability of the plant, the level of utilizing automatic control and system protection, and reduced the working load of operation and maintenance. However, on the opposite side of the desirability scale, (b) Vendors and System retrofit providers of the Instrumentation and Control (I&C) upgrade were found to be lacking in their technical after-sales support, which included but were not limited to projected lifetime supply of hardware spare parts with supply of prices information. (c) Some parts used in the I&C upgrade were becoming out-of-date and may not be available in the market. The aging time of DCS systems is still not very clear and more study on it is required.

Best Practice Guide: The best approach to instrumentation and control upgrade is to study the options carefully. The OEM and vendor/supplier should be selected very carefully and a proven background of excellent service verified. Most companies have stringent pre-qualification processes to screen out undesirables. However, of equal importance is the system to use in the upgrade itself. How compatible is it with the controlled hardware and equipment? How balanced are the components in terms of technology maturity? The following should be preferably sought: (a) quickness of response to service calls / proximity to the plant of an OEM's representative (a locally–based dealer, for example, or a field service engineer), (b) Parts commonality, (c) Excellent OEM's back-up for training of plant personnel, (d) Calibration support.

Source of Survey Information: Hangzhou Banshan Generation Co. Ltd. (Unit # 4).

Lesson Learned No.2

Plant Area/Component: Instrumentation and Control.

Specific Case / Reason for Upgrade: The original control system was out-of-date. It was upgraded to a Distributed Control System.

Lesson(s) Learned from the Experience: The upgraded system has simplified wiring connections, centralized control system layout and improved plant automation and control. The drawbacks of the new DCS system are: (a) the large number of cables, which were replaced, since the old system did not use shielded cables. A DCS system requires high quality input signals, which old, unshielded cables can not provide. And (b) the modules of the new DCS system are prone to breakage.

Best Practice Guide: A shift to a later generation of control and instrumentation architecture and philosophy requires new methods of protection and signal transfer. The new industry standard of instrumentation and control along with the manufacturer’s recommendation should be followed accordingly.

Source of Survey Information: NanChang Power Plant

Lesson Learned No.3

Plant Area/Component: Instrumentation and Control

Specific Case / Reason for Upgrade: The original control systems used hard-wire connections to communicate among each other, and the automatic start-up and shutdown could not be achieved. The control systems could not meet the requirements, for peak load operations. The parts were not interchangeable among different systems and therefore numerous spare parts have to be kept on warehouse stock inventory. In 2002, Master Control System (MCS), Data Acquisition System (DAS), Digital Electro-Hydraulic (DEH), Flame Safety Supervisory System (FSSS), Supervisory Control System (SCS) and Electric Control Systems were integrated into a uniform Distributed Control System (DCS) platform to increase the automation and control level of the plant. At the same time, the DCS was integrated with the Management Information System (MIS) by making use of the extension capability of XDPS-400 system. The integrated system provided real time data for office automation, unit status monitoring and power generation economic analysis and therefore improved the overall plant management.

Lesson(s) Learned from the Experience: After this upgrade, all subsystems are now using interchangeable parts; hence, outcome is reduced quantity of spare parts and maintenance cost. The data can now be shared among sub-systems. Automation and control of boiler, turbine, and electric system have improved. Unit safety protection system is in full operation. Data collected by the DAS are also fully used. All systems have been running well since the update.

Best Practice Guide: Management, information, instrumentation and control integration in a power plant is a tricky thing to handle. If a single provider can be dealt with by the plant, it would be best. However, there are providers who are best in their own fields, but preferably there should be chosen a minimum number, if not a single lead Supervisory Control and Data Acquisition System (SCADA), MIS and DCS providers with their subsystems working compatibly and harmoniously among one another into one integrated plant management system.

Source of Survey Information: Guangzhou Zhujiang Power Plant

Lesson Learned No.4

Plant Area/Component: Instrumentation and Control System

Specific Case / Reason for Upgrade: The original Flame Safety Supervisory System (FSSS) was upgraded to a Westinghouse system in 2002.

Lesson(s) Learned from the Experience: The targeted degree of coordinated control was achieved.

Best Practice Guide: Always choose products that have a proven field performance record. This is especially true to state-of-the-art products, which are one of the most dynamic products/services in the power industry. For newly established brand names, always ask for proof of satisfactory performance, such as field test results, product standard certifications, and company background. A demonstration product run/field testing should be most welcome, if offered by the prospective supplier without strings attached.

Source of Survey Information: Power Plant 'B' (Unit No. 5)

Lesson Learned No.5

Plant Area/Component: Instrumentation and Control

Specific Case / Reason for Upgrade: Obsolescence and reliability issues. Units 1 & 2 were upgraded from WDPF & DIASYS to Ovation Expert Control System.

Lesson(s) Learned from the Experience: Outcomes of this upgrade are (a) improved performance (b) enhanced reliability (c) data presentation flexibility. Problem encountered during installation was extra-effort needed in loop checking and function testing of each I/O's accuracy.

Best Practice Guide: The experience of this plant is typical to other plants when shifting I&C from obsolete systems to cutting-edge technology.

Source of Survey Information: Pagbilao Power Plant (Units 1&2)

(10) Flue Gas Desulfurization

Lesson Learned No.1

Plant Area/Component: Flue Gas Desulfurization

Specific Case / Reason for Upgrade: An additional component in the power plant intended to meet regulatory requirements.

Lesson(s) Learned from the Experience: Emission control and mitigation are getting attention more than ever in power plants. Failure to meet permitting requirements can impact heavily on the financial viability of a project.

Best Practice Guide: It is a good practice to be one step ahead in preparations for stricter implementation of emission control regulations. Utilize turn-around or Test & Inspection (T&I) shutdowns as an opportunity to install FGD and other pollution control components in the plant.

Source of Survey Information: NanChang Power Plant

Lesson Learned No.2

Plant Area/Component: Flue Gas Desulfurization

Specific Case / Reason for Upgrade: Emission Control Permitting Requirement; two wet FGD systems for 2 x 300-MW units were installed in 2005.

Lesson(s) Learned from the Experience: Sulfur removal efficiency of 93% was achieved and annually tens of thousand tons of SO_2 were removed.

Best Practice Guide: Follow regulations on emissions strictly and on a timely manner. Being ordered to halt operations, even momentarily can damaged both revenues and goodwill.

Source of Survey Information: Guangzhou Zhujiang Power Plant

(11) Reheater Tube Assembly

Lesson Learned No.1

Plant Area/Component: Reheater (RH) Tube Assembly Upgrade

Specific Case / Reason for Upgrade: The reheater assembly had been sagging for a number of months and the degree of tube degradation had prompted the plant to replace a portion of the assembly, which was from the RH Outlet header back to half of the entire tube length towards the RH inlet header. There were 73 elements or tubes involved in the replacement and the upgrade was from chrome-molybdenum alloy tubing to stainless steel tubing.

Lesson(s) Learned from the Experience: The use of shop-welded transition pieces for the dissimilar weld connections (see Figure 19) has proven to be very effective; no failures occurred traceable to those welded connections after the upgrade. For the record, there was a last minute decision to change the welding rod from stainless to Inconel. If anything, the drawback in that upgrade was that it was only done halfway. Lately, when the other half (midway of assembly towards RH Inlet header) was found no longer fit for prolonged service, it was realized that access towards the area would be very difficult since the upgraded half (stainless steel tubes) are now resisting easy ingress towards the work area.

Best Practice Guide: (1) Always use a shop-welded transition piece (or safe-ends) whenever dissimilar metal welds are used for very high-temperature applications. (2) Include in an upgrade project a degradable part of an assembly that might be very difficult to access later due to the installation of the current upgrade.

Source of Survey Information: Actual power plant upgrade/refurbishment case as directly observed by a member of the Study Team.

(12) Steam Coil Air Heater

Lesson Learned No.1

Plant Area/Component: Steam Coil Air Heater

Specific Case / Reason for Upgrade: After 4 years of operation, the original SCAH were found to be sagging with its finned tubes losing the doughnut supports that were slipping off tangent from lower tubes. The SCAH were oriented horizontally from inlet header to outlet header and sometimes caused water hammer during start-up. The purpose of the SCAH is to keep the cold end temperature of the exhaust duct always above the dew point temperature of the flue gas.

Lesson(s) Learned from the Experience: The SCAH upgrade comprised of a similarly horizontally oriented tube assembly but a design improvement was introduced by providing a 4" slope over a 30-ft. length of assembly. Due to this built-in slope there was thorough drainage of condensate within the tubes every shutdown; hence no water hammer had occurred after upgrade and sagging of the assembly did not recur. The support ring design was also improved by replacing the doughnut-shaped support rings with hexagonal-shaped locking-type rings that do not disengage from the adjacent support rings under harsh and vibrating service conditions.

Best Practice Guide: As much as possible, an upgrade should introduce an improvement over the original or previous equipment. This improvement can be in the form of an improved design or a superior material vs. that of the original component.

Source of Survey Information: Actual power plant upgrade/refurbishment case as directly observed by a member of the Study Team.

(13) Reheat Desuperheater

Lesson Learned No.1

Plant Area/Component: Reheat Desuperheater

Specific Case / Reason for Upgrade: After a life assessment inspection run, it was reported that the cold reheat (CRH) pipes at the downstream side of the reheat desuperheating spray had thinned down to critical values. It was consistent in all four units of the station, where there are two RH Desuperheater per unit. A verification of the purchase order on file pertaining to the spray nozzles and pipe sections containing the sprays revealed that there were no pipe liners provided to mitigate the effect of erosion. During the Test and Inspection Outage, though not originally scheduled, the CRH pipe sections containing the sprays were replaced/refurbished with liners and another upgrade on the spray nozzles with improved design was initiated. The plant was concerned about reported catastrophic failures of reheat piping causing personnel harm in some parts of the world.

Lesson(s) Learned from the Experience: Condition and life assessment results do not merely serve as planning inputs. Results of such efforts also bear on personnel safety and asset preservation.

Best Practice Guide: It is a best practice reaction to act immediately on critical matters especially on issues that affect personnel safety and well being. Traceability on the records of purchased items is a very important feature of every power plant material. Ideally, plant material records should be traceable back to their sources, i.e., from their individual heats/batches (in case of steel products) complete with inspection and test results.

Source of Survey Information: Actual power plant upgrade/refurbishment case as directly observed by a member of the Study Team.

(14) Electro –Hydraulic Control Fluid Polishing System

Lesson Learned No.1

Plant Area/Component: Electro-Hydraulic Control Fluid Polishing System Upgrade

Specific Case / Reason for Upgrade: The steam turbine governors are modulated using the electro-hydraulic control system. The make-up, Fyrquel Electro-hydraulic Control Fluid used in the EHC system needs to be polished from their transport drums before final usage. The plant portable polishers were getting less efficient and leaky. An upgraded centralized polishing station was designed and built in-house using used electro-hydraulic positive displacement pumps and hydraulic filters from warehouse stocks.

Lesson(s) Learned from the Experience: Used power plant components / parts applied to severe service may be utilized for less severe service with satisfactory results. Such was the case of a number of positive displacement sliding vane-type pumps which had served well in the heart of the electro-hydraulic control (EHC) turbine governing system (discharge pressure ~3000 psig). These pumps upon showing signs of wear, were usually sidelined, but had found a good recycling application by serving in the less severe polishing station application (discharge ~60 psig). The EHC Polishing system reservoir is illustrated in Figure 20.

Best Practice Guide: Utilize plant resources fully; recycle items where they can still serve effectively in a different and less severe application.

Source of Survey Information: Actual power plant upgrade/refurbishment case as directly observed by a member of the Study Team.

(15) Desalination Plant

Lesson Learned No.1

Plant Area/Component: Desalination Plant

Specific Case / Reason for Upgrade: The heart of a desalination plant is the brine recirculation pump. After a number of years of operation, the brine recirculation pump casings (all six of them in the entire plant) had deteriorated as a result of stress corrosion cracking (SCC). The plant approached the pump OEM to obtain the same pattern casing, but cost was too prohibitive. Two replacement casings (trial orders) were sourced from a reputable competitor brand. The casings were slightly bigger and had to come with brand-new impellers too. The complete brand new pumps (w/ superior casing materials) were still lower priced than the original brine recirculation pump OEM's replacement casings.

Lesson(s) Learned from the Experience: Initially, the new casings had shown signs of erosion corrosion biased towards the suction flange. It was analyzed as the result of inner casing recirculation since the pump flow was throttled slightly to match system demand. The problem was later sorted out by providing recirculation flow.

Best Practice Guide: Try all possible and acceptable but most practical and economical options to meet upgrade and refurbishment work. If their pricing becomes too prohibitive, it may not always be the best option to go back to the original OEM's in upgrading plant equipment/components, except perhaps on major ones like turbines, surface condensers and steam generators.

Source of Survey Information: Actual power plant upgrade/refurbishment case as directly observed by a member of the Study Team.

6.2 Summary of Best Practice Recommendations

6.2.1 Best Practice Guide for APEC Level Refurbishment and Upgrade Practices

This first list of guidelines is intended for those who interact between international and regional agencies and organizations and are capable of influencing sectorial and industrial groups within APEC economies.

(1) Continue to promote Best Practices for Refurbishment and Upgrade amongst electric power generating plants located in APEC member economies.
(2) Initiate a program to collect information pertaining to older unit refurbishment and upgrade from various coal-based power generating plants within APEC and organize the collected information in a database that can be effectively used as a readily retrievable source of information for the electricity power industry within APEC.
(3) Screen out the best and latest information available from this recommended database and publish the information on a regular basis for dissemination to APEC member economies. Dissemination of lessons learned and best practices information can be done by print media or by allocating a section in the APEC/EGCFE website for such purpose.
(4) Solicit for technical reports regarding actual cases of older coal-fired power generating plant upgrades and refurbishments. Preferably these technical reports shall be comprehensive enough to cover the following phases: (a) plant remaining life assessment, if applicable (b) decision-making tools used in justifying upgrade/refurbishment (c) actual upgrade details (d) post upgrade findings including benefits quantified
(5) Organize an APEC-sponsored symposium or workshop which can be used as a forum to present the technical papers mentioned in the preceding guideline # 4. This event can be attended by various interested parties like electric utility executives and plant operators, original equipment manufacturers (OEMs), members from the academia, etc.

