# ASEAN CLEAN COAL TECHNOLOGY (CCT) HANDBOOK

# FOR POWER PLANT

Ver. 2

ASEAN CENTRE FOR ENERGY

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| | |
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## Foreword

The 34th ASEAN Ministers on Energy Meeting (AMEM), which was held in September 2016 in Kuala Lumpur, Malaysia, emphasised ASEAN's key strategy regarding the Coal and Clean Coal Technology (CCT) Programme under the ASEAN Plan of Action for Energy Cooperation 2016-2025; to enhance the image of coal in ASEAN. In this regard, the Ministers noted the planned activities of the ASEAN Forum on Coal (AFOC) among others, to undertake cooperative activities to enhance knowledge and information sharing on carbon capture and storage (CCS), capacity building in CCT and activities to enhance the image of coal in the light of global environmental concerns. The Ministers were also informed of AFOC's plans to undertake a feasibility study and demonstration project for a CCT facility with the involvement of DPs, IOs and the private sector, to develop a joint policy research paper on coal, and institutional and human capacity building in the ASEAN coal sector. The Ministers emphasised the importance of continued efforts towards increasing the uptake of clean energy technology in the region and the continued strengthening of cooperation with DPs and IOs and the private sector to this end. The Ministers look forward to the development of both the concept and the study itself, to identify and establish an ASEAN Coal Centre of Excellence, as well as to establish a fully functioning ASEAN Coal Database and Information System.

Similarly, the 13th ASEAN Ministers on Energy Meeting Plus Three (China, Japan, Korea) that was held in September 2016 in Nay Pyi Taw, Myanmar recognised that coal continues to be a major fuel source in the region. The Ministers reiterated their collective call to increase efforts to develop partnership programmes, continue public financial support for new coal-fired power plants, and promote policies for clean coal technologies (CCT) including high-efficiency coal-fired power generation. These efforts, collectively, will contribute to energy security and the reduction of GHG emissions, the upgrading of low rank coal technologies, and coal gasification/liquefaction, and also develop the industry in the region.

Coal is expected to play a greater role in the energy security of the ASEAN Member States. It has the fastest demand growth in the power generation sector amongst the ASEAN Member States, notably, in Indonesia, Malaysia, Philippines, Thailand, and Vietnam.

One of the planned activities of AFOC in 2017, is the development of an ASEAN Clean Coal Technology (CCT) Handbook for Power Plants - Version 2. The handbook is a collaborative partnership between the ASEAN Centre for Energy (ACE) and the Japan Coal Energy Center (JCOAL) in cooperation with the ASEAN Forum on Coal (AFOC). As a sequel to the first handbook released in 2014, the 2nd version of the handbook aims to provide a deeper insight and updated information on the status and plans of the AMS concerning the promotion and opportunities for the deployment of coal and clean coal technology, while also detailing the best practices and trends in CCT application and development in Japan that may also find suitable application in the AMS. The current handbook consists of two (2) parts, namely: i) Policy Chapter; and ii) Technology Chapter. The Policy Chapter provides the latest information about AMS CCT policies, status, and development plans. Led by ACE, the information in this chapter was distilled from various sources such as capacity building workshops on CCT in 2016, government websites, and AFOC Focal Points. On the other hand, the Technology Chapter (Chapter III and Chapter IV) is designed to serve as an updated technical reference, by providing ideas and insights to relevant policy makers, as well as utility officers and engineers of the AMS. It also covers coal-fired power plant systems, Japan's experiences in pursuing better environmental management within a coal power generation, the introduction of clean-coal fired power plants in Japan, and the Integrated Coal Gasification Combined Cycle (IGCC) as the next generation of established technology. This chapter is prepared by JCOAL in collaboration with various technology providers and CCT users in Japan.

ACE hopes that the handbook will serve as a useful reference to the AMS in the development of relevant and appropriate policy measures that will encourage the timely development and adoption of CCT towards energy security and economic growth in an environmentally-friendly and sustainable manner.

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**Abbreviations and Acronyms**

| Abbreviations and Acronyms | Meaning |
|---|---|
| ACE | ASEAN Centre for Energy |
| A-USC | Advanced ultra-supercritical |
| AEO4 | The 4th ASEAN Energy Outlook |
| AEC | ASEAN Economic Community |
| AFOC | ASEAN Forum on Coal |
| AH | Air Preheater |
| AIG | Ammonia Injection Grid |
| APG | ASEAN Power Grid (APG) |
| APC | Advanced Process Control |
| API | American Petroleum Institute |
| ASEAN | Association of Southeast Asian Nations |
| A-USC | Advanced Ultra Supercritical |
| AUX | Auxiliary |
| AVT | All Volatile Treatment |
| BCP | Boiler Circulating Pump |
| BFP | Boiler Feed Pump |
| BMCR | Boiler Maximum Continuous Rating |
| BOP | Balance of Plant |
| BUF | Boost Up Fan |
| CAGR | Compound Annual Growth Rate |
| CC | Contestable Consumer |
| CCGT | Combined Cycle Gas Turbine |
| CCS | Carbon dioxide Capture and Storage |
| CCT | Clean Coal Technology |
| CCTs | Clean Coal Technologies |
| CDM | Clean Development Mechanism |
| CEPO | Clean Energy Programme Office |
| CERTP | Clean Energy Research Test-bedding Programme |
| CESP | Clean Energy Scholarships Programme |
| CFB | Circulating Fluidized Bed |
| CFD | Computer Fluid Dynamics |
| CFPP | Coal Fired Power Plant |
| CIS | Central Intermediary Scheme |
| CNE | Civilian Nuclear Energy |
| COP | Conference of the Parties |
| COD | Commercial Operation Date |
| $CO_2$ | Carbon Dioxide |
| Cr-C | Chromium Carbide |
| CSP | Competitive Selection Process |
| CSU | Continuous Ship Unloader |

| Abbreviations and Acronyms | Meaning |
|---|---|
| CTF | Clean Technology Fund |
| CWT | Combined Water Treatment |
| DCS | Distributed Control System |
| DBP | Development Bank of the Philippines |
| DEPP | Department of Energy Policy and Planning |
| De-NOx | NOx Removal Equipment |
| De-SOx | SOx Removal Equipment |
| DPs & IOs | Dialogue Partners and International Organisations |
| DOE | Department of Energy |
| DP | Dialogue Partner |
| DU | Distribution Utilities |
| EAC | Electricity Authority of Cambodia |
| ECO | Economizer |
| EDB | Economic Development Board |
| EDC | Electricité du Cambodge |
| EDL | Electricité du Lao |
| EE&C | Energy Efficiency and Conservation |
| EGAT | Electricity Generation Authority of Thailand |
| EIRP | Energy Innovation Research Programme |
| EP | Electrostatic Precipitator |
| ESP | Electrostatic Precipitator |
| EVAP | Evaporator |
| FDF | Forced Draft Fan |
| FGD | Flue Gas Desulfurization |
| FiT | Feed-in Tariff |
| FSH | Final Super Heater |
| GAH | Gas Air Heater |
| GGH | Green Gas Heater |
| GHG | Greenhouse Gas |
| GoI | Government of Indonesia |
| GoM | Government of Myanmar |
| GoV | Government of Vietnam |
| GT | Gas Turbine |
| GTFS | Green Technology Financing Scheme |
| GTCC | Gas Turbine Combined Cycle |
| HELE | High-Efficiency, Low-Emissions |
| HDR | Header |
| HHV | Higher Heating Value |
| HIP Turbine | High and Intermediate Pressure Turbine |
| HP Turbine | High Pressure Turbine |
| HRSG | Heat Recovery Steam Generator |
| HWT | Hot Water Treatment |

| Abbreviations and Acronyms | Meaning |
|---|---|
| IDF | Induced Draft Fan |
| IGCC | Integrated coal Gasification Combined Cycle |
| INDC | Intended Nationally Determined Contributions |
| IP Turbine | Intermediate Pressure Turbine |
| JCF | JGC Coal Fuel |
| KEN | the National Energy Policy (KEN) |
| KM CDR | Kansai Mitsubishi Carbon Dioxide Recovery |
| LCOE | Levelized Cost of Electricity |
| LP Turbine | Low Pressure Turbine |
| LRC | Low Rank Coal |
| LHV | Lower Heating Value |
| MEEP | Moving Electrode Type Electrostatic Precipitator |
| MFO | Marine Fuel Oil |
| MME | Ministry of Mines and Energy |
| MPa | Mega Pascal |
| MW | Mega Watt |
| NEC | The National Energy Council |
| NGO | Non-Government Organisation |
| NOx | Nitrogen Oxides |
| OFA | Over Firing Air Port |
| PC | Pulverized Coal |
| PDP | Power Development Plan |
| PEA | Provincial Electricity Authority |
| PEP | Philippine Energy Plan |
| PLN | Perusahaan Listrik Negara (State Electricity Company) |
| PM | Particulate Matter |
| PPA | Power Purchase Agreement |
| PPT | Power Point Presentation |
| PSA | Power Supply Agreement |
| PSO | Power System Operator |
| PV | Photovoltaics |
| RA | Republic Act |
| R&D | Research and Development |
| RBM | Risk Based Maintenance |
| RE | Renewable Energy |
| REDP | Renewable Energy Development Plan |
| REF | Rural Electrification Fund |
| REPP | Regional Energy Policy and Planning |

| Abbreviations and Acronyms | Meaning |
|---|---|
| RH (R/H) | Re-Heater |
| RNG | Random Number Generator |
| RSM | Response Spectrum Method |
| SCR | Selective Catalytic Reduction |
| SC | Super Critical |
| SH (S/H) | Super Heater |
| ST | Steam Turbine |
| TAGP | Trans ASEAN Gas Pipeline |
| TDF | Tire Derived Fuel |
| TPES | Total Primary Energy Supply |
| UBC | Upgrading Brown Coal |
| USC | Ultra-Super Critical |
| WW | Water Wall |