6.2.2 Best Practice Guide for Power Plant Refurbishments and Upgrade – (Central Planning Applications)

This second list of guidelines is intended for those who are involved with the wider scope of company business, especially for those who are engaged in companies having multi-site operations. Several of these statements are broad in nature. Nevertheless, they are key guideposts to ensure that options taken for refurbishments and upgrades always fall within the boundaries set by the corporate leaders. Management actions at the top of the corporate ladder obviously affect the decisions at the plant level, as plants are guided by corporate policy. In this exercise of plant asset life extensions, the inter-action between power plant management and corporate management reflects a vivid example of a two-way synergistic process, where data inputs from individual power plants are as important to corporate headquarters as directives and policy guidelines are equally valuable to power plant managers and operators. Both inputs taken together produce a more potent collaborative effect. The following are suggested guidelines for power plant life extension programs, including power plant upgrades, refurbishments and retrofits:

(1) Correlate upgrade and refurbishment programs in the broader context of the company's business environment. The company general policy guideline for generation capacity addition, capacity replenishment, meeting load commitment to major clients, and other matters pertaining to capacity upgrade must be aligned with the company's objectives, strategies, and regulation compliance policy.

(2) Follow a stringent and sound yardstick in ranking and making financial decisions. Economic analysis shall always be part of corporate decisions involving capital expenditure, including plant asset service life extensions. Without the bottomline financial numbers indicating good chances of success in committing company funds and resources, approval of funds for a project is unlikely from corporate management. In some cases, difficulty in producing clear quantitative indicators requires qualitative statements to substantiate claims of potential project benefits.

(3) Reach outside for guidance from the leading players in the industry. Close relationships and good coordination with external parties such as fuel supply companies, transmission companies, emission regulatory bodies (government and quasi-government offices) and the electric power market (customers most importantly) must be maintained. Information obtained from these external sources is vital in organizing a list and identifying the risks and obstacles facing every refurbishment or upgrade project.

(4) Seek experts' advice. Contacts with experts' groups in the power industry need to be developed. They are in constant search for breakthroughs that could offer a great relief to obstacles faced by existing power plants in various ways, including safe life extensions of old plants. Innovators and suppliers of new technologies are a great help in providing new ideas and solutions to perennial power plant problems.

(5) Constantly evaluate existing fleet inventory. Only a serious and diligent program of plant asset condition monitoring can provide a true picture of a company's power generation capability in the long term. Additionally, condition monitoring feedbacks trigger actions for preventive and corrective moves to slow plant component deterioration and service life consumption.

(6) Support the collection and storing of sufficient upgrade and refurbishment technical and economic information /data that will materially contribute to "APEC's Lessons Learned Database".

6.2.3 Best Practice Guide for Power Plant Refurbishments and Upgrade – (Plant Level Applications)

This third list of guidelines consists of generalized recommendations derived from individual cases reported by each plant's experience during the survey collection phase. This is not an exhaustive list. Many additional 'Best Practice' ideas are available from the public domain through the Internet and from the public and private libraries, which can be accessed. Indeed, a great deal of information was derived from these sources, as stated in the study base document. Much of this additional information was used in other areas or sections of this report. The following summary of best practices contains the project study team's suggestions or recommendation in direct response to what was stated by the respondents to the survey questionnaires. It is augmented by actual cases of similar power plant observations by the project team members. There could have been many more cases of lessons learned from coal-based power plant refurbishments and upgrades. However, since these were not among the survey returns, they are not correspondingly responded to with best practice suggestions by the study team:

(1) Best Practice Recommendations for Coal Pulverizer Upgrades

(a) Calculate the loading capacity of each component of a new hydraulic system and compare each component's capacity to expected maximum loads at specific points in the support system.

(b) Thoroughly review specifications for new pulverizer supports, or any other part thereof, before actual installation, including hydraulic oil chemical and mechanical properties, especially hydraulic oil stability over time and under constant stress.

(c) Pressure-test (using same hydraulic oil) the support system components, including connecting tubing and valves under a test pressure which is 150% of rated load at its support.

(d) In cases where a hydraulic support system replaces a spring support system, a hydraulic relief mechanism should be provided to allow for thermal expansion of both system oil and supported load. The original spring supports, apart from its main function of supporting the pulverizer, did have dual extra functions, which is partly absorbing structural vibration and thermal expansion (minimal it may be) of the pulverizer unit.

(e) Use hard surfacing overlay as temporary best practice solution to counter the effects of wear and tear on pulverizer table liners. A more extensive repair, if possible, should be done during a longer turnaround shutdown.

(2) Best Practice Recommendations for Air Heaters

(a) Plant owners should first verify the performance of the new replacement units (in this particular case, the air heater), through research or from inquiry from those who are identified as earlier users of said component.

(b) The root cause of the problem must be identified first prior to deciding upon an upgrade. Perhaps the inherent position, location, thermal expansion provisions or support system is inadequate. In addition, a thorough review of the material specifications should be used in the replacement unit.

(c) As much as possible, a complete set of air heater assembly equipment shall be installed at a single plant shutdown. Proper logistics and thorough planning will save both time and effort during installation.

(d) Ensure that in-house plant maintenance personnel are well trained to handle newly acquired/installed plant components. During the process of buying the new equipment, the vendor should required by the purchase contract to provide the plant with special repair tools, necessary maintenance spare parts, technical, operating and maintenance manuals, training, etc. The plant management should ensure beforehand that the vendor provides locally accessible after-sales field support.

(e) Closely monitor leakages and motor loads, and be mindful of the best timing to act on refurbishment of aging equipment.

(f) The original equipment manufacturer (OEM) should be asked to inspect an air heater performance/condition upgrade situation and have the power plant in-house project engineering staff coordinate with the OEM. Otherwise, engage a private engineering consultancy with the proper expertise to examine the problem.

(g) Ensure to protect high-temperature materials (especially metallic rotating parts) of operating plant equipment from weather elements that can cause uneven thermal movements/distortion during operations. Insulate plant sections properly where needed.

(3) Best Practice Recommendations for Boiler Burners

(a) If possible, include in the purchase/procurement requests provisions for testing the integrity and performance of ordered equipment. This should be done for both bench scale/rig test and full scale runs. It must be witnessed by a representative of the buyer or a designated group to oversee the testing itself.

(b) Ensure that results fully meet contract performance guarantees during and after the acceptance test. It is important to retrain the operators in the operation procedures and calibration of the newly installed burners.

(c) Specify from the beginning the range of parameters and (severe) conditions to which the burner parts and components will be subjected and must withstand.

(d) Find the root cause of every problem; refer the problem to the OEM, to an independent consultant or in-house engineering staff, if in-house staff is fully equipped and qualified to conduct the kind of investigation required for a particular problem.

(4) Best Practice Recommendation for Burner Ignitors

Always have a boiler burner bench or rig test trial conducted before a new system or design is brought to mainstream use.

(5) Best Practice Recommendations for Induced Draft Fans

(a) Make use of less rigid fan-motor connection(s) whenever possible.

(b) Always use/specify materials that best match the service requirements. For example, given the same basic material chemical compositions and dimensions, tougher components such as forgings are preferable over castings in applications that are prone to fatigue failure. Similarly, stainless steel should be selected vs. plain carbon steel for corrosive service applications.

(c) Whenever, new and heavier weights (masses) are added into existing equipment, especially on one which has a rotating part such as a fan or pump, the foundation requirement should always be recalculated and modified if the existing foundation is found inadequate as shown by calculation results.

(6) Best Practice Recommendations for Boiler Sootblowers

(a) All new sootblower equipment or parts thereof must be exercised and utilized according to their design and purpose. Not using them could eventually lead to early failure.

(b) Piping handling compressed air, or any other gases or liquids at the plant (in this case used for sootblowing), should preferably be subjected to pressure tests (hydro or pneumatic) to a test pressure of 150% of the system design working pressure.

(7) Best Practice Recommendation for Steam Turbines

(a) In major steam turbine upgrades, it is best to provide an overall approach prior to undertaking the work. This should be done in any kind of refurbishment work, where almost all sections of the turbine from the governing stage of the HP turbine, the IP turbine stages and down to the LP stages, and other critical parts, are changed and retrofitted.

(b) In all cases, the nameplate rating of the generator shall always be referred to before enhancing load generating capacity. Enhancement of generating plant capacity in one part of the system could shift the burden to the next weaker part of the system. It would be like shifting the weakest part of a link into the next weaker link, once the weakest is reinforced or restrengthened.

(c) Conduct the following steps or procedures before start-up: (i) Consult the steam turbine OEM about the impact of replacing components of the original turbine on the bearing capabilities, i.e., specs and so forth. (ii) The new turbine rotor and casing/sealing clearances must be checked against the originals, as well as turbine OEM recommended new values, if any. (iii) The natural frequencies, including the 1st, 2nd, and 3rd critical, need to be verified if affected by the steam flow path modification. (iv) The new upgraded rotor needs to undergo thorough balancing, especially the dynamic balancing required during the commissioning phase after upgrade shutdown.

(d) Any additional capacity that can be obtained from a steam turbine retrofit should be utilized, but it must first be determined that running the plant at the augmented capacity will not exceed the design heat and mass balance limits of the system.

(e) Older power plants, once running as base-loaded units but are now relegated to cycling duties, need to reexamine the impact of the change in their mode of operation. For older steam turbine-generators that are no longer assigned for base-load duties, partial-arc or sequential valve governing capability can be beneficial in improving efficiency at less than rated capacity operations.

(8) Best Practice Recommendation for Condensers

(a) On surface condensers, specifications of all original (for new construction) and replacement units (for retrofits and upgrades) need to be screened and evaluated thoroughly. It is best to use reliable industry standards as guideline documents in specifying and ordering power plant equipment.

(b) Conduct a life assessment inspection on the condenser to anticipate its remaining useful or economical service life. The Heat Exchange Institute (HEI) in a number of its earlier publications notes an upper limit of 10% of the total number of condenser tubes that can be plugged, below which the condenser can still continue to operate without impacting on the turbine performance.

(9) Best Practice Recommendation for Instrumentation and Control

(a) The best approach to instrumentation and control upgrade is to study the options carefully. The OEM and vendor/supplier should be selected very carefully and have a proven, verified background of excellent service. Most companies have stringent pre-qualification processes to screen out weak candidates. However, of equal importance is the system to use in the upgrade itself. How compatible is it with the controlled hardware and equipment? How balanced are the components in terms of technology maturity? The following preferably should be sought:

- (i) Quickness of response to service calls / proximity to the plant of an OEM's representative (a locally –based dealer, as an example or a field service engineer),
- (ii) parts commonality,
- (iii) excellent OEM's back-up for training of plant personnel,
- (iv) calibration support.

(b) A shift to a later generation of control and instrumentation architecture and philosophy requires new methods of protection and signal transfer. The new industry standard of instrumentation and control along with the manufacturer's recommendation should be followed accordingly.

(c) Management, information, instrumentation and control integration in a power plant is a delicate thing to coordinate. It is best if a single provider can be retained by the plant. However, there are providers who excel in their specific fields. Nevertheless, for a given job, it is preferable that a minimum number, if not a single lead Supervisory Control and Data Acquisition System (SCADA), MIS and DCS provider, be chosen. Their subsystems should work compatibly and harmoniously among one another to provide one integrated plant management system. If more than one provider is involved, hold regular coordination meetings.

(d) Always choose products which have a proven field performance record; this is especially true to state-of-the-art products, which are one of the most dynamic products/services in the power industry. For newly established brand names, always ask for proof of satisfactory performance, such as field test results, product standard certifications, and company background. A demonstration product run/field testing should be welcomed, if offered by the prospective supplier without strings attached.

(10) Best Practice Recommendation for Flue Gas Desulphurization

(a) It is a good practice to attempt to anticipate and be one prepared for stricter implementation of emission control regulations. Utilize turn-around or Test & Inspection (T&I) shutdowns as an opportunity to install FGD and other pollution control components in the plant.

(b) Strictly follow and comply with regulations on emissions in a timely manner. Being ordered to halt operations, even momentarily, can damage both income/revenues and customer goodwill.

(11) Best Practice Recommendation for Reheater

(a) For superheater or reheater upgrade work, always use a shop-welded transition piece (or safe-ends) whenever dissimilar metal welds are used.

(b) Include in an upgrade project a degradable part of an assembly which might be very difficult to access later due to the installation of the current upgrade.

(12) Best Practice Recommendation for Steam Coil Air Heater

As much as possible, an upgrade should introduce an improvement over the original or previous equipment, be it in the form of an improved design or a superior material. This applies not only to SCAH upgrades, but also to all other power plant upgrades.

(13) Best Practice Recommendation for Reheat Desuperheater

As applied in this case towards the reheat desuperheater upgrade, which was accelerated in pace as usually done in most plant situations, it is a best practice reaction to act immediately on critical matters. This is especially important with issues that affect personnel safety and well being. Traceability in the records of purchased items is a very important feature for all power plant materials. Ideally, plant material records should be traceable back to their sources, i.e., from their individual heats/batches (in case of steel products) complete with inspection and test results.

(14) Best Practice Recommendation for Electro-Hydraulic Control Fluid Polishing

Utilize plant resources fully; recycle items where they can still serve effectively in a different and less severe application. This has been demonstrated in the case of the Electro-hydraulic Control Fluid polishing station in-house plant design and fabrication reusing components available from plant recycle stock.

(15) Best Practice Recommendation for Desalination Plant

As demonstrated by this desalination plant experience, it is best practice to try all possible and acceptable, yet most practical and economical, options to meet upgrade and refurbishment work. If the OEM pricing becomes too prohibitive, it may not always be the best option return to the original OEM in upgrading plant equipment/components, except perhaps on major ones like turbines, surface condensers, and steam generators.

ACKNOWLEDGEMENTS

This project was completed for and funded by the ASIA-PACIFIC ECONOMIC COOPERATION organization.

The authors wish to acknowledge and thank Mr. Scott Smouse and Mr. Arthur Baldwin, APEC Expert Group on Clean Fossil Energy, of USDOE/National Energy Technology Labs for their guidance and many contributions to this project.

Similarly, we wish to thank the Delegations of Design Institutes from China for their valuable support and insight regarding the current status of the electricity industry in China.

Lastly but most especially, our heartfelt thanks go to the power plants, which have unselfishly provided us the valuable information that was required in developing this report.

REFERENCE

1. APEC Energy Working Group, New Energy Technologies, Measuring Potential Impacts in APEC (APEC#205-RE-01.1), 2005.

2. APEC Energy Working Group, Cost and Effectiveness of Upgrading and Refurbishing Older Coal-Fired Power Plants in Developing APEC Economies, 2005.

3. U.S. Nuclear Regulatory Commission, *Nuclear Plant Aging Research Program Plan*, NUREG-1144, Rev. 2, Washington, DC, June 1991.

ATTACHMENTS

Figure 18 Boiler Integrity Inspection Guide List

NO.	Item of Inspection	NDT (Day + Crew) Replica tion	Hard ness	Helical Skip UT	MT (MPI)	(RVI) Video	Con-ventional	EMAT	Continuous UT Robot	USTM	TOFD	Visual	oxide thicknes	tube sample	others	Remarks
1	Metallurgical Inspection (MLAS) of Superheater Outlet Header	O	X		X							O				Replica 8 points
2	Metallurgical Inspection (MLAS) of Reheater Outlet Header	O	X		X							O				Replica 6 points
3	Measurement of Superheater Tubes Thickness by UT Robot								◆							10 panels
4	Measurement of Reheater Tubes Thickness by UT Robot								◆							1RY RH - 5 panels 2RY RH - 5 panels
5	Measurment of Eco Tubes Thickness by UT Robot								◆							6 panels
6	Sampling Tube Inspection for Water Wall Tubes													O		3 tubes
7	Sampling Tube Inspection for Suprheater Tubes													O		3 tubes / selected from # 3
8	Sampling Tube Inspection for Reheater Tubes													O		2 tubes / selected from # 4
9	Sampling Tube Inspection for Eco. Tubes													O		2 tubes
10	Measurement of Thickness for Water Wall Tubes by UT							X		O		O	X			900 points
11	Measurement of Thickness for Division(Platen) Wall Tubes by UT							X		O		O				150 points
x	Measurement of Thickness for Deflection Arc Tubes by UT									O		O				200 points
13	Measurement of Thickness for Superheater Tubes by UT									O		O	X			Same panels for -3 (296 points)
14	Measurement of Thickness for Reheater Tubes (1RY/2RY) by UT						O			O		O	X			Same panels for -4 (120 points)
15	Measurement of Thickness for Eco. Tubes by UT									O		O				56 panels (500 points)
16	Measurement of Scale Thickness for Superheater Tubes by UT						O			O		O	X			Same panels for -3 (350 points)
17	Measurement of ScaleThickness for Reheater Tubes(1RY/2RY) by UT						O			O		O	X			Same panels for -4 (300 points)
18	Internal Inspection for Water Wall Header by Video Scope					O										ø101.6 x t 14.7 2 headers
19	Internal Inspection for Superheater Header by Video Scope					O										ø110 x t 20 1 headers
20	Internal Inspection for Reheater Header by Video Scope					O										ø100 x t 15 2 headers
21	NDI (MT) of Weld of Stub Tubes at Water Wall Header				O							O				60 tubes
22	NDI (MT) of Weld of Stub Tubes at Division(Platen) Header				◆		X					O				20 tubes
23	NDI (MT) of Weld of Stub Tubes at Upper Reieaser Header				O	X	X					O				30 tubes
24	NDI (MT) of Weld of Stub Tubes at Superheater Header				O											100 tubes
25	NDI (MT) of Weld of Stub Tubes at Reheater Header				O											100 tubes
26	NDI (MT) of Weld of Stub Tubes at Eco. Header				O											24 tubes
27	NDI(MT) of Weld of Spacer for Superheater tubes				O											Same Panels for -3 (1,000 points)
28	NDI(MT) of Weld of Spacer for Reheater tubes				O											Same Panels for -4 (500 points)
29	NDI(MT/UT) of Weld of Attachment at Water Wall tubes by Helical Skip UT			O	O											1,500 points
30	Visual Inspection by MHI's Boilers Design Engneer														O	For Pressure Parts & Non-Pressure parts
31	Inspection for Steam Drum (UT - TOFD) of weld joints	X			X		O			X	O					(UT-80M) Internal / External parts
32	Inspection for Water Drum											O				Water Drum
33	Inspection of Superheater Desuperheater					X						O				OD 6B 1RY DeSH 2RY DeSH
34	Inspection for Air Heater											O				For Air Preheater
35	Combustion Adjustment Test														◆	Combustion Confirmation & Load Swing Test
36	Inspection (MT) of Steam Drum Riser and Downcomer Piping				O		X					O				For Riser Tube Nozzle & Downcomer Nozzle
	Boiler Sub-total															
37	Visual Inspectiion of Burner Nozzles (N - 1)											O				For Burner Nozzle of 208 sets
38	Actuation Check of Burner Nozzle Tilt (N - 2)														◆	For Burner Nozzle Tilt of 8 sets
39	Actuation Check of Wind Box Damper (N - 3)														◆	Actuator Check of 80 sets
40	Hydro Test of Burner Gun (N - 4)														◆	Hydro Test of Burner Gun of 32 sets
42	Inspection of Burner Tip Spray Plate (N - 5											O				For Burner Tip Spray Plate of 32 sets
	Combustion Sub-total															
43	Metallurgical Inspection (MLAS) and NDE(MT and UT-TOFD) for MS Pipe	O			O		O				O	O				Replica 10 points MT & UT 4 points
44	Metallurgical Inspection (MLAS) and NDE(MT and UT-TOFD) for HTR Pipe and Standby Feed Pump	O			O		O				O	O				Replica 12 points MT & UT 4 points
45	Measurement of Thickness for Feed Water Pipe by UT									O		O				20 point spacing x 8 160 points
46	Measurement of Thickness for Condensate Pipe by UT									O		O				20 point spacing x 8 160points
47	Measurement of Thickness for Spray Pipe by UT									O		O				15x6 Point = 90 points 5x4 Point = 20 points
48	Inspection of Welded T-piece for CRH (LTR) Pipe by UT	X			X		O			X	X	O				18 pc (36point)
49	Inspection of Hanger fo MS,HRH and CRH											O				MS:29, HTR:23, & LTR:31pcs.
	Piping Sub-total															
	Additional Headers Inspected by IC															
1	Primary Reheater Inlet Header	X			X	X										
2	Economiser Inlet Header				X	X	X					X				
3	Economiser Inlet Header Elements								X	X						
4	Primary S/H Inlet Headers	X			X		X					X				
5	Primary S/H Outlet Headers	X			X	X	X					X				
6	Secondary S/H Inlet Headers	X			X		X					X				
7	Tertiary S/H Inlet Header	X			X	X	X					X				
8	Ecocmiser Outlet Hearder				X		X		X	X						
9	LHS Wall Upper Header				X	X	X									
	Tubes															
10	Primary S/H Tubes	X	X													
11	Primary R/H Tubes	X														
12	Secondary R/H Tubes	X														

Note: IC had performed an inspection on all headers and introduced more inspection items.

UT Robot was performed only on straight tubes not continueously to the bend parts.(at front panels)

Legend:

O -- **Required scope**

◆ -- **Required scope but not performed by Inspection Contractor (IC)**

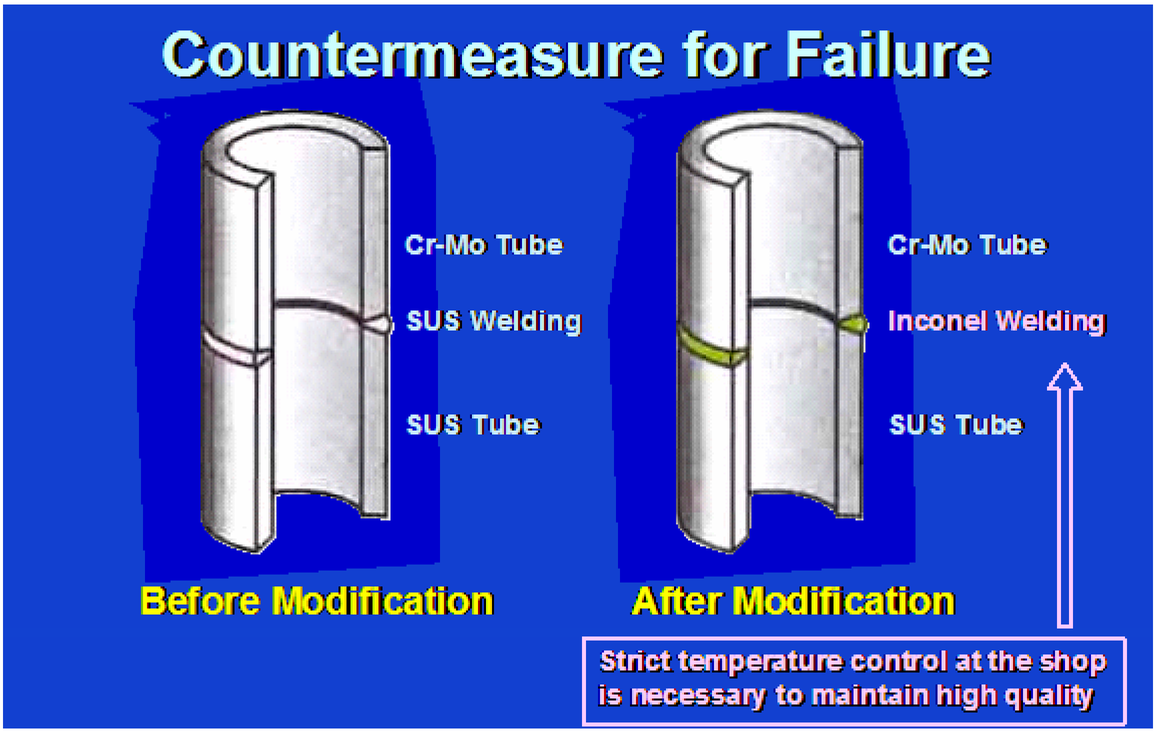
X -- **Added inspection item by Inspection Contractor (IC)**

(green) -- Appreciated inspection

(orange) -- **Not Appreciable**

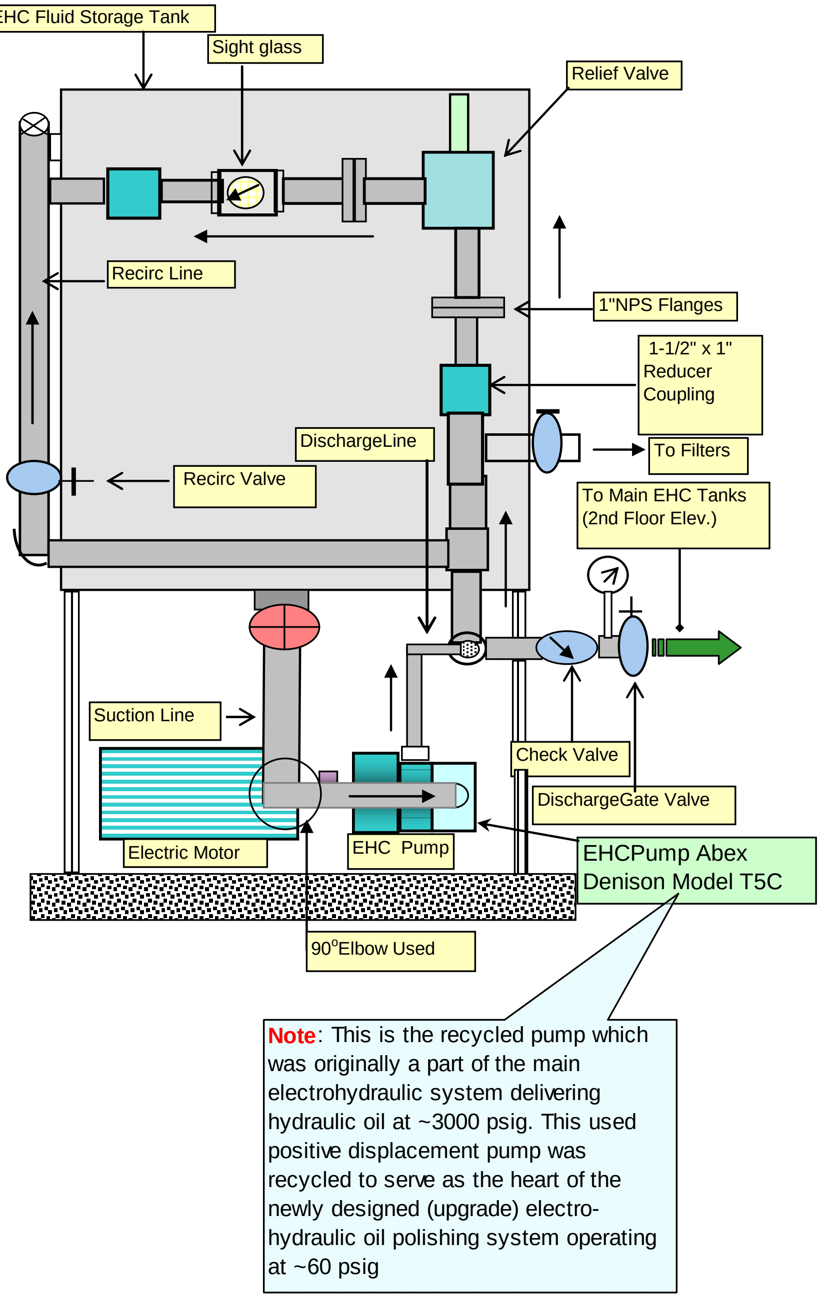
(yellow) -- Speciallist should be required to performed the inspection

Figure 19 Recommended Transmission Pieces for Dissimilar Metal Tube Connections
Courtesy of Mitsubishi Heavy Industries Corp.



Note: Shown above are transition pieces or 'safe-ends'. These are pieces of dissimilar metals which are shop-welded under more controlled (vs. field welding) conditions. In the field, when installing new (upgraded) Superheater (SH) or Reheater (RH) coils, only similar metal welds are allowed to ensure integrity of all weld joints. In using the above shop-welded transition pieces, for eventual field-welding application, the chrome-molybdenum end of the transition piece will be welded to existing chrome-moly materials within the boiler, such as headers and remaining portion of SH or RH tubes. The stainless steel end of the transition piece will be welded to the new stainless steel (upgrade) coils. Also shown above is a modification on a design using stainless steel weldment which is modified using a weldment with Inconel welding material used for the dissimilar metal weld junction.

Figure 20 Electro-Hydraulic Control Fluid Polishing Station (Upgraded version)



Appendix 1: 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)
APEC Expert Group Chair on Clean Fossil Energy
and
WorleyParsons Group, Inc.

Reading, PA, USA
December 6, 2007

QUESTIONNAIRE RESPONSE:

(1) Is cost effectiveness, which includes 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 OEM. FGDs and ESPs get more attention than pressure parts 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**: A question was added regarding the approximate number of power plants in China that are likely to be retired soon. The answer was given that *about 10,000 MW of old generating capacities*

shall be replaced with new ones annually for 5 years resulting in a total of 50,000 MWe 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 4 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 generations?