**UNITS**

| | |
|---|---|
| ktoe | Kilotonnes of oil equivalent |
| kVA | 1,000 Volt Amps |
| Mtoe | Million tonnes of oil equivalent |
| $MW_{ac}$ | Megawatt alternating current |
| MW | Megawatt electricity |
| MWh | Megawatt-hour |
| $MW_p$ | Megawatt peak |
| Toe | Tonne of oil equivalent |

**CURRENCIES**

| | |
|---|---|
| IDR | Indonesian Rupiah |
| MYR | Malaysian Ringgit |
| SGD | Singapore Dollar |
| THB | Thai Baht |
| USD | United States Dollar |
| VND | Vietnamese Dong |
| PHP | Philippines Peso |

# Chapter 1 - Regional Energy Policy

## 1.1 Introduction

The ASEAN Economic Community (AEC), established in December 2015, provides broad directions towards achieving the vision of having an AEC by 2025 that is highly integrated and cohesive; competitive, innovative and dynamic; with enhanced connectivity and sectoral cooperation; and a more resilient, inclusive, and people- oriented, people-centred community, which is also integrated with the global economy. The AEC is a major milestone in the regional economic integration agenda of ASEAN, offering opportunities with a huge market of USD 2.6 trillion and over 622 million strong people. In 2014, ASEAN was the 3rd largest economy in Asia and the 7th largest in the world. In the energy sector, the AEC is crucial in the identification of the emerging trends and requirements of an integrated economy that will set the path towards energy security, economic competitiveness including diffusion and adoption of technologies under the framework of sustainable development. The AEC is projected to grow by at least 4% per year on average over the next five years, but could increase to 6.1% - provided ASEAN moves towards greater integration, where member states continuously implement domestic structural reforms to raise both their productivity and competitiveness.[1]

Energy is key to the realisation of the AEC. However, while the region's economy is on a steadily expanding trend, its main energy indicators are substantially still under the world's average. As of 2015, ASEAN electricity consumption was 1,178 kWh/capita, compared to the world's 2,824 kWh/capita, while final ASEAN consumption was 0.703 toe/capita compared to the world's 1.317 toe/capita. Data showed that about 131 million ASEAN people still live in the dark.[2] To increase the electrification ratio, the fuel mix in the power generation of ASEAN Member States (AMS) is expected to shift significantly towards coal and natural gas, moving away from oil in the period 2013-2035. This is expected because of policies common to most AMS to reduce their dependency on oil, including major oil producing countries such as Indonesia and Malaysia. Coal use is expected to increase tremendously in power generation, as more coal fired power plants are planned for construction in line with fuel switching plans (away from oil).

On the directives of the 34th AMEM in 2016, the Energy Ministers recognised that the direction and role of coal in the region is moving towards Clean Coal Technologies (CCT) utilisation. To enhance the image of coal in the ASEAN region, the Ministers noted the planned activities of the ASEAN Forum on Coal (AFOC) including cooperative activities to enhance the

[1] The APAEC 2016-2025 Phase 1: 2016-2020, from various forecasts.

[2] The World Bank Electric power consumption (kWh per capita)

knowledge and information sharing regarding Carbon Capture and Storage (CCS), capacity building in CCT, and other activities to enhance the image of coal in the light of global environmental concerns. The Ministers were also informed of the AFOC's plans to undertake a feasibility study and demonstration project for a CCT facility with the involvement of Dialogue Partners, International Organisations and the private sector, to develop a joint policy research paper on coal, and institutional and human capacity building in the ASEAN coal sector. The Ministers emphasised the importance of continued efforts towards increasing the uptake of clean energy technologies in the region and the continued strengthening of cooperation with DPs and IOs and the private sector to achieve this.

Since the result of the Conference of the Parties (COP) 21 in Paris was adopted and endorsed by 195 countries, ASEAN took the agreement as the direction of cooperation activities with Dialogue Partners in addressing the issue of global climate change. The rapid development of CCT is a significant factor to help address concerns raised by global climate change. The technology will provide opportunities to enlighten the 131 million people, who still live in the dark, through an affordable and environmental friendly approach. Increasing the use of coal by the AMS in the future will be a major challenge for the Paris Agreement. However, the support from the governments through the policy on the CCT will help to accelerate the adoption of the technology in addressing the environmental challenges. The question is not only how to apply the CCT in the short-term, but also how the region is able to develop the technology in a sustainable manner in the future.

This handbook aims to provide updates on policies related to coal and to serve as a source of guidelines to assist the AMS in selecting the appropriate technologies for CCT implementation to enhance energy security, economic competitiveness, environmental sustainability, and international cooperation in the ASEAN region.

## 1.2 ASEAN Long-term Energy Path

Over the past few years, the ASEAN Total Primary Energy Supply (TPES) has reflected the trend of steady economic growth and the notable demographic developments of the region. Between 1990 and 2013, the TPES grew at an average annual rate of 4.2% to fulfil the demand of the economy, which has been growing at an average rate of 5.1% every year. This was relying heavily on the use of fossil fuels: coal, oil, and natural gas.

Back in the 1990s, fossil fuels accounted for 55.4% of TPES, with 238 million tonnes of oil equivalent (Mtoe) in the total primary energy demand. This number reached 80% with 619 Mtoe of TPES in 2013. While oil kept its majority share from 37.6% in 1990 to 41.1% in 2013, in fact, it was actually coal that increased its market share during this period. From only 13 Mtoe in 1990, or a 5.3% share, the demand for coal soared to 124 Mtoe in 2013, which is 20.1% or equal to 10.4% of average growth every year during the period 1990 to 2013[3].

Between 1990 to 2013, the average growth of electricity generation was at a rate of 7.5%. Due to the considerably large number of gas-fired power plants that were constructed during the 1990-2000 era, and coal-fired power plants that were constructed between 2000-2013, in the region, oil-fired power plants which had the largest market share with 42.5% in 1990, lost its share dramatically to levels of only 4.2% in 2013; equal to a negative growth of 2.8% every year. Meanwhile, the share of coal and natural gas has grown significantly with 10.2% and 12.1% average growth every year to reach market share levels of 31.5% and 43.8% in 2013, respectively.

During this period, ASEAN also continued to increase its efforts with regard to green energy. A heavy reliance on hydro-power, together with geothermal and other renewable energy sources such as solar and wind, led to a significant contribution totalling 22.7% of the share in 1990, which is equal to 35.3 TWh. In 2014, this number reached a 26% share in total generation or equal to 169.3 TWh, generated from a 51.63 GW installed capacity of renewable energy.

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[3] ASEAN Energy Outlook 4, 2015