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 generations.*

(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 – Experts' 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 Laboratory 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:

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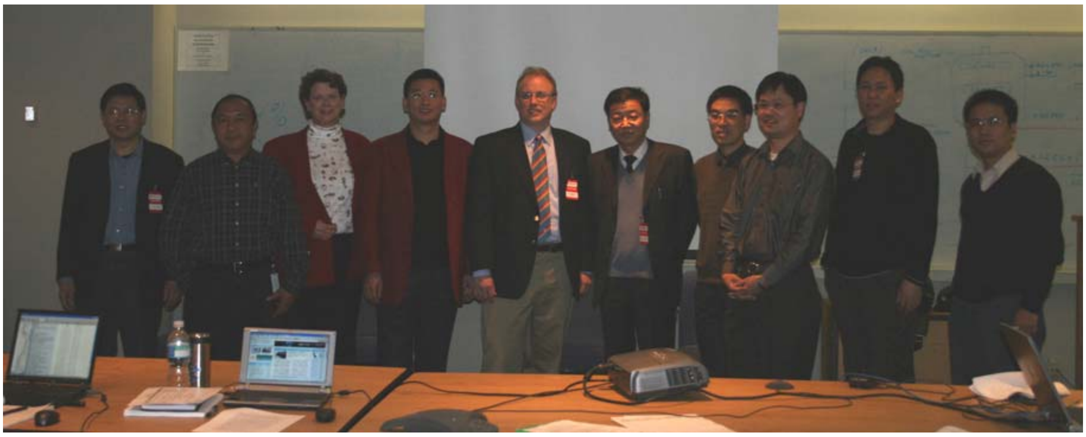
Scott Smouse, APEC Expert Group Chair on Clean Fossil Energy, USDOE/NETL
Arthur Baldwin (by teleconference), Project Manager, USDOE/NETL
James Van Laar, Director, Power Consulting Group, WorleyParsons Group, Inc.
Qinghua Xie, Senior Mechanical Engineer, WorleyParsons Group, Inc.
Napoleon Lusica, Project 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 2: Survey Response Summary from Power Plants

Note: The following is a tabulated summary of all the responses to the questionnaires sent out by the Study Team. Responses coming from Chinese Power Plants were all translated into English as contained herein.

No	Plant Name (Plant Owner)	Plant General Information	Completed Upgrades & Retrofits	Performance Improved Problems/Issues During/After Upgrade
1	Hangzhou Banshan Generation Co., Ltd. (China Huadian Corporation)	State owned; Fuel: Bituminous; Fuel LHV: 20162 kJ/kg; Fuel HHV: 21840 kJ/kg; Unit No: 4; Design unit capacity at maximum continuous rating (MCR): 125 MW; Original mode of operation: Base load; Current mode of operation: Not identified; Steam cycle parameters: Main steam pressure: 13.2±0 The best approach 5 MPa Main steam temperature: 535 °C Hot reheat steam temperature: 535 °C; Boiler Type: Tangential pulverized-coal-firing boiler; Turbine Manufacturer: Shanghai Steam Turbine Co Ltd; Boiler Manufacturer: Shanghai	**Boiler Island** a) Air Heater Because of high air leakage rate and serious ash clogging, the Φ6.7m regenerative air heater originally equipped with the #4 boiler was completely replaced by a new Howden 24VN1750 air heater in 2000. The new air heater consists of 24 sectors with different types of heat transfer elements. The total heat transfer surface area of the new air heater is 9150 m^2. The upgrade used plant's own funding of 3,000,000 RMB. b) Boiler Burner In 2007, to save energy and reduce emissions of the boiler of Unit #4, the #1~#4 burners at the bottom level of the boiler were replaced with new oil-saving ignition burners (The original pulverized-coal concentrators and elbows remained). With total 40 kg/h fuel oil input rate for the four burners, the boiler can be ignited successfully at cold starts and the combustion of pulverized-coal in the furnace is very good. The boiler capacity is 1050 kg/h firing fuel oil. The upgrade used plant's own funding of 1,500,000 RMB. c) Boiler Soot-blower	a) Air Heater The air leakage rate was reduced from 12% before upgrade to 6% after upgrade. The unit has been successfully operated about 50,000 hours since upgrade. 2% of net unit efficiency improvement was achieved, and unit reliability was improved. b) Boiler Burner The upgrade allowed the operation of ESP during the start-ups and part load operations (because the main fuel is coal and the fuel oil is used as an auxiliary fuel for ignition and stable combustion). This resolved the black smoke emission from the stack and hence the emissions met the regulation requirements. It has been successfully operated about 3,000 hours since upgrade. Boiler efficiency is 91.02%. c) Boiler Soot-blower

		Boiler Works Ltd.	All original soot-blowers had never been used after installation. The erosions of blowers were severe, mechanical devices were not functioning, and motors were broken. The blowers were damaged and could not be operated. They were replaced with 18 new IR-3 furnace blowers, 4 new IK-525 superheater blowers. The steam pipes for blowers were re-arranged The upgrade used plant's own funding of 2,000,000 RMB. d) In 2007 lean oil ignition system was modified.	The upgrade effectively reduced high-temperature erosion of the water wall and surface slagging. It improved the boiler efficiency and reduced the slagging and fouling at the superheater also, which in turn reduced the potential accidents caused by fouling and slagging. The unit reliability was improved.
			Turbine Island a) Steam Turbine There were some major issues of the turbine before upgrade. The blade was Soviet-era Russian design in 1950s, which has high losses and low efficiency. There were no shrouds on the tips or were with struts of rotating blades at some stages, which increased the leakage loss and blade trailing edge loss. Original flow path design caused low efficiencies of HP, IP, and LP turbines. The velocity ratios and enthalpy drop distributions were unreasonable for some stages, which caused the thermodynamic characteristic parameters were offset from the optimized values so that the stage efficiencies were low. Due to the reasons mentioned above, the unit had a low overall efficiency and high fuel consumption rate. The heat rate increased from 8671 kJ/kWh to 9096 kJ/kWh during more than 10 year operation. The modifications were made as following: **a-1) HP Turbine Retrofit** **Governing stage of HP turbine** The working pressure at the nozzles was high. The nozzles also had high pressure drop and small volume flow rate. The blades of the nozzle stage were short and	Turbine heat rate was improved by 1021.3 kJ/kWh.

			wide and relative blade height was small which resulted in great secondary loss. Using meridian contraction surface for the blades is an effective way to reduce the static blade loss. The new nozzle design was changed from the original casting part to the milled single part of stationary blades together with inner ring of the nozzle group which was made by Shanghai Steam Turbine Co Ltd. The blade ends were welded to the outer ring, which assured the manufacturing precision of the blade and the meridian surfaces at the blade tips. Because the meridian contraction surface was used in the nozzle distributor at governing stage in the HP turbine, the flow path area increased at the nozzle throat. Therefore the original rotating blade pattern could not be used. During this modification, we used the new design blades with smoother curves to reduce the flow loss. The new blades are equipped with shrouds and using dovetail belt to form a whole collar. Radial sealing teeth were increased from three pieces to five pieces. **Employing aft-loaded high efficiency stationary blade pattern** Aft-loaded high efficiency stationary blade pattern was employed to 18 stages of the new design pressure stages, including HP stages #2-9 and IP stages #10-19. A significant advantage of applying the new blade pattern is reducing the secondary flow loss significantly. The stage efficiency and rigidity of the blade were also increased. Through many calculations and wind tunnel testing, it was confirmed that the overall loss factor of the annular stationary blades with new design pattern could be decreased approximately by 20% compared to the original design pattern. With the same bow length, the cross-section bending coefficient of the new blade is 30% greater than the old blades so that the bending stress and deflection of the stationary blades were	

			significantly reduced. **Pressure stage nozzles** For the distribution nozzles, the stationary blades from stage 2 to stage 9 in the HP section adopted the new design of the divergence blade structure to replace the original design of small blade with the stiffener structure. It is well known that the circumferential flow loss around the stiffener is large. In addition, the accurate alignment between the stiffener and small blade is difficult to achieve, which causes additional loss. In contrast, the divergence blade design can assure the strength and rigid of the partition board and dramatically reduce blade flow loss. The partition board of the divergence blade still employed the traditional encircling belt hole and the welding structure. In order to assure safe operation, the board body, the outer ring of the partition boards from level 2 to level 6 used forging parts to improve the partition board strength. In the new design of twisted stationary blades of 10-23 stages, the stationary blades from 10 to 23 stages in the IP and LP sections adopted the entire three-dimensional twisted profiles. This was the first time to use this advanced technology extensively is steam turbine design in China. Theoretical analysis and tunnel blowing experiments showed that, comparing with the original design, the new design reduced the total loss coefficient by 25%, and increased stage efficiency by 2%. Based on the manufacturing facility capability in Beijing Heavy Machine Works and its experience of the manufacturing the parts using fabrication drawings from GEC-Alstom in France, the twisted stationary blades still used milled stationary blades and the traditional fabricating method of welding inner and outer shrouds structure, which can achieve good fabrication precision and high rigidity.	

			Blade pattern optimization for the rotating stage 2 to 9 The original design of 2~9 rotating stages in the HP turbine of the 125-MW steam turbine adopted former Soviet Union NKTN (central boiler and turbine research institute)'s T1 blade pattern, which has a high blade pattern loss. Lately, it was changed to domestic HQ-1 blade pattern. In this new design, the relatively advanced French blade pattern was applied, which has a very small amount of loss. **All the tips of the rotating blades equipped with integrated tip cover** The dimensions of the inner side paths of tip covers had high level of precision which reduced the flow loss. The outside of the tip cover is of a cylinder surface (manufactured as raised concavity), the steam sealing teeth number increased from 2 pieces to 4 pieces. The riveted joints on the tips of the rotating blades were removed for less stress concentration for safer operation. **a-2) IP Turbine Flow Path Retrofitting** IP partition plates from 10 to 19 stages also used after-loading fish head-shaped welded plate, among them the plates from 10 to 17 stages used traditional punch welded structure, and the plates at stage 18 and stage 19 were directly welded between stationary blades and plates. Forging parts were used to increase the strength of the plates. Buckets with integral tip covers were used on the top of the IP rotating blades. The outside surfaces were manufactured as raised concavity. Steam sealing teeth were increased from 2 pieces to 4 pieces to reduce leakage. From stage 14 to the last stage of the IP section, slanting channel was used to replace the original stepped design. Hence a smooth curve was formulated to reduce flow loss.	

			The high precision inner side paths of the integral tip covers reduced the flow loss. The riveted joints on the tips of the rotating blades were removed for less stress concentration for safer operation. The manufacturing cost of the integral tip covers slightly increased, but the overall technical and economic benefits were very remarkable, especially in safe operation and maintenance field. In this overall technical retrofitting of 125-MW flow path, the mature structure mentioned above were applied, which is using blades for 10 to 14 stages in the IP turbine, twisted blades for 15 to 19 stages. In addition, HP and IP rotors were replaced according to the requirement of the retrofitting. **a-3) LP Turbine Flow Path Retrofitting** In order to significantly improve the efficiency of the LP turbine, a complete retrofitting was implemented on the LP flow path. A smooth curve was formulated to reduce flow loss by replacing the original stepped design to a slanting channel design. The first 5 stages' roots were raised to make the distribution of the flow area and radial distance more reasonable. All tips of the rotating blades adopted integral tip cover design. The last stage blade was prolonged from 700mm to 710mm, and its blade pattern was streamlined with the mode of the original 665 blade. Except for that the tip of the last stage rotating blade was beset with three steam sealing teeth at the same size, all other five stages were beset with four overlapped steam sealing teeth to reduce leakage losses. All the original straight steam sealing rings of the partition plate and LP steam sealing were changed to slanting-even teeth sealing rings.	

			All the original cast-iron low pressure partition plates were replaced by welded cast-steal plates to increase the rigidity of the partition board. LP stationary blades were twisted blades with constant-section areas at the stage 20 and 21. Twisted blades with variable cross-section areas at stage 22 and 23 were adopted and straight blades with variable cross-section at the last stage and the second last stage were used. The merits of these three types of stationary blades are high efficiency and reliable strength. The original de-moisture device was modified to improve the performance of draining and protect the last stage blades. **a-4) Miscellaneous** In order to increase the supporting rigidity of radial bearings, all #1, #2 and #3 bearings with lining plates were changed to integrated ball bearings to improve the reliability of steam turbine operation. The original slot slide system and the turbine casings were not replaced in the retrofit, the thermal expansion of the new rotor and partition plates had to meet the original cylinder heat expansion. At the same time, the method of steam fed to the original gland sealing had to be adjusted. Due to the change of the rotor material, the expansion characteristic of the machine changed significantly. Hence, the cold start up time and warm-up time, ramp rate, sealing steam temperature were adjusted to avoid unit vibration. The turbine upgrade used plant's own funding of 18,600,000 RMB.	

			Instrumentation and Control In 1999 some upgrades of I&C System were made using plant's own funding of 3,000,000 RMB. a) The control system was upgraded to DCS system. b) The transmitters were changed to type 3051 transmitters. c) Some of electrical-driven valves were upgraded to integral electrical valves, and some major actuators were upgraded to intelligent actuators. 6) Bentley system was upgraded from model 3300 to 3500 in 2006.	**Performance Improvements** Upgrades increased the operating reliability of equipments, the level of utilizing automatic control and system protection, and reduced the working load of operation and maintenance. **Issues and Problems** Vendors of system retrofitting should have provided reliable and in time technical support, which includes, but not limited to, lifetime of hardware and supplying prices of spare parts, a complete design of automatic control and protection system which has impacts on the reliability and economic performance of the unit. With the improvement and optimization of the control system, the requirements on the performance of measurement devices and actuators also increased. If the retrofitting were capital intensive, it should be taken into account that if the original DCS system will be able to meet the required control capacity and system I/O points for new equipment and system in the future. Some parts used in the current DCS systems are becoming out-of-date and may not be available in the market, which may make the supply of some spare parts harder and harder. Therefore, it is possible that some vendors may significantly increase the prices of the parts. The aging time of DCS systems is still not very clear and needs more study on it.
			Electrical **N/A**	**N/A**
			Others In 2000 FGD system retrofitting was performed.	