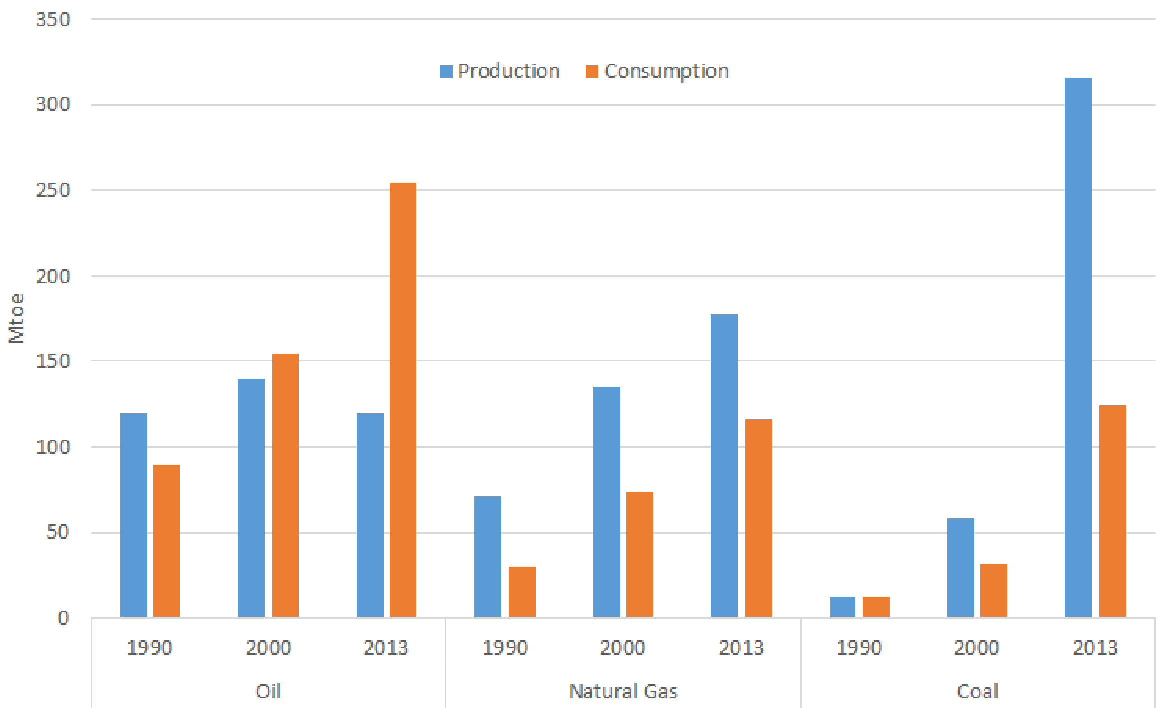


Figure 1. Fossil Fuels Production and Consumption in 1990, 2000, and 2013

Source: The 4th ASEAN Energy Outlook, 2015

ASEAN as a region, is a net energy exporter of fossil fuels, given the fact that the level of production of coal and natural gas substantially exceeds the region's consumption levels, this is despite the fact that it is a net importer of oil to meet supply requirements (see Figure 1). ASEAN's consumption of crude oil amounted to 254.6 Mtoe in 2013, outmatching its production by approximately 134.6 Mtoe. The production and consumption of natural gas indicates a similar pattern. While the production still outweighs consumption by about 61.1 Mtoe, the higher average growth rate of consumption (6.1% between 1990-2013) compared to the growth rate of production (4% across the same time period) will, if unchanged in the mid-term, shift the balance of the region's trade towards becoming a net natural gas importer. As for coal, a steady increase in production capacities delivered a remarkable expansion in the production path: with an average annual growth rate of 15% between 1990 and 2013, the production of coal and lignite reached 316 Mtoe in 2013, outmatching the consumption by 191.5 Mtoe. About 90% of production takes place in Indonesia, given the vast reserves in Sumatera and Kalimantan, and to a minor extent, in Vietnam at about 7%.

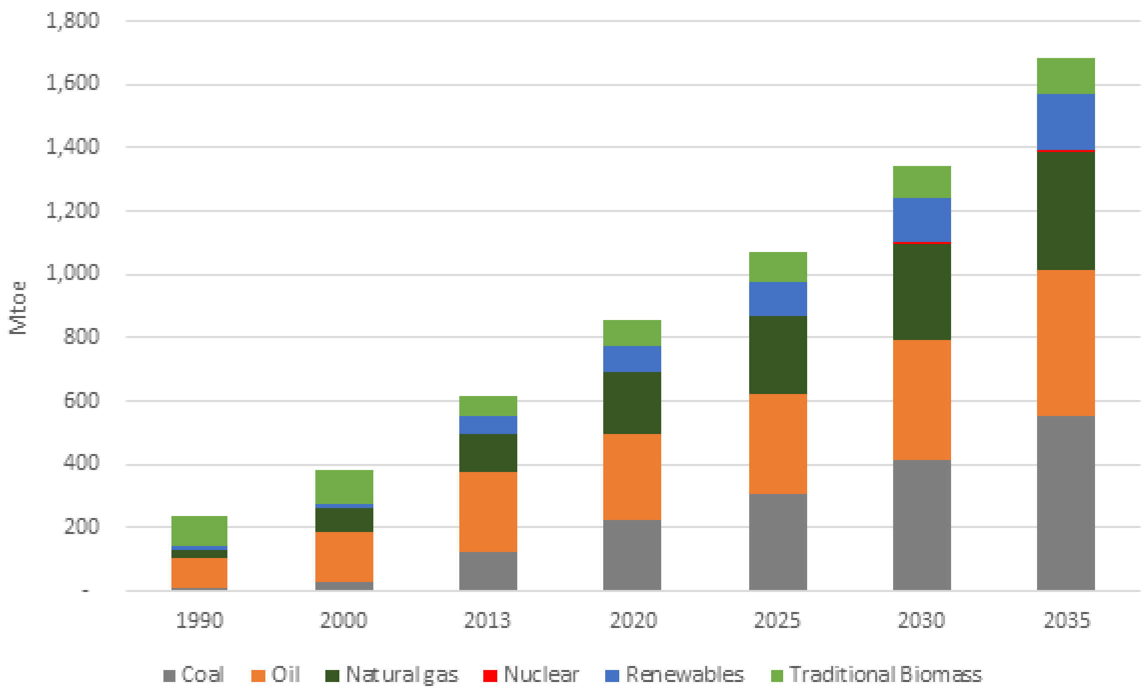


Figure 2. ASEAN Primary Energy Demand; Past and Projections

Source: The 4*th* ASEAN Energy Outlook, 2015

The trend of fossil fuels is expected to continue into the future (see Figure 2.). ASEAN as a region is a net energy exporter of fossil fuels, given the fact that the production of coal and natural gas substantially outweighs the region's consumption, even though crude oil is imported to fulfil its supply requirements. With economic growth at 6.1% on average every year, while the population keeps expanding at the yearly average growth rate of nearly 1%, the ASEAN Centre for Energy's (ACE)'s 4th ASEAN Energy Outlook (AEO4) forecasted that the demand for primary energy will grow by an average of 4.7% per year from 2013 to reach 1,685 Million tonnes of oil equivalent (Mtoe) in 2035 under a Business as Usual (BAU) Scenario.

While efforts have been made by ASEAN, at both regional and national levels, for the successful implementation of stronger policies on various energy efficiency and renewable energy targets, this region is expected to continue to rely on fossil fuels to merit the economic growth, with an increasing share to 82.4% of the primary energy demand in 2013.

However, as the previous period witnessed oil with the major share, this trend is likely to shift in the following decade as the projected rapid growth in electricity consumption will be largely met by coal-fired power generations. Whereas coal only accounted for 20.1% of the primary energy in 2013, coal demand is expected to have the highest increase among other fuel types, with a yearly average growth rate of 7.0%, thereby overshadowing the share of oil from 2025 and then fully take over to reach a 33% share in 2035, equivalent to 556 Mtoe. Backed by Indonesia, as one of the world's major producers and exporters, coal is the major source to fulfil ASEAN sharp increase in the demand for energy for economic development.

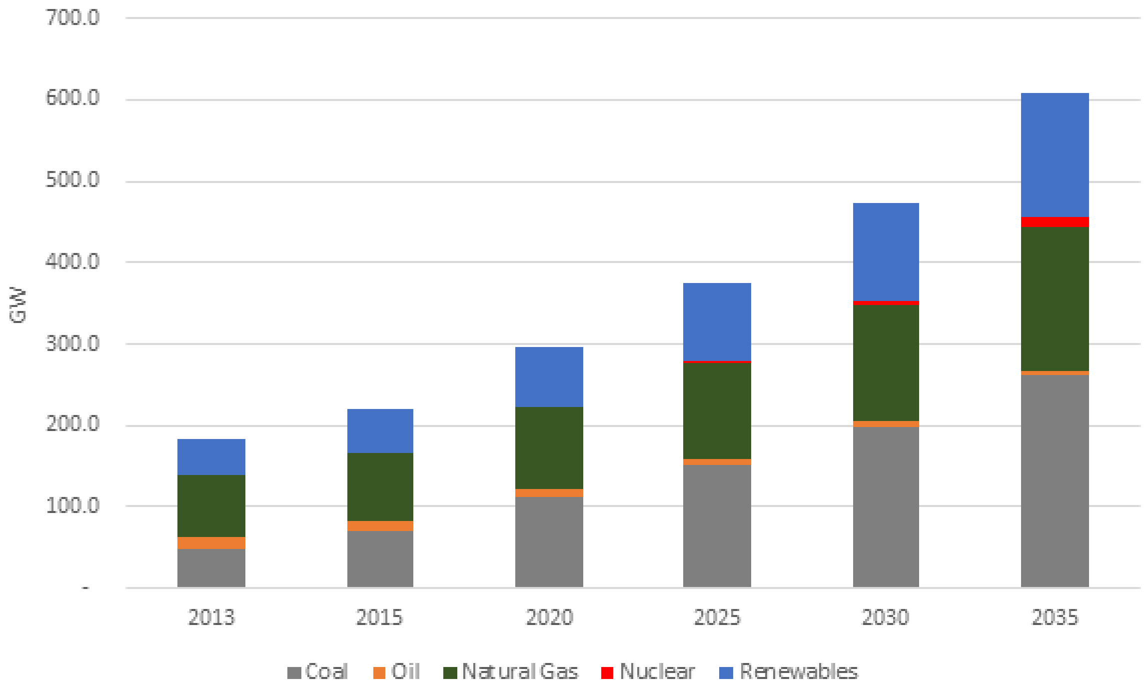


Figure 3. ASEAN Installed Capacity, Fuel-Based Projections

Source: The 4th ASEAN Energy Outlook, 2015

The overall electricity capacity increases are projected to rise from 184 GW in 2013 to 374 GW in 2025, while reaching 607 GW by 2035, an average growth of 5.6%, which indicates the commitment needed to cope with the increasing electricity demand growth in ASEAN. Projections indicate a coal based plants capacity increasing from a starting value of nearly 47 GW in 2013 to 152 GW in 2025 and 261 GW by 2035, equal to an average growth per year of 8.1% (see Figure 3). This is a rapid increase that also has strong implications on coal production, as the demand for fuel will also rise.