2	HuBei Hanxin Power Generating Co. (China GuoDian Group)	State owned; Fuel: not indicated; Fuel LHV: 20075 kJ/kg; Unit No: 2; Design unit capacity at maximum continuous rating (MCR): 326 MW; Steam cycle parameters: Main steam pressure: 16.7 MPa Main steam temperature: 537 °C Hot reheat steam temperature: 537 °C; Boiler Type: Tangential pulverized-coal-firing boiler; Turbine Manufacturer: Shanghai Steam Turbine Co Ltd; Boiler Manufacturer: Shanghai Boiler Co Ltd. Original commercial operation date June 28, 1996.	**Boiler Island** a) Air Heater Because of high air leakage and poor heat transfer the air heater was upgraded in 2004. The original sealing structure was changed and the heat transfer elements were replaced. The upgrade cost was plant's own funding of 3,800,000 RMB. b) Boiler Burner To improve the combustion efficiency and stability the original boiler burners were replaced with horizontal lean-rich burners in 2004, The upgrade used plant's own funding of 2,000,000 RMB. c) Boiler Soot-blowers To improve the performance the original soot-blowers were replaced with deflagration soot-blowers in 2004. The upgrade used plant's own funding of 4,000,000 RMB.	a) Air Heater **Performance improvement** The air leakage rate decreased from 20% before upgrade to 10% after upgrade. Total operating time after the upgrade is 25,000. **Issues/problems after upgrade** Air leakage rate increased with operation time after upgrade. b) Boiler Burner The total operating hours after upgrade are 25,000. c) Boiler Soot-blowers Boiler efficiency was improved. The total operating hours after upgrade are 25,000.
			Turbine Island a) Steam Turbine In 2004 the Brandon steam seal of the turbine was retrofitted. The turbine governing stage nozzles were replaced. The retrofit cost plant's own funding of 5,300,000 RMB. b) Drainage system Drainage system was optimized. c) Condenser Because of the insufficient heat transfer surface area of the original condenser the steam turbine back pressure was high and caused poor turbine performance. The condenser heat transfer surface area was increased and original condenser tubes were replaced with stainless	Turbine performance was improved. Turbine heat rate decreased by 189 kJ/kWh The total operating hours after upgrade are 25,000. Condenser back pressure decreased by 2 kPa.

			steel tubes in 2004. The condenser upgrade cost was 10,800,000 RMB, and it was from plant's own funding.	
			Instrumentation and Control In 2004 the original control system was upgraded to DCS system using plant's own funding of 15,000,000 RMB.	The unit reliability and efficiency was improved. The total operating time after upgrade is 25,000 hrs.
			Others Turbine flow path retrofit of Unit #1 is expected to be started in April 2008. The cost is expected to be around 45,000,000 RMB. 25 g/kWh of fuel consumption rate decrease and 30 MW of unit power output improvement are expected. Turbine nozzle retrofit of Unit #2 is expected to be started in April 2008. The cost is expected to be around 45,000,000 RMB. 5 g/kWh of fuel consumption rate decrease and 20 MW of unit power output improvement are expected.	
3	NanChang Power Plant Unit# 10 & 11 (China Power Investment Group Co)	State owned; Fuel: Sub-bituminous; Fuel LHV: 12600 kJ/kg; Fuel HHV: 14700 kJ/kg; Unit No: 10 & 11; Design unit capacity at maximum continuous rating (MCR): 125 MW;	**Boiler Island** a) Air Heater (Unit# 10 & 11) Because of high air leakage rate the air heaters of Unit# 10 & 11 were upgraded in 2004. One layer of air heater was replaced. The upgrade cost was plant's own funding of 1,500,000 RMB.	a) Air Heater **Performance improvement** Unit #10 air leakage rate decreased from 28% before upgrade to 12% after upgrade. The unit reliability increased. Unit #11 air leakage rate decreased from 30% before upgrade to 8% after upgrade. The unit reliability increased. Air heater maintenance cost reduced by ~300,000 RMB for each unit. The total operating time after the upgrade is 22,000

		Original mode of operation: Base load; Current Mode of Operation: Peak load; Steam cycle parameters: Main steam pressure: 13.24 MPa Main steam temperature: 535 °C Hot reheat steam temperature: 535 °C; Boiler Type: Tangential pulverized-coal-firing boiler; Total burners per boiler: 12; Turbine Manufacturer: Shanghai Steam Turbine Co Ltd; Boiler Manufacturer: Shanghai Boiler Co Ltd. Original commercial operation date of Unit #10: April 1987. Original commercial operation date of Unit #11: May 1988.	b) Boiler Burner (Unit# 10 & 11) To resolve unstable combustion issue in the boiler, the original boiler burners were replaced with shuttle type burners in 2006, The upgrade cost, 360,000 RMB, was from plant's own funding. c) Boiler Soot-blowers (Unit# 10 & 11) Due to the poor soot-blowing performance, original soot-blowers were replaced with compressed air soot-blowers. The upgrade cost, 600,000 RMB, was from plant's own funding. d) Induced Draft Fans (Unit# 10 & 11) To improve the ID Fans' performance and decrease the electricity consumption, hydraulic couplings were added to the existing ID Fans of units 10 &11 in 2000 and 2001 respectively. The upgrade cost, 600,000 RMB for each unit, was from plant's own funding.	hours for each unit. **Issues/problems during the upgrade** Insufficient funding, not a complete modification. Three layers of air heater have not been retrofitted yet for each unit. b) Boiler Burner **Performance improvement** Excess air ratio decreased from 6.5% to 5.0%, and the boiler efficiency increased by 2%. **Issues/problems after the upgrade** Unstable combustion issue still remained c) Boiler Soot-blowers **Performance improvement** Boiler efficiency increased and ash accumulation on the heating surface in the boiler was reduced. The total operating time of Unit #10 after the upgrade is 22,000 hrs. The total operating time of Unit #11 after the upgrade is 27,500 hrs. **Issues/problems during the upgrade** Compressed air valves leakage. **Issues/problems after the upgrade** The improvement of soot blowing performance was not so significant. d) Induced Draft Fans(Unit# 10 & 11) The Upgraded ID Fans has been operated without any problems and the total operating hours for each unit after the upgrade is 44,000 and 38,500 respectively.

			Turbine Island a) Condenser (Unit# 10) In 2004 original condenser copper tubes were replaced with stainless steel tubes due to the copper tube leakage. The total cost of 1,200,000 RMB was from plant's own funding. b) Condenser (Unit# 11) In 2005 original condenser copper tubes were replaced with stainless steel tubes due to the copper tube leakage. Total upgrade cost, 1,200,000 RMB, was from plant's own funding. c) Steam Turbine (Unit# 11) In 2002 steam flow Paths for HP, IP and LP turbines were modified. Shaft seals and blade & stationary vane sealing were also modified. The last stage blade and back pressure were optimized and the 1st stage blade was modified to reduce erosion. The total cost of 20,000,000 RMB was from plant's own funding.	a) Condenser (Unit# 10) Turbine performance was improved. Turbine heat rate decreased by 0.37 kJ/kWh Condenser back pressure decreased by 0.6 kPa. The total operating hours after upgrade are 22,000. b) Condenser (Unit# 11) Turbine performance was improved. Turbine heat rate decreased by 0.37 kJ/kWh Condenser back pressure decreased by 0.6 kPa. The total operating hours after upgrade are 16,500. c) Steam Turbine (Unit# 11) **Performance improvement** Turbine heat rate improved by 777.89 kJ/kWh. **Issues/problems during the upgrade** The cooling system for the generator had to be modified accordingly. **Issues/problems after the upgrade** The cooling time of the turbine cylinders increased after shut-down.
			Instrumentation and Control (Unit# 10 & 11) The original control systems for Unit #10 & 11 were out of date, and were upgraded to DCS systems in 2002 and 2001 respectively The total upgrade cost for each unit was 2,000,000 RMB which was plant's own funding.	The upgraded system has simplified wire connections, centralized control system layout and improved plant automation and control. The total operating time after upgrade for Unit #10 & 11 is 34,000 and 38,500 hrs respectively. **Issues/problems during the upgrade** A DCS system requires high quality of input signals. Some signals in the old system did not use shielding cables. A large number of cables were replaced. **Issues/problems after the upgrade** Modules in DCS system were prone to being broken.

			Others (Unit# 10 & 11) A new FGD was added to each unit in May 2007. Total capital cost 25,000,000 RMB.	
4	Taizhou Power Plant (Zhejiang Southeast Electric Power Co, Ltd)	State owned; Fuel: Bituminous; Fuel LHV: 19250 ~ 20460 kJ/kg; Unit No: 2; Design unit capacity at maximum continuous rating (MCR): 125 MW; Steam cycle parameters: Main steam pressure: 13.24 MPa Main steam temperature: 535 °C Hot reheat steam temperature: 535 °C; Boiler Type: Pulverized-coal firing boiler, Model SG420-50414 ; Turbine Manufacturer: Shanghai Steam Turbine Co Ltd; Boiler Manufacturer: Shanghai Boiler Works Ltd. Original commercial operation date: August 1983.	**Boiler Island** a) Air Heater Original air heater had a high air leakage rate, severe corrosion, abrasion and ash plugging. The exhaust gas temperature from original air heater was high. In 1999, the air heater was replaced with a new Howden 235VN1550 regenerative air heater. The total upgrade cost of 6,200,000 RMB was from plant's own funding. b) Boiler Burner To reduce the fuel oil consumption four original bottom burners were replaced with air atomized oil-saving burners.	a) Air Heater **Performance improvement** The system reliability was improved. The air leakage rate decreased from 19.5% before upgrade to 6.0% after upgrade. The ID Fans' shaft work decreased by 92 kW and the FD Fan shaft work dropped by 98 kW. The exhaust gas discharge temperature decreased by 40.1 ºC. **Issues/problems during upgrade** It was difficult to disassembly the gear transmission system.
			Turbine Island a) Steam turbine Due to the low efficiency of the steam turbine, flow paths in HP, IP and LP turbines were modified in 2002.	
	Power Plant "A"	State owned; Fuel: Meager Coal; Unit No: 1; Design unit capacity at	**Boiler Island** a) Air Heater Original air heater had a high air leakage rate. In 1999. The sealing type was changed in the air heater.	a) Air Heater **Performance improvement** The system reliability was improved. The air leakage

5	(Huadian Power International Corporation Limited)	maximum continuous rating (MCR): 330 MW; Original mode of operation: Peak load; Current mode of operation: Peak load; Steam cycle parameters: Main steam pressure: 16.7 MPa Main steam temperature: 537 °C Hot reheat steam temperature: 537 °C; Boiler Type: Tangential, pulverized-coal firing boiler; Turbine Manufacturer: Shanghai Steam Turbine Co Ltd; Boiler Manufacturer: Shanghai Boiler Co Ltd. Original commercial operation date: September 1993.	The total cost of upgrade, 2,600,000 RMB, was from plant's own funding. b) Boiler Burner To reduce the fuel oil consumption, the burners were upgraded in 2005. The cost of upgrade of 4,900,000 RMB was from plant's own funding. c) Boiler Soot-blowers Due to the poor soot-blowing performance, original soot-blowers were replaced with acoustic soot-cleaner in 2006. The upgrade cost of 1,100,000 RMB was from plant's own funding.	rate decreased from 8% before upgrade to 3.5% after upgrade. The net unit efficiency increased by 0.27%. Total operating time after upgrade for the unit is 11686 hrs. c) Boiler Soot-blowers **Performance improvement** Boiler efficiency increased due to improved heat transfer. Boiler tube failures decreased. The total operating time of the unit after the upgrade is 11,686 hrs.
			Turbine Island a) Steam turbine The flow paths in HP and IP turbine were modified in 2002.	a) Steam Turbine The total operating time of the unit after the upgrade is 39,862 hrs.
6	Guangzhou Zhujiang Power Plant	State owned; Fuel: Bituminous; Unit No: 1, 2, 3 & 4; Design unit capacity at maximum continuous rating (MCR): 300 MW; Original mode of operation: Peak load and shift load; Current mode of operation: Peak load and shift load; Steam cycle parameters: Main steam pressure: 16.7 MPa	**Boiler Island** a) Air Heater Original air heater had a high air leakage rate. In 1998, 24 sealing pieces were added at the radial and axial directions of the air heater cold end while original heat transfer elements and sealing pieces were kept the same as before. The total upgrade cost of 250,000 RMB was from plant's own funding. b) Coal Pulverizer The used pulverizer is Model RP 783 bowl-Type medium speed mill and its rated capacity is 33.1 tonne/h.	a) Air Heater **Performance improvement** The system reliability improved. Air leakage rate decreased from 20% before upgrade to 10~12%% after upgrade. Currents of Induced Draft Fan motors dropped from 105~110A to below 100A. b) Coal Pulverizer **Performance improvement** After upgrade, the stone-coal discharge decreased by

		Main steam temperature: 537 °C Hot reheat steam temperature: 537 °C; Boiler Type: Tangential, pulverized-coal firing boiler; Turbine Manufacturer: Harbin Turbine Co Ltd; Boiler Manufacturer: Harbin Boiler Co Ltd. Original commercial operation date: 11/1992, 4/1993, 4/1996 and 11/1997 for Unit 1, 2, 3 & 4 respectively.	After years' operation, the edges of milling bowls were worn off about 10-15 mm. The wind ring gap was large and beyond its normal range. It caused air speed decreasing and air moving direction changing at the wind ring. The air carrying capability of coal powder decreased and the coal-air separation efficiency dropped and hence mill performance dropped. At the mean time, coal discharge quantity increased and certain amount of coal was wasted. The mill bowls were modified and 6 pieces of detachable extension ring were added to each bowl to adjust the wind ring gaps to 6~10 mm. The total upgrade cost of 180,000 RMB was from plant's own funding, and each unit cost 30,000 RMB. c) Boiler Burner In the operation, the burner nozzles were deformed due to the poor welding. Burner swing was not smooth and burner nozzles were prone to being damaged due to the high combustion temperature. The original burner nozzles were replaced by casting heat-resistant steel burner nozzles in 2002. The total upgrade cost of 800,000 RMB was from plant's own funding. d) Boiler Soot-blowers All the boiler soot-blowers were upgraded in 2003. No further information was provided. e) Induced Draft Fans The original Induced Draft Fan rotating blades were prone to breaking because the cast aluminum moving blades could not meet the strength requirements. The original rotating blades were replaced by forged aluminum rotating blades in1997.	356.4 Tonne/month. The units have been running since upgrade. c) Boiler Burner **Performance improvement** The whole-body casting steel burner nozzles were well formed and not prone to deforming in the operation. The burners swing smoothly. The units have been running since upgrade. e) Induced Draft Fans **Performance improvement** The ID Fans have been successfully running to present since the cast aluminum moving blades were replaced by the forged aluminum moving blades, and

				the machine reliability increased significantly.
			Turbine Island a) Steam turbine The turbine nozzle stages were upgraded in 2005. No further information was provided.	
			Instrumentation and Control The original control systems used hard wire connections to communicate among each other, and the automatic start-up and shut-down could not be achieved. The control systems could not meet the requirements for peak load operation. The parts were not interchangeable among different systems and numerous spare parts were needed. In 2002 MCS, DAS, DEH, FSSS, SCS and Electric Control Systems were integrated into a uniform DCS platform to increase the automation and control level. At the mean time, the DCS system was integrated with MIS system by making use of the extension capability of XDPS-400 system. The integrated system provided real-time data for office automation, unit status monitoring and power generation economic analysis and hence improved the overall plant management.	**Performance improvement** After the update, all sub-systems used interchangeable parts and hence reduced the quantity of spare parts and maintenance cost. The data can be shared among systems. Automation and control of boiler, turbine and electric system were improved. Unit safety protection system was in full operation. Data acquisition points of DAS system were also fully used. All the systems have been running well since the update.
			Others Two wet FGD systems for 2 x 300-MW units were installed in 2005. Sulfur removal efficiency of 93% was achieved, and tens of thousands of tons of SO_2 were removed annually. Plasma ignition systems were installed for Unit #2 and #3 in early 2007 and 2008 respectively (at cost of 5 millions RMB/unit). 600 tonnes of fuel oil have been saved so far.	

7	Power Plant "B" (Unit #1) (Huadian Power International Corporation Limited)	State owned; Fuel: Bituminous; Fuel LHV: 17200 kJ/kg; Unit No: 1; Design unit capacity at maximum continuous rating (MCR): 335 MW; Original mode of operation: Base load; Current mode of operation: Peak load; Steam cycle parameters: Main steam pressure: 16.7 MPa Main steam temperature: 545 °C Hot reheat steam temperature: 545 °C; Boiler Type: Tangential, pulverized-coal firing boiler; Turbine Manufacturer: Dongfang Steam Turbine Works Boiler Manufacturer: Dongfang Boiler Works; Original commercial operation date: November 1985.	**Boiler Island** a) Air Heater Original air heater had a high air leakage rate. In 2002, the sealing of the air heater was replaced with dual sealing. The total cost of upgrade of 1,500,000 RMB was from plant's own funding. b) Boiler Burner To improve boiler combustion performance at partial load operation, original burners were replaced with Rich-lean burners. c) Boiler Soot-blowers The original infrasonic soot-blowers were replaced with steam soot blowers in 2002. The cost of upgrade, 1,500,000 RMB was from plant's own funding.	a) Air Heater **Performance improvement** The system reliability improved. The air leakage rate decreased from 15% before upgrade to 7% after upgrade. b) Boiler Burner **Performance improvement** The boiler combustion performance at partial load operation was improved. **Issues/problems after the upgrade** The nozzles are easy to wear, and it results in poor combustion performance. c) Boiler Soot-blowers The problem of over-heating of pipe wall was resolved. Boiler gas exiting temperature was significantly reduced.
			Turbine Island a) Steam turbine Steam flow paths for HP, IP and LP turbines were upgraded. Shaft seals and blade & stationary vane sealing were modified. The total upgrade cost of 10,000,000 RMB was from plant's own funding.	a) Steam Turbine **Performance improvement** Turbine heat rate improved by 330 kJ/kWh. **Issues/problems during the upgrade** Capital cost was intensive.

			Instrumentation and Control The plant original control system was upgraded to a DCS system to increase the automation and control level in 2002. A total upgrade cost of 10,000,000 RMB was from plant's own funding.	**Performance improvement** The system coordinated control of the plant was achieved after upgrade.
8	Power Plant "B" (Unit #5) (Huadian Power International Corporation Limited)	State owned; Fuel: Bituminous; Fuel LHV: 19600 kJ/kg; Unit No: 5; Design unit capacity at maximum continuous rating (MCR): 648 MW; Original mode of operation: Base load; Current mode of operation: Peak load; Steam cycle parameters: Main steam pressure: 16.7 MPa Main steam temperature: 541 °C Hot reheat steam temperature: 541 °C; Boiler Type: Wall-fired, pulverized-coal firing boiler; Turbine Manufacturer: Dongfang Steam Turbine Works Boiler Manufacturer: Foster Wheeler;	**Boiler Island** a) Air Heater Original air heater had a high air leakage rate. In 2007, following upgrades were made to the air heater using plant owned finding 1,500,000 RMB: The air heater was modified from 24 cells to 48 cells and a top layer of regenerative surface was added; The sealing gap was adjusted and the sealing was modified to frame adjustment type.	a) Air heater **Performance improvement** The reliability was improved. However the air leakage rate was the same as before. **Issues/problems after the upgrade** Because this was the first 600-MW boiler retrofit, there were some problems of the modification design. The motor electrical load the air heater increased after retrofit, which impacted the unit operation load. Currently we are looking at further modification to resolve the problem.
			Instrumentation and Control The original FSSS was upgraded to a Westinghouse system in 2002 using 1,000,000 RMB plant's own funding.	**Performance improvement** The coordinated control was achieved.

		Original commercial operation date: January 1991.		
9	Fengzheng Power Plant (Unit #1, 2, 3, 4, 5 & 6) (North United Power)	State owned; Fuel: Bituminous; Fuel LHV: 21703 kJ/kg (Unit #1 & 2), Fuel LHV: 21248 kJ/kg (Unit #3, 4, 5 & 6); Design unit capacity at maximum continuous rating (MCR): 200 MW (Unit #1, 2, 3, 4, 5 & 6); Original mode of operation: Peak load (Unit # 1& 2), peak and base load for Unit #3 & 4, base load (Unit #5 & 6); Current mode of operation: Peak load (Unit # 1& 2), peak and base load for Unit # 3&4, base load (Unit #5 & 6); Steam cycle parameters: Main steam pressure: 13.73 MPa Main steam temperature: 540 °C Hot reheat steam temperature: 540 °C; Boiler Type: T-fired, pulverized-coal firing boiler; Turbine Manufacturer: Harbin Turbine Co. Ltd Boiler Manufacturer: Wuhan Boiler Co., Ltd; Original commercial operation	**Boiler Island** a) Air Heaters The air heater structure of Unit #1 & 2 had significant wear. In 2006, the bottom layer structures were replaced with new ones. The upgrade finding of 1,260,000 RMB for each unit was from the plant owner, North United Power. Unit #3 air heater seals had significant wear and were replaced in 2005, and the upgrade cost of 1,260,000 RMB was from the plant owner, North United Power. Unit #5 air heater seals had significant wear and were replaced in 2007, and the upgrade cost of 1,260,000 RMB was from the plant owner, North United Power. b) Induced Draft Fans The Induced Draft Fans of Unit #1, 3 & 5 were upgraded in 2006 2005 and 2007 respectively to meet the increased capacity demand due to replacing the original electrostatic precipitators by new baghouses. The fan impellers were modified. The total upgrade cost of 1,500,000 RMB for each unit was from the plant owner, North United Power (900,000 RMB was used for fan impellers modification and 600,000 RMB was for motor upgrade). c) Burners The burners of Unit #2 & 3 were upgraded in 2007 and 2005 respectively to reduce fuel diesel consumption. The original burner igniters were replaced with oil-saving igniters. The upgrade cost was 1,200,000 RMB for each. For the same reason as stated above, the burners of Unit	**Performance improvement** The air leakage for Unit #3 improved from 30.2/39.8% before to 10.2/9.8% after upgrade. **Issues/problems after the upgrade** The top layer structures of Unit 1 & 2 still have leakage points. The air leakage rate of Unit # 3 air heater is still higher then what we expected. b) Induced Draft Fans The units have been running since upgrades. **Issues/problems after the upgrade** Because the foundation of the machine was not modified corresponding, the vibration of the machine is significant and affects the unit performance for Unit #1. c) Burners Unit #2 has run 2878 hours since upgrade. Unit #3 has run 22105 hours since upgrade, and the excess air ratio decreased from 1.67% to 1.54%. Unit #5 has run 590 hours since the burners were upgraded.

		date are 11/1989 (Unit #1), 12/1990 (Unit #1), 06/1993(Unit #3), 12/1993(Unit #4), 02/1995 (Unit #5) and 12/1995 (Unit #6).	#5 were replaced at the cost of 1,200,000 RMB from North United Power.	
			Turbine Island a) Steam turbine The flow paths of Unit # 1, 2 LP steam turbines were modified to improve the efficiency before 1997. It has been running 91177 and 97079 hours respectively for Unit # 1 & 2 since upgrade. An unidentified amount of funding was from the plant owner, North United Power. In 2007 the steam flow paths of HP, IP and LP turbines of Unit #5 & 6 were modified to improve the turbine efficiency. The shaft seal and blade & stationary vane seal were also upgraded. The total upgrade cost was 19,800,000 RMB from North United Power for each unit.	Unit # 6 has operated around 24066 hours since upgrade.
			Others The original electrostatic precipitators of Unit 1, 3 & 5 were replaced with baghouses. The cost was 14,960,000, 14,980,000 and 14,960,000 RMB for each unit.	**Performance improvement** The solid concentration at the baghouse exit after replacement was 41.8 mg/Nm^3 and 41.9 for Unit #1 and 3 respectively. The solid removal efficiency for each unit increased to 99.8%. For Unit #5, the solid concentration at the baghouse exit after upgrade was 21.8 mg/Nm^3 and the solid removal efficiency increased to 99.9%.
10	Power Plant "C"	State owned; Fuel: Bituminous Coal; Fuel LHV: 20390 kJ/kg (Unit #1 & 2), Unit No: 1 & 2; Design unit capacity at maximum continuous rating (MCR): 600 MW; Steam cycle parameters:	**Instrumentation and Control** Unit #1: The original coordinated control system was out of date and it was difficult to find the spare parts. In 2000 the original system was replaced with FOXBO I/A DCS System. The cost of upgrade was 50,000,000 RMB plant's own funding. Unit #1 & 2: In 2000, original DEH system of Unit #1 was upgraded	Unit #1 **Performance improvement** The responding of the new control system was faster than the original one. The system is easier to be modularized.

		Main steam pressure: 17.26 MPa Main steam temperature: 540 °C Hot reheat steam temperature: 540 °C; Boiler Type: Tangential, pulverized-coal firing boiler; Turbine Manufacturer: Harbin Steam Turbine Co Ltd; Boiler Manufacturer: Harbin Boiler Co Ltd. Original commercial operation date for Unit #1 & 2 is September 1989 and 1993 respectively.	from a Westinghouse system to a Xinghua System. Unit # 2: The malfunctions occurred often for the manual operation of original control system. It was difficult to find the spare parts for the system. In 2005 the original system was replaced with a DCS System. The cost of upgrade was 50,000,000 RMB plant's own funding.	Unit #2 **Performance improvement** The system is easier to be modularized, and the control logic is easier to be modified.
			Boiler Island a) Soot-blower Unit #1 & 2: In 2000 an acetylene gas pulse type soot-blowing system for the air heater was added to. The original steam soot-blowing system was still kept. The upgrade cost was 500,000 RMB. b) Air heater Unit #2: In 2005, the original air heater was replaced by a new Howden air heater due to the high air leakage. The total cost of the upgrade was 20,000,000 RMB from government funding. c) Pulverizer Unit #2: The original spring loading systems for the medium speed bowl-Type mills were replaced by hydraulic loading systems. The mills were not modified. d) Burner Unit #2: Secondary air baffles of the boiler did not synchronize during the operation. The original baffles were modified to achieve low-NOx combustion.	b) Air heater Unit #2: **Performance improvement** The air leakage rate decreased from 11% before upgrade to 7% after upgrade. The reliability increased. The operating time after the upgrade is 30,000 hours. **Issues/problems after the upgrade** The heat expansion due to the temperature and unit load was high, and once caused a unit trip because some portion of the air heater was cooled by the rain. Some measures were taken and the operation became normal. **Performance improvement** The pulverizer capacity increased by 20%. **Issues/problems after the upgrade** Hydraulic system oil leakage occurred. d) Burner Unit #2: **Performance improvement** The boiler excess air ratio decreased. The NOx emission reduced by 10 ppmv @ 4% O_2. Average annual maintenance cost reduction was 100,000 RMB.
			Turbine Island a) Steam turbine	a) Steam turbine

			Unit # 2 The flow paths of HP, IP and LP turbines, the blade & stationary vane sealing, shaft seal and 1st stage blade were modified. The total cost of upgrade was 60,000,000 RMB plant's own funding.	Unit #2: **Performance improvement** The turbine heat rate improved by 180 kJ/kWh. **Issues/problems after the upgrade** Bearings' temperature and vibration increased.
11	Pagbilao Power Plant (Unit # 1) (TEAM Energy Corporation)	Private Company; Fuel: Sub-bituminous Coal; Fuel HHV: 25000-26,000 kJ/kg (Unit #1), Unit No: 1; Design unit capacity at maximum continuous rating (MCR): 385 MW; Original mode of operation: Base load for Unit #1 & 2); Current mode of operation: Shift load (Unit # 1 & 2); Steam cycle parameters: Main steam pressure: 17.26 MPa Main steam temperature: 541 °C Hot reheat steam temperature: 541 °C; Boiler Type: pulverized-coal firing boiler; Turbine Manufacturer: MHI; Boiler Manufacturer: MHI. Original commercial operation date for Unit #1 is June 1996 and 1993 respectively.	**Boiler Island** a) Air heater Unit #1 & 2: In 2004, because of frequent high differential pressure (clogging) the Air-Heater hot element was changed from DU-MHI to DU-Korea; Intermediate element was changed from SNF-MHI to 50% SNF-MHI and 50% Korea. The upgrade used un=identified amount of plant's own funding. b) Coal Pulverizer (MVM24F/Roller, 44.9 tonne/hr) Unit #1&2: In 2006, to minimize table liner wear, the table liner hard surface overlay was applied. Roller tire replacement from MHI Tire to Firth Rixson Casted. Y-2000 c) Burners Unit #1 & 2: In 2002 to improve air flow, burner tip was replaced with airopit design using plant's own funding.	a) Air heater Total operating hours after upgrade is 24,720 hrs. No measured performance data available. b) Coal Pulverizer Total operating hour is 10,474 hours after upgrade.
			Instrumentation and Control Unit #1 & 2: Due to obsolescent and reliability issue, Unit - 2 and Unit 1 were upgraded from WDPF & DIASYS to Ovation Expert Control system in 2004 and 2006 respectively.	Total operating hours after upgrade is 15,648 respectively. Fro each unit **Performance improved:** Enhanced reliability; Flexibility of data presentation; Availability date transfer to other system via OPC. **Problem and issues during implementation of upgrade:**

				Effort in Loop checking & function test of each I/O's fro accuracy. No significant operating problems and issues after upgrade.