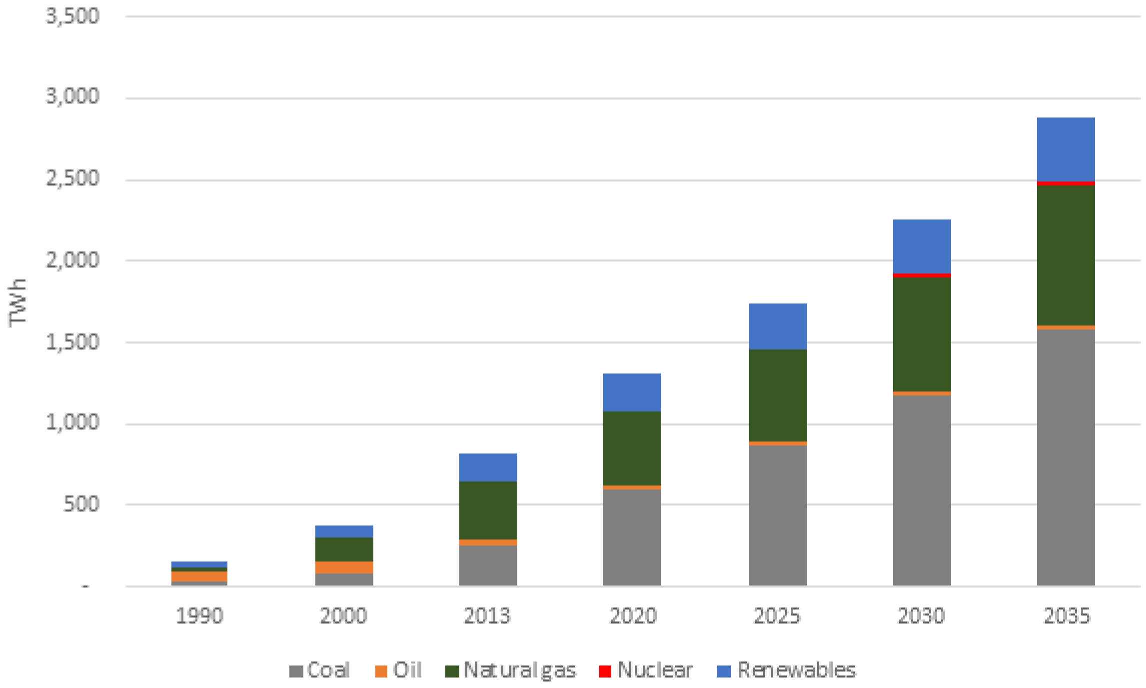


Figure 4. ASEAN Power Generation, Fuel Based; Past and Projections

Source: The 4th ASEAN Energy Outlook, 2015

In terms of power generation, the value will increase from 821.1 TWh in 2013 to 1,743.2 TWh in 2025 and 2,883.7 TWh in 2035, equal to an average annual growth rate of 5.9% (see Figure 4.). With a similar pattern to the previous period, fossil fuel-based power plants retain a dominant share of 79.4% in 2035, with coal as the main contributor, replacing natural gas in the process. In the projections, coal-based generation will increase to 867 TWh in 2025 and 1,577 TWh in 2035. It also replaces natural gas generation as the most dominant generation type and reaches a share of 55% by 2035, exceeding natural gas generation which only reaches 32%.

Renewable energy generation is increasing from 2013 with an average growth rate of 4.4%. While the generation in 2013 is 153 TWh, it is expected to reach 286 TWh in 2025 and 392 TWh in 2035. Although this represents considerable growth, the overall share is expected to drop to 13% in 2035; simply as a result of the huge increase in coal generation.

Notably, coal is expected to replace oil as the main fuel source in primary energy demand and to also replace natural gas as the main fuel source in power generation. High demand for coal is not a phenomenon in ASEAN, as this region has abundant resources of the cheapest fossil fuels. The 2015 oil price slump was on a level that no one could have predicted. The new prices bring the competitiveness of oil and natural gas down to levels that are similar to other types of fuel, indeed even to a tolerance level with coal, which was previously known as the cheapest fossil fuel. However, with the uncertainty on this pricing pattern, combined with the existence of large reserves that are affordable at a low price, compounded by the non-existence of a carbon price, coal is more appealing than other available options.

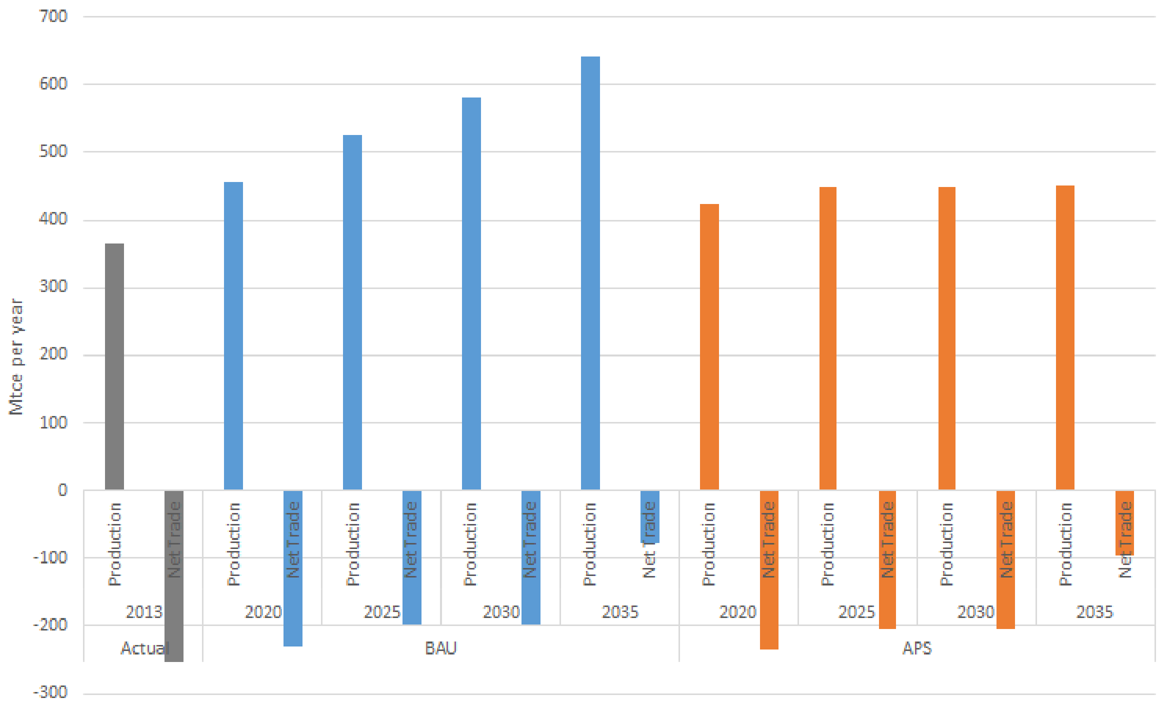


Figure 5. ASEAN Coal Production and Net Trade Projections

Source: The 4$^{th}$ ASEAN Energy Outlook, 2015

However, this is not without the challenges of resource depletion. As of the year 2013, according to the BGR[4] as quoted by the AEO4, ASEAN had total coal reserves of approximately 27 billion metric tonnes (bcm), with around 40% of these resources recorded as hard coal reserves, while the remaining 60% are brown coal reserves, and are mostly locked in Indonesia and Vietnam. With the expected production under two scenarios; the Business as Usual (BAU) Scenario and the Advancing Policy Scenario (APS), AEO4 anticipates that the coal reserves will remain at only 12-14 bcm in 2035 (see Figure 5). In the BAU Scenario, the production is expected to reach 641 bcm at 2035, while in the APS only 452 bcm - similar with the level of the BAU production in 2020.

1.3 The New APAEC 2016-2025 (Phase I: 2016-2020)

The 32nd ASEAN Ministers on Energy Meeting (AMEM) held on 23rd September 2014 in Vientiane, Lao PDR, endorsed the theme of the new ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025 as *"Enhancing Energy Connectivity and Market Integration in ASEAN to Achieve Energy Security, Accessibility, Affordability, and Sustainability for All"*. The APAEC is a series of guiding policy documents to support the implementation of multilateral energy cooperation to advance regional integration and connectivity goals in ASEAN. It serves as a blueprint for better cooperation towards the theme of the new APAEC under the framework of the AEC for the designated period[5].

The key initiatives under this APAEC include embarking on multilateral electricity trading to accelerate the realisation of the ASEAN Power Grid (APG), enhancing gas connectivity by expanding the focus of the Trans-ASEAN Gas Pipeline (TAGP) to include Liquefied Natural Gas (LNG) regasification terminals as well as promoting clean coal technologies. It also includes strategies to achieve higher aspirational targets to improve energy efficiency and increase the uptake of renewable energy (RE) sources, in addition to building capabilities on nuclear energy. Plans to broaden and deepen collaboration with ASEAN's Dialogue Partners (DPs), International Organisations (IOs), academic institutions and the business sector will be stepped up to benefit from their expertise and enhance capacity building in the region.

The APAEC 2016-2025 will be implemented in two phases. Phase I will cover the period 2016-2020 for the implementation of short to medium-term measures to enhance energy security cooperation and to take further steps towards connectivity and integration. In 2018,

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[4] Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) or Federal Institute for Geosciences and Natural Resources of Germany.

[5] The APAEC 2016-2025 Phase 1: 2016-2020,

there will be a review of the progress of Phase I, which will guide ASEAN in charting the route and directives for Phase II (2021-2025).

The APAEC Phase I 2016-2020 will continue to focus on the seven programme areas as in the previous APAEC, namely: i) ASEAN Power Grid (APG), ii) Trans-ASEAN Gas Pipeline (TAGP), iii) Coal and Clean Coal Technology (CCT), iv) Energy Efficiency and Conservation (EE&C), v) Renewable Energy (RE), vi) Regional Energy Policy and Planning (REPP), and vii) Civilian Nuclear Energy (CNE).

The CCT programme was established to recognise coal's role as a major fuel source for power generation in the ASEAN region. The programme commenced during the first development process of APAEC in 1999-2004. The first five year of APAEC supported the energy cooperation agenda of the Hanoi Action Plan (HAP) under the ASEAN Vision 2020 that consisted of six (6) fundamental Programme Areas, which included the CCT. CCT aims to address the environmental issues raised from coal production and utilisation in ASEAN, specifically to enhance the image of coal through the promotion of clean coal technologies (CCT).

Under the APAEC Programme Area No 3: Coal and Clean Coal Technology, the five (5) outcome-based Strategies are shown in Table 1.3.1.

Table 1. APAEC Programme Area No 3: Coal and Clean Coal Technology

| Outcome-based | Actions |
|---|---|
| **Strategy 1:** Promote clean coal technologies for power generation to contribute to clean energy development and economic | a. Promote best practices through the annual ASEAN Coal Awards in areas of Coal Mining, Coal Distribution, CCT Utilisation in Coal Fired Power Plant and Industries to relevant stakeholders.<br>b. Organise at least two (2) Capacity Building Workshops on CCT.<br>c. Conduct at least one (1) feasibility study on CCT and disseminate results. |
| **Strategy 2:** Increase the level of awareness of the public on the benefits of coal use. | a. Organise at least one (1) event to enhance coal's image in the light of global environmental concerns.<br>b. Enhance the appreciation by the general public of coal's benefits through at least one (1) dissemination Workshop on ASEAN Coal Awards Best Practices on a particular CSR project. |

| | |
|---|---|
| **Strategy 3:** Promote intra-ASEAN coal trade and increase investment in CCT. | a. Organise at least one (1) ASEAN Coal Business Roundtable and Conference.<br>b. Develop business/financing model to promote greater participation of public and private sector, DPs, IOs in the adoption of CCT.<br>c. Study and propose (1) CCT demonstration project with the involvement of one (1) DPs IOs. |
| **Strategy 4:** Conduct policy research to enhance coal development and use, and build capacity. | a. Implement and publish at least one (1) joint policy research paper on coal.<br>b. Intensify institutional and human capacity building in the ASEAN Coal Sector.<br>c. Identify and establish one (1) ASEAN Coal Centre of Excellence.<br>d. Organise high level policy discussion with at least one (1) DP/IO. |
| **Strategy 5:** Establish a fully functional ASEAN Coal Database and Information System (ACDIS). | a. Establish the focal point system and coordination mechanism in the AMS to submit data and information in a timely manner to the ACDIS.<br>b. Organise ACDIS training in the AMS.<br>c. Develop and maintain a yearly ACDIS Statistical Monitor including an integrated coal price and trade database, news on coal policy and related developments, to address harmonization. |

CCT is a category or a collection of the latest technologies that allow for the use of coal to reduce the impact on the environment and to meet regional environmental regulations[6]. CCT is an approach to reducing emissions of air pollutants, GHG emissions (specially $CO_2$), and to increase the energy efficiency of existing power plants. An increase in energy efficiency reduces the amount of fuel consumed and reduces the quantity of the pollutants and greenhouse gases emitted. In addition to the increase of thermal efficiency, carbon capture and storage (CCS) of $CO_2$ is one of the primary techniques to reduce pollutants and $CO_2$ emissions under the CCT utilisation.

The ASEAN Forum on Coal (AFOC), assisted by ACE, implemented various activities to enhance the promotion and cooperation of the AMS concerning coal and clean coal technologies. In order to improve coal policies and strategies by the AMS, the AFOC has successfully organised various seminars, workshops and capacity-building activities focusing on the promotion of clean coal technologies, carbon capture and storage, upgrading of low rank coal, environmental emission standards for coal-fired power plants and the promotion of coal's image and the clean coal initiative for ASEAN.

[6] Definition by ACE

## 1.4 The Growing Role of Coal and CCT in ASEAN

ASEAN is at the forefront of the global steam coal market, a role the region is set to continue in the coming decades. At the end of 2013, Southeast Asia had 28 billion tonnes of proven coal reserves, about 3% of the world's total, with the vast majority (80%) located in Indonesia and most of the remaining quantity in Vietnam. The region has a considerably larger resource base, which could be converted to reserves as production expands. Coal production in the region has experienced spectacular growth over the last decade. Since 2000, ASEAN's coal output expanded by a factor of five; from 83 Mtce to 450 Mtce, mainly driven by rising consumption from two large importing countries; China and India. The proximity to fast-growing coal markets and low production costs has provided a significant competitive advantage to ASEAN coal producers. However, recently, the growth in production and exports has slowed markedly from this very rapid pace in response to the overcapacity in the coal market and the low-price environment. When considering the reserves of fossil fuels, ASEAN has been a net importer of oil since 1995 and it is still a net exporter of natural gas and coal until 2016. An ASEAN internal study discovered that ASEAN will likely see a supply gap starting in 2017[7]. New prospects in ASEAN are located offshore in deep water or as unconventional gas which is not easy to extract. ASEAN will continue to be an important player in the global fossil fuels market in the coming decades, backed by Indonesia as one of the world's major producers and exporters. So, with its abundant reserves, coal is the natural choice for the region to fulfil its sharp increase in the need for energy for economic development.

Moreover, spread across the region, the infrastructure to generate electricity from coal is already well established. Generating electricity from coal is also an affordable supply, with a relatively stable price, and avoids dependency on sun or wind. Renewable energy, such as geothermal, hydro, wind and solar, will also play an important role in ASEAN's energy future, however they are not going to displace coal or alter the position of coal as an affordable and abundant source of energy in AMS.

Electricity generated by coal provides baseload electricity, which is the power the region relies on 24 hours a day, 7 days a week to spur the economic growth. A constant supply of energy to power the region at an affordable price is vital for the region as it attempts to develop the economy and lift people from the marginal community.

The study by Fraunhofer Institute for Systems and Innovation Research in 2013 (Figure 6) shows the calculated Levelised Cost of Electricity (LCOE) of renewable energy technologies

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[7] ASEAN Council on Petroleum (ASCOPE) on its Trans-Asian Gas Pipeline (TAGP) Masterplan

in comparison with a fossil fuel power plant. Only wind power, when located at a very good onshore site, has achieved lower costs compared to new hard coal or CCGT power plants. In summary, there is no hesitation that coal is the best option and is also expected to hold a major role since the LCOE for a brown coal is only at 0.038 to 0.053 Euro/kWh, with hard coal at 0.063 to 0.080 Euro/kWh and from CCGT power plants at 0.075 to 0.098 Euro/kWh.

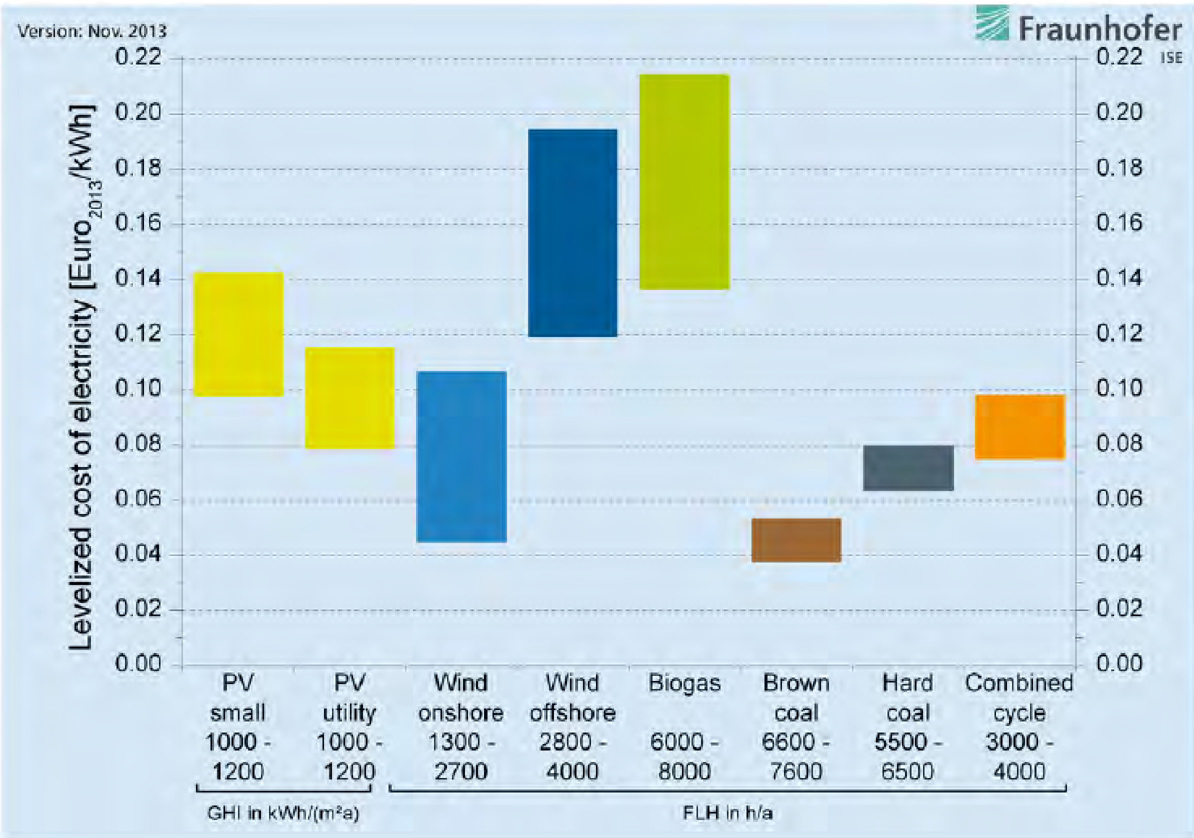


Figure 6. LCOE of Various Technologies[8]

Source: Fraunhofer-Institut für Solare Energiesysteme ISE Levelized Cost of Electricity-Renewable Energy Technologies, November 2013

[8] The value under the technology refers in the case of PV to solar irradiation (Global Horizontal Irradiance/Irradiation-GHI) in kWh/(m²a); in the case of other technologies it reflects the number of full load hours (FLH) of the power plant per year (hours per annum or h/a).