Note: 1) Per requirement by information some providers, some plant names are not exposed in this table and Plant "A","B" or "C" are used instead.

2) All the information in the response from the information providers are presented in this table.

Appendix 3: A Best Practice Guide for Developing APEC Economies

<table>
<tr><td rowspan="2">BEST PRACTICE GUIDE FOR DEVELOPING APEC ECONOMIES AS DERIVED FROM LESSONS LEARNED IN REFURBISHING COAL-FIRED POWER PLANTS
Issuing Organization:</td><td colspan="2">Document No.</td></tr>
<tr><td>Issue Date</td><td></td></tr>
<tr><td>Contents:
1) Purpose
2) Introduction
3) Strategic Guidelines
4) Note to Users
5) Best Practice Guide Outline
6) Best Practice Guide Activities (Annotated)
7) Discussions – Elaborations</td><td colspan="2">Prepared by:</td></tr>
<tr><td colspan="3">Section 1) Purpose
The purpose of this document is to set a simple road map or guideline to be used as reference in planning for the refurbishment and upgrades of old coal-fired power plants located in APEC developing economies. Included in this document are suggestions on decision-making in finding the best course of action pertaining to the upkeep of existing units as well as methods of determining the proper timing of refurbishment and upgrade.</td></tr>
<tr><td colspan="3">Section 2) Introduction

The following is a set of guidelines issued as an Appendix 3 to the Asia-Pacific Economic Cooperation (APEC) Study Report entitled Lessons Learned in Upgrading and Refurbishing Older Coal-Fired Power Plants – A Best Practice Guide for Developing APEC Economies (EWG 05/2007). This report is released as an outcome of a study conducted by the WorleyParsons Group under the supervision of and in collaboration with the Expert Group on Clean Fossil Energy (EGCFE) under the APEC Energy Working Group (EWG).</td></tr>
<tr><td colspan="3">Section 3) Strategic Guidelines</td></tr>
</table>

a) Users of this document should refer its contents to the mission and long-term objectives of his/her own organization and seek compatibility of this document with those missions and long-term objectives. As an example to note: perhaps, this information would not serve much and render justice to time spent if the reader's organization is primarily engaged in buying and selling bulk power and not involved in actual generation. Similarly, players in the power generation field, who are focused on the renewable energy sector, may not find this piece of guideline significantly relevant to their field of interest. b) The user of this document may look at this guideline only as an additional piece of information on top of what has been generated internally by within respective organizations. As an example, in the area of planning and decision-making, users are advised to rely first on their own corporate plans, which are more specific to their cases, before taking the more generic approach provided herein. Outside references such as this guideline may be used only as a reminder or counter-check material. c) For users based and operating within APEC developing economies, they are reminded that there can be faster changes in regulatory provisions now than it used to be; therefore, they are advised to constantly refer to their respective government's regulatory legislations, policies, provisions and restrictions in order to ensure that loopholes and shortfalls are fully covered.
Section 4) Note to Users
It is presumed that parties who will refer to this piece of work would consider this as an instrument, which is relevant to their field of interest. Therefore, the user is expected to be appreciative of or familiar with either top management power utility planning or with plant site situations, or both. The premised situation of application for this piece of work is an environment suited for developing economies within the APEC region, but parties outside of the region may find this document applicable to their own situation. There can be a great span of commonalities between developing APEC economies and the rest of the of the world in so far as coal-based power generation is concerned. On this regard, every reader is invited to take the information herein given as a recommendatory piece of advice. Likewise, the reader is welcome to give reactions and share opinions in order to make this document reflective of as many situations there are as possible.
Section 5) Best Practice Guide Outline
This ***Best Practice Guide*** will present a broader look at the generating asset management of coal-fired generating power plants. This approach can be applied whether the interested party is an upstart or a long time player in the industry; whether the interested party is an owner or manager of a single site or a fleet of coal-fired power generators spread in multiple sites. In view of this wider approach, this document will present the best practice guideline from the point of upkeep and monitoring of plant conditions up to the point of deciding upgrades/refurbishments.
Summarily, this approach will proceed as follows:
• Benchmarking and Record-Keeping
• Strict and Regular Calibration of Instrumentation
• Daily Performance Monitoring
• Periodic Performance Evaluation/Audit
• Condition Monitoring Practices
• Remaining Life Assessment Efforts
• Options for Generating Capacity Replenishments
• Choosing Refurbishment and Upgrade Options

• Lessons Learned from Actual Cases of Upgrades and Refurbishments	
• Benefits recorded from Actual Cases of Upgrades and Refurbishments	
• Best Practice Guide for Future Upgrade and Refurbishment Activities	
Section 6) Best Practice Guide Activities (Annotated)	
Activity	**Annotations**
Benchmarking and Record-Keeping	This involves what everybody seems to be doing but is not necessarily keeping in strict adherence to initial plans. The most important aspect in this activity is to keep original and verified data about equipment capacity test records, heat balance values, etc. and continuing to compile daily data logging of information in a historical archive for future use and review.
Strict and Regular Calibration of Instrumentation	Plant instrumentation, need to have strict routine of calibration schedules. Flowmeters and other components of metering systems can have signals drifting from accuracy spans over time. Accuracy of instrumentation is very important in keeping tract of efficiency and maintaining plant reliability.
Daily Performance Monitoring	Some plants have installed continuous Data Logging Systems as part of Data Acquisition System (DAS) modernization of older units; if not automated, data logging by operators on log sheets are as valuable as electronic recording.
Periodic Performance Evaluation/Audit	This is a common practice of large utility companies and normally conducted by a special group which can be in-house or contractual type of activities. Results Engineering Units usually do this activity on a monthly, bi-monthly or quarterly basis, depending on the program set by the company. Usual parameters audited are unit heat rates and efficiencies.
Condition Monitoring Practices	Condition monitoring is now built into online instrumentation but some companies do back it up with activities done by personnel and staff working under preventive and predictive maintenance groups or units. Usual monitored parameters are equipment vibration levels, heat emission, pressure and temperature excursions, gage thickness readings of pipes and pressure vessels, sound levels, etc. Continuous Emission Monitoring Systems (CEMS) and programs are specialized concerns dedicated to pollution control.
Remaining or Remanent Life Assessment Activities	The key ingredient in plant life extension is remaining life extension technology. There is a vast array of methods available for the assessment of remaining life in power plant steels. Remaining life assessment offers a tool to estimate the useful remaining lifetime and avoid premature scrapping of the equipment, component or part.
Options for Generating Capacity	This is a top corporate-level decision to make. Management can have several options to use including a special committee formation and can be an important topic for board of director's discussions. However, the result of this effort could spell the difference between keeping retireable old power plants; ergo, upgrading and extending their useful lives, or scrapping them in

Replenishment	lieu of brand new modern units .
Choosing Refurbishment and Upgrade Options	This step shall be required only if it would turn out after a thorough feasibility and economic study that the best corporate option would be to extend the life of the generating unit(s); possibly so, a unit which is still several years from end of design life may require refurbishment to bring back operating efficiency to economically viable levels or to correct reliability that has suffered because of a component degradation. Discussed and elaborated in Section 7.
Lessons Learned from Actual Cases of Upgrades and Refurbishments	These lessons are discussed and elaborated under Section 7.
Benefits recorded from Actual Cases of Upgrades and Refurbishments	These benefits are discussed and elaborated under Section 7.
Best Practice Guide for Future Upgrade and Refurbishment Activities	This guide becomes the summary and highlights of the steps mentioned in this document. Discussed and elaborated in the following Section 7.
Section 7) Discussions – Elaborations	
Choosing Refurbishment and Upgrade Options Refurbishment/upgrade options follow after owner's decision to bring back conditions and/or performance of power generating units back to economically acceptable levels. This may be required of a unit long before the expected end of its design life but has degraded prematurely, or it may be applied to a unit which has gone past its expected design life, but the owners would prefer to have it run for a number of years more for economic reasons.	
Screening tools or decision-making aids usually utilized to choose the best option are:	
I. Quantitative Screening Methods	There are various ways of quantifying bottom-line figures in financial and economic terms to come up with the best choices. To name a few:
a) Levelized Life Cycle Cost of Electricity	The levelized costs can be interpreted as a constant level of revenue necessary each year to recover all the expenses over the life of a power plant. Levelized cost of any power plant is a function of all the fixed and varying annual costs (capital, O&M, and fuel). By this definition, it makes this evaluation tool a bit difficult to use for a refurbishment project which only affects a portion of a power plant that has been depreciated for a major portion of its service life.

b) Discounted Cash Flow Rate of Return	A valuation method used to estimate the attractiveness of an investment opportunity. Discounted cash flow (DCF) analysis uses future free cash flow projections and discounts them (most often using the weighted average cost of capital) to arrive at a present value, which is used to evaluate the potential for investment. If the value arrived at through DCF analysis is higher than the current cost of the investment, the opportunity may be a good one. Calculated as: $DCF = \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \ldots + \frac{CF_n}{(1+r)^n}$ CF = Cash Flow r = discount rate (WACC)
c) Internal Rate of Return (IRR)	The discount rate often used in capital budgeting that makes net present value of all cash flows from a particular project equal to zero. Generally speaking, the higher a project's internal rate of return, the more desirable it is to undertake the project. As such, IRR can be used to rank several prospective projects a power utility company is considering. Assuming all other factors are equal among the various options, the option with the highest IRR will be chosen. IRR is sometimes referred to as the Economic Rate of Return (ERR)
d) Return of Investment (ROI)	It is a performance measure that is used to evaluate the efficiency of an investment or to compare the efficiency of a number of options or projects. To calculate ROI, the benefit (return) of an investment is divided by the cost of the investment, the result being expressible as a ratio or percentage.
II. Qualitative Screening Methods	Just like the Quantitative Screening method, there are also several options to utilize in picking for the best option of a specific project. This aspect of the selection process is specially fit for choosing the best make, type, model or specifications should be chosen among options for a certain application, equipment or component, which management has decided to upgrade or refurbish.
a) The Kepner-Tregoe (Technique)	A decision-making tool developed by Charles S. Kepner and Benjamin B. Tregoe in the 1960's. Commonly referred to as the 'KT Process', it involves the creation of structured, systematic processes, which are used to maximize the critical thinking skills of key stakeholders in a particular situation, project decision or opportunity. The Decision Analysis KT tool is a systematic

Decision Making Analysis	process for making a balanced choice. On the other hand, another KT tool, the Potential Problem (or Opportunity) Analysis tool, is a systematic process for protecting an action or a plan.
b) The Analytic Hierarchy Process	Introduced by Thomas L. Saaty, this concept of decision-making structures a problem as a hierarchy. This is then followed by a process of prioritization.
c) Grid Analysis	This tool is suitable for making a choice (such as choosing the best air heater replacement make/model) where many factors and options must be considered. It is particularly powerful when there are a number of good alternatives to choose from and many different factors to take into account. This tool serves effectively where there is no single clear and preferred option.
d) Paired Comparison Analysis	This screening tool can help one to work out the importance of a number of options relative to each other. Paired comparison analysis helps to set priorities where there are conflicting demands on resources. It is also an important tool for comparing completely different options, such as whether to use limited funds to upgrade Distributed Control Systems, the Air Heaters, or Sootblowers in a Coal-based Power Plant.
Lessons Learned from Actual Cases of Upgrades and Refurbishments	
• Air Heater Replacements	There were cases noted in this study when the rates of air leakage have remained unchanged after the replacement or upgrade. (Power Plant 'B" Unit 5)
	In some cases, leakage has progressed over time after retrofit.
	It was difficult to disassemble the gear transmission system.
	The motor electrical load of the air heater increased after the retrofit, which impacted on the unit operation load.
	The top layer structures on some units still have leakage points.
	The thermal expansion was high and once caused a unit trip, because some portion of the air heater was cooled by the rain causing thermal distortion; Measures were taken and operation became normal.
• Burners	unstable combustion issue still remained after the upgrade
	the nozzles wear easily resulting in poor combustion performance

• Sootblowers	the improvement of sootblowing performance was not significant (not as expected
	Compressed air is leaking on valves
• Steam Turbine	The cooling system for the generator had to be modified accordingly
	the cooling time of the turbine cylinders increased after shutdown
	Capital cost was assessed later as intensive relative to benefits
	Bearing temperature and vibrations increased after upgrade
• Pulverizer	Hydraulic system oil leakage occurred
• Induced Draft Fans	Because the foundation of the machine was not modified correspondingly, the vibration of the machine was significantly high and that affected the performance of the power generating unit.
• DCS System	Vendor lacks reliable and on time support
	some parts used in the retrofit are near obsolescent stage
	A new DCS system requires high quality of input signals; some signals in the old system did not use shielded cables. Consequently, A large number of cables were replaced
	Modules of the new DCS system were prone to be broken
Benefits recorded from Actual Cases of Upgrades and Refurbishments	
Air Heater Replacements	Air leakages have reduced in the cases of Hangzhou Plant Unit 4, HuBei Hanxin Plant Unit 2, NanChang Power Plant Units 10 & 11, Taizhou Power Plant Unit 2, Power Plant ‘A’ Unit 1, Guangzhou Zhujiang Units 1 – 4, Power Plant ‘B” Unit 1, Fengzheng Power Plant Units 1&2, Power Plant ‘C’ Unit 2.