In view of the recent situation; where ASEAN is increasingly becoming more dependent on coal resources as an available source, while other fossil fuels are on the decrease, it is prudent to pursue and employ all the necessary measures to use coal in an efficient way and to prevent and reduce its environmental impacts. In this context, ASEAN needs to utilize the latest and most efficient and clean coal technologies. In line with the above trend, it's required that the ASEAN long-term $CO_2$ emissions path needs to be curbed. This requires an increased role for low-carbon and zero-carbon energy technologies to be embedded in the long-term national energy programs in order to achieve a low -carbon development path in the ASEAN energy sectors. With its ability to reduce emissions by up to 90% from large point source emitters - such as coal fired power plants, coal gasification and liquefaction plants, and oil and gas processing plants - High-Efficiency, Low-Emissions (HELE) coal are important low-carbon technologies for ASEAN in developing its pathway into a low emission future.

The aim of deploying HELE technologies such as Supercritical (SC) technology, Ultra-supercritical (USC) technology, Advanced ultra-supercritical (A-USC) technology and Integrated gasification combined cycle (IGCC) is twofold: to increase conversion efficiencies and reduce $CO_2$ emissions[9].

Both supercritical and ultra-supercritical technologies are available now, with even higher efficiencies possible when advanced ultra-supercritical becomes available. Low-rank coal that is available abundantly in ASEAN could be utilised with more efficient technology, notably by employing pre-combustion drying. Expanded use of IGCC also promises a higher efficiency and reduced $CO_2$ emissions for the region. In the near future, the total installed capacity is 35 GW with the following breakdown: Indonesia 9,000 MWe, Malaysia 5,080 MWe (supercritical and ultra-supercritical), Philippines 500 MWe (supercritical), Thailand 1200 MWe (ultra-supercritical and supercritical), and Vietnam 20,336 MWe (supercritical and ultra-supercritical).

In the long term, (see Figure 7), electricity generation from different coal-fired power technology will already be in place, therefore it will be important to slowly increase generation from plants deploying HELE technology, while simultaneously decreasing generation from subcritical plants, and also encourage the installation of CCT on plants that are deploying HELE technology[10] (SC, USC and IGCC).

[9] International Energy Agency (IEA)

[10] Identified by IEA

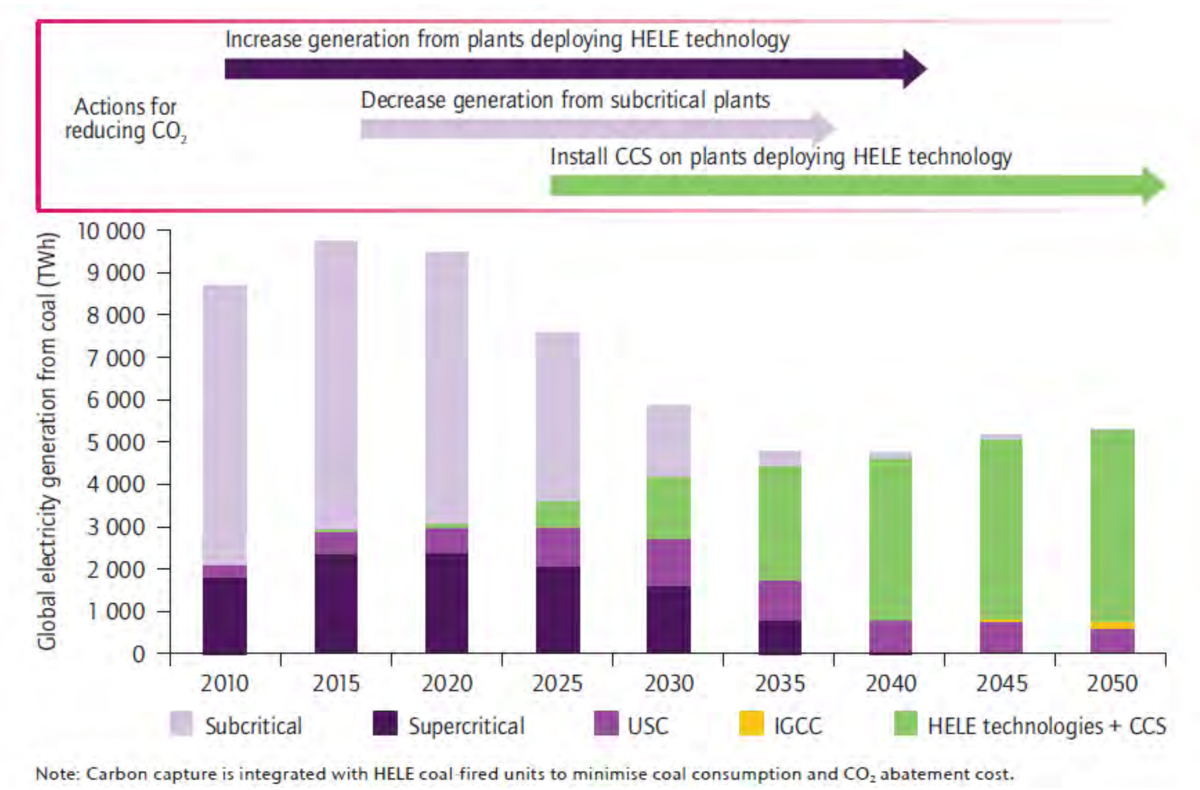


Figure 7. Electricity Generation from Different Coal-fired Power Technologies[11]

Source: Technology Roadmap: High-Efficiency, Low-Emissions Coal-Fired Power Generation, IEA, 2012

However, there are significant barriers for the region to implement CCT. Even though many advanced technologies for environmentally friendly coal utilisation have been developed, it has not been properly implemented due to financing limitations. For example, the most famous project involves retrofitting one 110 MW unit of its Boundary Dam Power Station by SaskPower of Canada to capture 90% of the $CO_2$, where the cost of the total investment for the CCT project sits at $1.23 billion. Although, due to a decreased capture rate by its CCS technology and also a failure to deliver the promised $CO_2$ to Cenovus Energy, SaskPower had to pay $12 million penalties in 2014, while more are expected for 2015.

SaskPower remains confident that revenue from captured $CO_2$ will be greater than the penalties, however for ASEAN, where most Member States have limited capabilities in the

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[11] Note on Figure 7: HELE technologies including SC, USC and IGCC.

implementation of CCT in power plant projects, this will bring difficulties. What is also required for ASEAN is to see the next step for many $CO_2$ capture technologies to move to a demonstration scale. Without the experience that can only be gained through demonstration, CCT will not become a commercially investable proposition due to unresolved technical challenges and uncertain cost estimates. It is projected that once CCT are validated and their associated costs are proven through the operation of large-scale demonstration plants, only then will it become cost-competitive compared to other low-carbon energy technologies.

1.5 ASEAN Call for CCT

Some AMS like Brunei Darussalam, Thailand, Singapore, and Malaysia have achieved near universal electrification, and nearly full in the case of Vietnam (estimated at 99%). In 2030, the coal share is expected to be at 38.71% or 905 TWh, while in 2014, it exceeded 30% or equivalent to 294.5 TWh. The growth will render coal as the most popular source for power generation in ASEAN. Indonesia is the leading Member State in the expansion of coal followed by Malaysia and Thailand.

Currently, the total CFPP[12] is 10 GW and this will be increased significantly to more than 44 GW by 2018 (Table 1.5.1.). The ASEAN Ministers under the 13th ASEAN Ministers of Energy Meeting (AMEM) with the Plus three countries (China, Japan and Korea) reiterated their collective call to step up efforts to promote policies for clean coal technologies (CCT) including high-efficiency coal-fired power generation, which will contribute to energy security and the reduction of Green House Gas (GHG) emissions, to the upgrading of low rank coal technologies, and coal gasification/liquefaction, and the development of industry in the region.

Table 2. List of AMS Coal Fired Power Plant's Capacity (2016 - 2018)

| No | Country | Electrification Rates | 2016 Total CFPP Capacity (GW) | Total CFPP Planned Capacity in 2018 (GW) |
|---|---|---|---|---|
| 1 | Cambodia | 66.00% | 0.515 | 1.05 |
| 2 | Indonesia | 88.60% | 2.135 | 9.08 |
| 3 | Lao PDR | 85.90% | 1.878 | 2.478 |
| 4 | Malaysia | 98.20% | 3.9 | 6.9 |
| 5 | Myanmar | 32.00% | 0.12 | 9.9 |

[12] with CCT adoption

| | | | | |
|---|---|---|---|---|
| 6 | Philippines | 79.88% | 4.213 | 4.213 |
| 7 | Thailand | 100.00% | 2.276 | 3.946 |
| 8 | Vietnam | 99.00% | 3.95 | 3.95 |
| ASEAN | | 78% | 18.987*) | 41.517*) |

**) Excludes Brunei Darussalam and Singapore*

Source: Country Report Clean Coal Technology Transfer Programme, 2016.

The AMS are moving towards cleaner and more efficient technologies. As part of these efforts, many AMS have increased the role of coal in the national energy policy. There has also been considerable attention placed on the deployment of coal to fulfil the electricity demand. Most countries have adopted medium- and long-term targets for CCT adoption. Indonesia, Malaysia, and Thailand are leading in the CCT development with approximately 20 GW extra capacity for CFPP in 2018.

Additionally, under the spirit of COP 21 that states that emission reductions must be consistent with international climate objectives and must integrate environmental imperatives with the aims of energy security, economic development and an end to poverty, many countries including the AMS have included high -efficiency, low-emission coal-based power generation in their (Intended) Nationally Determined Contributions or (I)NDC. For that reason, there is a need for an international mechanism to be established to provide financial and other support necessary for countries to accelerate the construction of such projects, to build a pathway for a cleaner coal, a cleaner energy, and a cleaner future for ASEAN, and the world.

# Chapter 2 - CCT Status and Plans in the ASEAN Member States

## 2.1 Cambodia

### (1) Socio-economic Situation

Cambodia lies entirely within the tropics and is dominated by the Mekong River. The country's total land area is 181,035 $km^2$, of which approximately 49% is covered by forest, and is inhabited by 15 million people (2015).

Cambodia has made great strides in its economic development over the last ten years. In 2014, the GDP growth reached 7.1%, resulting in a GDP per capita of $1,105[13]. Cambodia has moved closer to lower middle-income status with its economic growth driven by solid performances in garment manufacture, tourism, paddy and milled rice, and construction.

### (2) Energy and Electricity Situation

Despite remarkable improvement in the energy sector, the electrification rate in Cambodia remains low. The majority of the population is not connected to electric power networks. Moreover, electricity cost remains one of the highest in both the region and the world. Investment in the electricity sector needs to be increased to encourage development.[14]

In recent decades, Cambodia has focused efforts on the reparation and expansion of the commercial energy sector to fulfil the energy demand. During the period 2006 to 2015, Cambodia installed more than five times its power capacity, an increase from only 300.12 MW in 2006 to 1,572 MW in 2015 (see Figure 8). This growth is equal to an average 20.20% increase every year, almost 2.5 times the level of economic growth. The structure of fuel has also changed, as the country decreased its reliance on oil from 94.18% in 2006 to only 16.41% in 2015, due to a substantial increase in hydropower and coal. With this, Cambodia produced 4,448.25 GWh electricity in 2015, where hydropower and coal contributes equally as the most significant fuels (see Figure 9).

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[13] ASEAN Secretariat (2015), ASEAN Statistic Leaflet

[14] Poch, K. and S. Tuy (2012), 'Cambodia's Electricity Sector in the Context of Regional Electricity Market Integration' in Wu, Y., X. Shi, and F. Kimura (eds.), Energy Market Integration in East Asia: Theories, Electricity Sector and Subsidies, ERIA Research Project Report 2011-17, Jakarta: ERIA, pp.141-172.

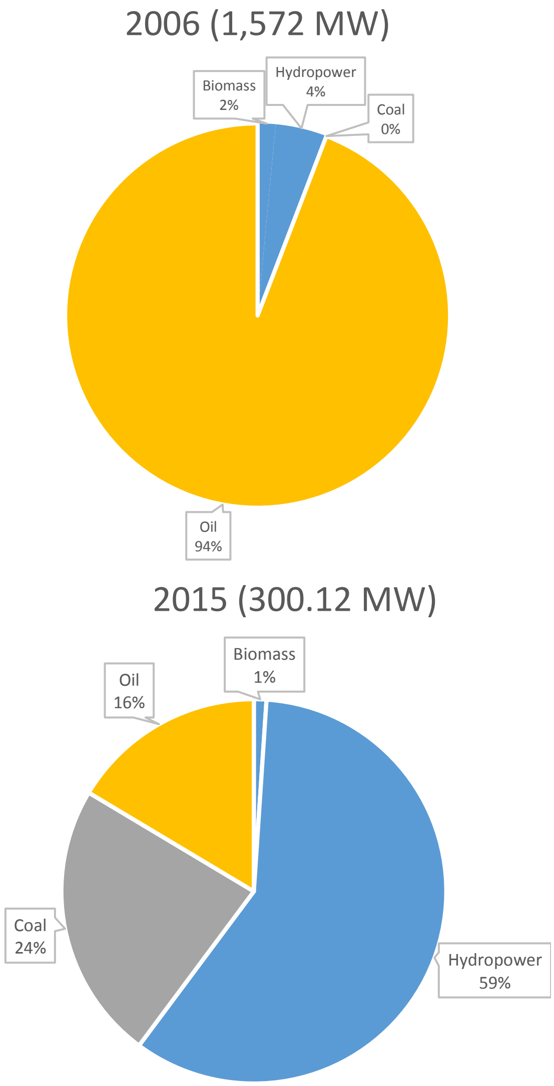



Figure 8. Cambodia's Installed Power Capacity, 2006 and 2015

Source: Cambodia Country Report, CCT Transfer Program by JCOAL, February 2016

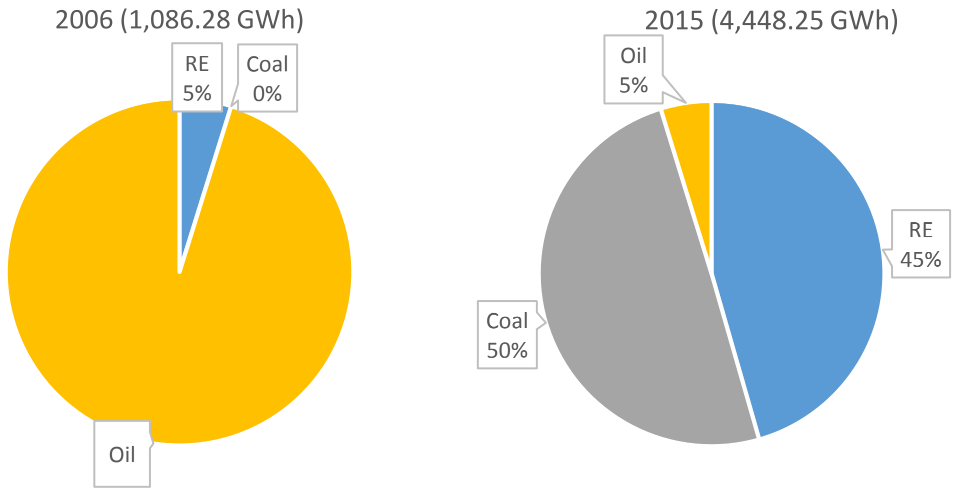



Figure 9. Cambodia's Power Generation, 2006 and 2015

Source: Cambodia Country Report, CCT Transfer Program by JCOAL, February 2016

(3) Policy on Energy and Electricity

A primary goal of the government is to reduce poverty, and create strategies for the development of sustainable and affordable energy supplies for the country. The Ministry of Mines and Energy (MME) was mandated to develop, implement, and manage the country's policies and plans involving the energy sector. Cambodia formulated an energy sector development policy in October 1994 with the following objectives:

1. To provide an adequate supply of energy throughout Cambodia at a reasonable and affordable price;
2. To ensure reliable, secure electricity supply at prices, which facilitate investment in Cambodia and development of the national economy itself;
3. To encourage exploration and the environmental and socially acceptable development of energy resources needed for supply to all sectors of the Cambodian economy; and
4. To encourage efficient use of energy and to minimise the detrimental environmental effects resulting from energy supply and consumption.

The government has undertaken Sector Reforms and Rehabilitation of Power Sector with the support of multilateral and bilateral agencies which aims to:

1. Re-establish an adequate supply of electricity nationwide through the direct support of donors and private sector participation in generation;
2. Strengthen the managerial sector and implementing capability;
3. Create the environment required for the sustained and efficient development of the power sector, open to competition and private sector participation; and
4. Extending its power sector objectives to rural areas.

Sector reform and restoration of the power sector has been in operation since 1994. With the restoration work undertaken, the power supply in Phnom Penh and Sihanoukville has improved considerably. The distribution network's repairs in Phnom Penh, Siem Reap, and Sihanoukville were completed in 1999.