Burners	Upgrade allowed the operation of ESP during the start-ups and part load operations.(Hangzhou Banshan); excess air ratio decreased from 6.5% to 5% and boiler efficiency increased by 2% (NanChang Power Plant Units 10 &11); the whole-body cast steel burner nozzles were well formed and not formed to deforming during operation; now swinging smoothly (Guangzhou Zhujiang Units 1 – 4); Boiler combustion performance at partial load improved (Power Plant 'B' Unit 1); Boiler excess air ratio was decreased; NOx emission reduced by 10 ppmv@4%O2; Avg. Maint. Cost reduction = Y100,000 (Power Plant 'C' Unit 2).
Sootblowers	Total boiler efficiency was improved (HuBei Hanxin Plant Unit 2); Boiler tube failures decreased (Power Plant 'A' Unit 1); Problem of overheating pipe wall resolved. boiler gas exit temperature was significantly reduced (Power Plant 'B' Unit 1)
Steam Turbine	Turbine heat rate improved substantially in some cases; in other cases, improvement was not as much. Heat rate gains vary from a few kJ/kWh to hundreds of kJ/kWh.
Pulverizer	Pulverizer capacity increased by 20% in one case; in another case, it was merely stated that wastage of coal has dropped significantly.
Induced Draft Fans	Frequent fan failures (poor reliability) were fixed by replacing the fan blades with sturdier blade material.
Instrument & Control / DCS System	A lot of improvement was noted in the instrument and Control Area. To mention some of these were: Improved automation, faster unit responses, coordination and integration of a networked control system, modular architecture promotes flexibility and quicker modification and a reduction in parts inventory due to commonality of spare items.

BEST PRACTICE GUIDE (for Future Coal-based Power Plant Upgrade and Refurbishment Activities)	
Coal Pulverizers	(a) Calculate the loading capacity of each component of a new hydraulic system and compare each component's capacity to expected maximum loads at specific points in the support system. (b) Additionally, new pulverizer support specifications need to be reviewed thoroughly before actual installation, including hydraulic oil chemical and mechanical properties, especially hydraulic oil stability over time and under constant stress (c) Pressure-test (using same hydraulic oil) the support system components, including connecting tubing and valves under a test pressure which is 150% of rated load at its support. (d) Lastly, in cases where a hydraulic support system replaces a spring support system, a hydraulic relief mechanism should be provided to allow for thermal expansion of both system oil and supported load. The original spring supports, apart from its main function of supporting the pulverizer, did have dual extra functions, which is partly absorbing structural vibration and thermal expansion (minimal it may be) of the pulverizer unit.

	Hard surface overlay is considered a best practice, although a stop-gap solution to counter the effects of wear and tear on pulverizer table liners.
Air Heaters	Plant owner should first verify the performance of the new replacement units (in this particular case, the air heater), through research or from inquiry from those who are identified as earlier users of said component.
	The root cause of the problem must be identified first prior to deciding an upgrade. Perhaps the inherent position, location, thermal expansion provisions or support system is inadequate. Another issue is a thorough review of the material specifications to be used in the replacement unit.
	As much as possible, a complete set of air heater assembly shall be installed at a single plant shutdown for whatever purpose. It would save both time and effort, if installation is well planned with proper logistics.
	Ensure that in-house plant maintenance personnel are well trained to handle newly acquired/installed plant components. During the process of buying the new equipment, vendor should be asked, and it should be stated in the purchase order contract, to provide the plant with special repair tools, necessary maintenance spare parts, technical, operating and maintenance manuals, etc. The plant should make sure that vendor provides a locally accessible after-sales field support.
	Keep close monitoring of leakages and motor loads and be mindful for the best timing to act on refurbishment of aging equipment
	The original equipment manufacturer (OEM) can be consulted to look at the situation and have the power plant in-house project engineering staff coordinate with the OEM. Otherwise, a private engineering consultancy with the right expertise to look at the problem can be consulted. [Note: The increase in the air heater motor electrical load is a logical outcome to increasing the rotating mass of the air heater.]
	Ensure to protect high-temperature materials (especially metallic rotating parts) of operating plant equipment from weather elements that can cause uneven thermal movements/distortion during operations. Insulate plant sections properly where needed.
	It is best to include in the purchase/procurement requests that, if possible, testing for the integrity and performance of ordered equipment be accomplished in both bench scale (rig test) and full scale runs and must be witnessed by a representative of the buyer or a designated group to oversee the testing itself.
	Ensure that during the acceptance test, results are fully meeting contract performance guarantees. Retraining of operators in tuning up the newly installed burners is an important step to take.

Boiler Burners	Specify from the start, burner parts and components that can withstand the severe conditions these parts will be subjected to in service.
	Find the root cause of every problem; refer the problem to the OEM, to an independent consultant or an in-house engineering staff, if in-house engineering is fully equipped and qualified to conduct the kind of investigation required in a particular problem.
Burner Ignitors	Always have a boiler burner bench or rig test trial conducted before a new system or design is brought to mainstream use.
Induced Draft Fans	Make use of less rigid fan-motor connection whenever possible.
	Always use/specify materials that best match with service requirements. For example, given the same basic material chemical compositions and dimensions, tougher components such as forgings are preferable over castings, in applications that are prone to fatigue failure. In the same token, stainless steel should be selected vs. plain carbon steel for corrosive service application.
	Whenever, new and heavier weights (masses) are added into an existing equipment, especially on one which has a rotating part, such as a fan or pump, the foundation requirement should always be recalculated and modified if the existing foundation is found inadequate as shown by calculation results.
Boiler Sootblowers	All new equipment or part must be exercised and utilized according to their design and purpose. Not using them could eventually lead to early failure.
	Piping handling compressed air, or any other gases or liquids at the plant (in this case used for sootblowing), should preferably be subjected to pressure tests (hydro or pneumatic) to a test pressure of 150% of the system design working pressure.
Steam Turbines	In major steam turbine upgrades, it is best to provide an overall approach in the work to be undertaken. Such should be done in any kind of refurbishment work, where practically all sections of the turbine from the governing stage of the HP turbine, the IP turbine stages and down to the LP stages, and other critical parts were changed and retrofitted.
	Always refer to the nameplate rating of the generator before enhancing load generating capacity. Enhancement of capacity on one part of the assembly or system could shift the burden to the next weaker part of the system.
	The plant shall do the following standard practice procedures before start-up (a) Consult the steam turbine OEM about the impact of replacing some components of the original turbine on the bearing capabilities, i.e., specs and so forth (b) The new turbine rotor and casing/sealing clearances must be checked against original, as well as, turbine OEM recommended new values, if any (c) The natural frequencies, including

	the 1st, 2nd, and 3rd critical, need to be verified if affected by the steam flow path modification (d) The new upgraded rotor needs to undergo thorough balancing, especially the dynamic balancing required during the commissioning phase after upgrade shutdown.
	Grab the opportunity of any additional capacity that can be obtained from a steam turbine retrofit, but ensure that running the plant at the augmented capacity would not exceed the design heat and mass balance limits of the system.
	For older steam turbine-generators which are no longer assigned for base-load duties, partial-arc or sequential valve governing capability would be a good feature provided to them.
Surface Condensers	On surface condensers, carefully screen and evaluate specifications of all original (for new construction) and replacement units (for retrofits and upgrades). It is best to use reliable industry standards as guideline documents in specifying and ordering power plant equipment.
	Conduct a life assessment inspection on the condenser to anticipate the remaining life of the condenser. The Heat Exchange Institute (HEI) in their earlier publications, mentioned an upper limit of 10% of the total number of condenser tubes that can be plugged, below of which the condenser can still continue to operate without impacting on the turbine performance.
	The best approach to instrumentation and control upgrade is to study the options carefully. The OEM and vendor/supplier should be selected very carefully and a proven background of excellent service verified. Most companies have stringent pre-qualification processes to screen out undesirables. However, of equal importance is the system to use in the upgrade itself. How compatible is it with the controlled hardware and equipment? How balanced are the components in terms of technology maturity? The following should be preferably sought: (a) quickness of response to service calls / proximity to the plant of an OEM's representative (a locally –based dealer, as an example or a field service engineer), (b) Parts commonality (c) Excellent OEM's back-up for training of plant personnel (d) Calibration support
	A shift to a later generation of control and instrumentation architecture and philosophy requires new methods of protection and signal transfer. The new industry standard of instrumentation & control along with the manufacturer's recommendation should be followed accordingly.
	Management, information, instrumentation and control integration in a power plant is a tricky thing to handle. If a single provider can be dealt with by the plant, it would be best. However, there are providers who are best in their own fields, but preferably there should be chosen a minimum number, if not a single lead Supervisory Control and Data Acquisition System (SCADA), MIS and DCS providers with their subsystems working compatibly and harmoniously among one another into one integrated plant management system.
Instrumentation and	Always choose products which have proven field performance record; this is especially true to state-of-the-art products, which are one of the

Control /DCS	most dynamic products/services in the power industry. For newly established brand names, always ask for proof of satisfactory performance, such as field test results, product standard certifications, and company background. A demonstration product run/field testing should be most welcome, if offered by the prospective supplier without strings attached.
Flue Gas Desulphurization	It is a good practice to be one step ahead in preparation for stricter implementation of emission control regulations. Utilize turn-around or Test & Inspection (T&I) shutdowns as an opportunity to install FGD and other pollution control components in the plant.
	Follow regulations on emissions strictly and on a timely manner. Being ordered to halt operations, even momentarily can damaged both revenues and goodwill.
Reheater	For superheater or reheater upgrade works (1) Always use a shop-welded transition piece (or safe-ends) whenever dissimilar metal welds are used (2) Include in an upgrade project a degradable part of an assembly which might be very difficult to access later due to the installation of the current upgrade.
Steam Coil Air Heater	As much as possible, an upgrade should introduce an improvement over the original or previous equipment; be it in the form of an improved design or a superior material.
Reheat Desuperheater	It is a best practice reaction to act immediately on critical matters especially on issues that affect personnel safety and well being. Traceability on the records of purchased items is a very important feature of every power plant material. Ideally, plant material records should be traceable back to their sources, i.e., from their individual heats/batches (in case of steel products) complete with inspection and test results.
Electro-Hydraulic Control Fluid Polishing	Utilize plant resources fully; recycle items where they can still serve effectively in a different and less severe application.
Desalination Plant	Try all possible and acceptable, yet most practical and economical option to meet upgrade and refurbishment work. If their pricing becomes too prohibitive, it may not always be the best option to go back to the original OEM's in upgrading plant equipment/components, except perhaps on major ones like turbines, surface condensers, and steam generators.

Appendix 4: Sample DCFROR Calculation Sheet

Hangzhou Banshan PP U# 4

	Net Present Value of CashFlows=		37	This value must approach ZERO		$ 428571	Air Heater	
	Discounted Cash Flow Rate of Return					$ 214286	Boiler Burner	
1a	**or DCFROR =**		**19.75%**			$ 285714	Sootblower	
1b	**Payback =**	**4.76**	years			$ 2657143	Turbine	
2	Gen. Cap.=	125	MW		Investment =	$ **3,585,714**		
3	Cap.Factor=	0.7						
4	Boiler Eff.=	0.9			Add. Annual Maint./Upkeep=	$ 358,571	Based on Turbine Upgrade Cost	
5	Yr. Hrs.=	8760	hours			% 10.00%	Percentage of Upgrade Cost	
6	kWh =	766500000	kWh/year	2 x 3 x 5 x 1000				
						(Fuel Savings) 5-Year Average =	753,458	
7	THR Save=	**425**	BTU/kWh					
8	Corr. HR =	472	BTU/kWh	7 x 4				
9	Savings(H)=	361,958	mmBTU	(6 x 8)/1000000				
10	Fuel Price=	**2**	$/mmBTU ==============>		Coal Price Adjustment =	**4.19**	$/mmBTU <==>	2008 coal price adjustment
11	Savings($)=	723,917	U.S. $/year	8 x 9	Savings Adjustment =	1,516,605	U.S. $/year <=>	2008 coal price adjustment
12	Inflation =	2%	% per year					

	Year	NPV Adjustment Factor	Cash Outflow Present Value	CASH OUTFLOW Amount ($)	CASH OUTFLOW Cash Flow Description	Cash Inflow Present Value	CASH INFLOW Amount ($)	CASH INFLOW Cash Flow Description	Inflation Adjustment Factor	Uninflated Cash Inflow	Restart
2000	0	1.00000	3,585,714	3,585,714	Initial Investment	723,917	723,917	Savings based on $2/mmBTU	1.000	723,917	
2001	1	1.19751	299,431	358571	Annual O&M of Upgrade	616,609	738,395	w/fuel price 2% vs. prior year	1.020	723,917	
2002	2	1.43403	250,045	358571	Annual O&M of Upgrade	525,207	753,163	w/fuel price 2% vs. prior year	1.040	723,917	
2003	3	1.71727	208,804	358571	Annual O&M of Upgrade	447,354	768,226	w/fuel price 2% vs. prior year	1.061	723,917	
2004	4	2.05644	174,365	358571	Annual O&M of Upgrade	381,042	783,591	w/fuel price 2% vs. prior year	1.082	723,917	
2005	5	2.46261	145,606	358571	Annual O&M of Upgrade	324,559	799,262	w/fuel price 2% vs. prior year	1.104	723,917	
2006	6	2.94900	121,591	358571	Annual O&M of Upgrade	276,449	815,248	w/fuel price 2% vs. prior year	1.126	723,917	
2007	7	3.53146	101,536	358571	Annual O&M of Upgrade	235,470	831,553	w/fuel price 2% vs. prior year	1.149	723,917	
2008	8	4.22896	84,790	358571	Annual O&M of Upgrade	358,624	1,516,605	Savings based on $4.19/mmBTU	1.000	1,516,605	0
2009	9	5.06422	70,805	358571	Annual O&M of Upgrade	305,464	1,546,938	w/fuel price 2% vs. prior year	1.020	1,516,605	1
2010	10	6.06445	59,127	358571	Annual O&M of Upgrade	260,185	1,577,876	w/fuel price 2% vs. prior year	1.040	1,516,605	2
2011	11	7.26224	49,375	358571	Annual O&M of Upgrade	221,617	1,609,434	w/fuel price 2% vs. prior year	1.061	1,516,605	3
2012	12	8.69661	41,231	358571	Annual O&M of Upgrade	188,766	1,641,622	w/fuel price 2% vs. prior year	1.082	1,516,605	4
2013	13	10.41427	34,431	358571	Annual O&M of Upgrade	160,785	1,674,455	w/fuel price 2% vs. prior year	1.104	1,516,605	5
2014	14	12.47120	28,752	358571	Annual O&M of Upgrade	136,951	1,707,944	w/fuel price 2% vs. prior year	1.126	1,516,605	6
2015	15	14.93438	24,010	358571	Annual O&M of Upgrade	116,650	1,742,103	w/fuel price 2% vs. prior year	1.149	1,516,605	7
			5,279,611		<=== Total Outflow ($)	5,279,648		<=== Total Inflow ($)			