Electricité Du Cambodge (EDC) is a wholly state-owned limited liability company that has been established to generate, transmit, and distribute electricity throughout Cambodia. To issue the license to electrical utilities for generation, transmission and distribution, and also to create favourable conditions for capital investments in the commercial operation of the electric power industry, the government established The Electricity Authority of Cambodia (EAC). The EAC was established under the Electricity Law (2001) to regulate the power sector. Every electricity provider is required to obtain a license from EAC. The Environment Protection and Natural Resource Management Law (1996) was introduced to reduce the adverse effects of the power sector on the environment. The law obliges all energy-related project developers to perform an Environmental Impact Analysis (EIA), which then must be reviewed and approved by the Environmental Steering Committee and the Project Review Teams.

(4) Power Sector Situation

Cambodia faces a major challenge to develop an adequate and reliable source of electrical power in the years ahead. Based on intensive studies on the best means of providing a national electricity supply network, the Royal Government will develop a long-term power sector strategy to enable Cambodia to meet the growing demand for electric power over the next 20 years. The strategy establishes the sector's policy and action plans for:

1. Investment in the power sector;
2. Priorities for generation and transmission;
3. Establishment of the power sector's Regulatory Framework;
4. Commercialisation of EDC;
5. Private sector participation:

6. Provincial and Rural Electrification

The objectives of private sector investment strategy in Cambodia are as follows:

1) Speed up the reparation of the power sector;
2) Mobilise capital that may not be available from multilateral lending Agencies;
3) Reduce the public-sector debt; and
4) Increase the efficiency of existing power utilities through increased competition and the transfer of technology and skills.

Cambodia will also utilise the expertise and financial assistance of multilateral and bilateral lending agencies to further develop the energy infrastructures in order to meet the energy requirements of the growing economy. The financial requirements will focus on electricity transmission and distribution, hydro-electricity generation as well as provincial and rural electrification.

- Priorities for Generation and Transmission

The load forecast for electricity generation in Cambodia is expected to face a significant increase in demand over the next 20 years. Electricity demand in Cambodia is projected to grow from 97MW and 522GWh in 1998 to 746MW and 2,634GWh in 2016. The majority of this growth will occur in Phnom Penh, although a significant growth is also expected in provincial towns.

To meet this increase in demand, Cambodia has decided to develop a National Transmission System. This System will allow access to energy generation by large-scale power stations to provincial centres and also allows Cambodia to access available hydroelectric sites. It will significantly reduce their reliance on imported oil for electricity generation and also the risks involved in transporting the oil. The Transmission System will require a major investment programme and will be developed over many years. Initial priorities will concentrate on the development of the first stage of the transmission system, the overhaul of the local generation and expansion of the distribution system in provincial towns.

Cambodia considers renewable energy as a tool for rural development. The Master Plan Study on Rural Electrification by Renewable Energy in Cambodia defines electrification in three levels: battery lighting, mini-grid, and national grid. The plan aims to provide universal village electrification via mini-grid or battery lighting by 2020. The grid quality is expected to reach 70% of households by 2030. The targets are to be achieved by grid expansion, mini-grid, cross-border supply from neighbouring countries, and indigenous renewable energy sources.

- Electricity Law

The Electricity Law of the Kingdom of Cambodia was adopted by the National Assembly on 6 November 2000 at the plenary session No.5 of term 2, and the Meeting was agreed by the Senate on the form and content of the law on 13th December 2000 at the plenary session No.4 of term 1. The Law was finally promulgated by Royal Decree DECREE No. NS/RKM/0201/03 dated 2nd February 2001 by Preah Bath Samdech Preah Norodom Sihanouk, King of Cambodia. The purpose of this law is to govern and prepare a framework for the electric power supply and services throughout the Kingdom of Cambodia. This law covers all activities related to the supply of electricity, provision of services and use of electricity, and other associated activities of the power sector.

In preparation of a framework for the electric power supply and services, the Law provides a legal public entity that has been granted the right to regulate the power sector in the country.

The Electricity Law provides that the Electricity Authority of Cambodia shall consist of three Members, including the Chairman. The Chairman and Members shall be designated and proposed by the Prime Minister and shall be appointed by Royal KRET. Each Member shall have a 3 (three) year term, which shall be staggered so that the term of the initial members shall expire at different times.

As per the Electricity Law of the Kingdom of Cambodia, no one may operate as an electric power, or provide electric power services, unless he/she has performed under and in accordance with the terms of a valid license issued by EAC. Any person, who is operating as an electric power utility at the time of promulgation of the Electricity Law, shall apply to EAC for a license within six months of receiving the initial notice from EAC.

Regulations, orders, and decisions issued by EAC are enforceable as per the Electricity Law. EAC is competent to file complaints in the courts of the Kingdom of Cambodia for any violation of the Electricity Law or the regulations, orders, decisions as well as licenses issued by EAC. The Law also provides for the rights, obligations, and penalty on the service providers as well as the consumers in order to establish fair condition in the business and the use of electricity. The enactment of the Electricity Law of the Kingdom of Cambodia is a big leap forward in bringing reforms in the electricity sector. These reforms will encourage the private investors to invest in the power sector in a fair, just, and efficient manner for the benefit of society.

To fulfil the target of providing enough sustainable quality power at a reasonable tariff to consumers throughout Cambodia, the Government has defined the following five-point strategic plan to be implemented during the term 2013-2018.

1. Plan for the investment and construction of generation sources to meet the demand of electricity; including addressing the problem of imbalance of electricity supply between dry and wet seasons.
2. Plan for development of transmission lines, grid substations, sub-transmission, and distribution lines to provide electricity throughout Cambodia to meet the need of electricity for daily life as well as for business and industry. The distribution licensees are required to extend the distribution lines to cover their entire distribution area as soon as possible. MME and EAC will monitor and on failure to do so, may allow another investor to develop the infrastructure and provide an electrical supply service in the area.
3. Plan to facilitate the poor people in rural areas to utilise electrical connections and use electricity through social programs implemented by REF. International Institutions are assisting REF for the program. The Minister has urged EDC to increase the budget provisions for the program.
4. The Minister urged the licensees, both state owned and in the private sector, to improve the quality, stability, safety of supply and ensure the satisfaction of the consumer.
5. Plan to reduce the gap between the tariff for electric supply in urban and rural areas.

- Electricity Business and Power Generation

Each year the infrastructure for the supply of electricity to consumers and the number of villages supplied with electricity increase due to the issuance of new licenses, expansion of area of supply, and the expansion of the grid supply. Between the year 2013 and 2014, the energy generated increased significantly by 72.79%, so that it could reduce its imports from Thailand and Vietnam (see Table 2.1.1).

With the addition of more HV transmission and MV sub-transmission systems, more and more licensees are getting connected to the grid supply and expanding their area of supply. This has resulted in the supply to more consumers and an improvement in the quality of supply. By the end of 2014, almost 98% of the consumers were connected to the grid system. More licensees are now supplying electricity for 24 hours a day. The grid supply has reduced the cost of supply and consequently the tariff for supply to consumers. Due to the lower cost and other measures taken by the Royal Government of Cambodia, in 2014 there has been a substantial increase in the number of consumers availing electricity supply. As reported by the licensees, the number of consumers by the end of 2014 was 1,424,735; which is almost 18.8% higher than the number reported in 2013. During 2014, a Time of Use tariff for MV consumers of EDC connected to National Grid has been introduced on an optional basis.

Table 3. Cambodian Electricity Sector Data 2013-2014

| Description | Unit | Data for 2013 | Data for 2014 | Percentage Increase |
|---|---|---|---|---|
| Energy Generated | Million kWh | 1,769.96 | 3,058.36 | 72.79 |
| Energy Imported from Thailand | Million kWh | 579.60 | 523.56 | (9.67) |
| Energy Imported from Vietnam | Million kWh | 1,691.31 | 1,265.72 | (25.16) |
| Energy Imported from Lao PDR | Million kWh | 10.73 | 13.77 | 28.33 |
| Total Import | Million kWh | 2,281.63 | 1,803.05 | (20.98) |
| Total Energy Available | Million kWh | 4,051.59 | 4,861.41 | 19.99 |
| Generation Capacity | kW | 948,993 | 1,511,338 | 59.26 |
| Number of Consumers | Number | 1,198,844 | 1,424,735 | 18.84 |
| Energy Sale to Consumers | Million kWh | 3,552.59 | 4,144.12 | 16.65 |
| Overall Loss Percentage | % | 12.32 | 14.75 | |

Source: Electricity Authority of Cambodia Report on Power Sector, 2015

Electricity generation facilities in the Kingdom of Cambodia for 2014 can be divided into four types: 1 - Hydropower Plants, 2 - Diesel Power Plants, 3- Thermal Power Plants using coal, and 4 – Plants using wood and another biomass. The major power plants added during 2014 were Stung Tatay Hydro Power Plant in Koh Kong Province and Coal Power Plant of C.I.I.D.G.Erdos Hongjun Electric Power Co., Ltd in Sihanoukville. During 2014 the following eight Hydropower Plants were in operation – Kirirom1, Kirirom 3, Kamchay, Stung Atay, Lower Stung Russei Chrum and Stung Tatay connected to the National Grid, Ratanakiri connected to the Ratanakiri power system of EDC, and Mondulkiri connected to the Mondulkiri power system of EDC. SL Garment Processing (Cambodia) Ltd, supplying part of its generation to EDC Phnom Penh, Angkor Bio Cogen Co., Ltd, Phnom Penh Sugar Co., Ltd, IED Invest (Cambodia) and Cam Chilbo Electric Power Co., Ltd use wood, agricultural products or waste as fuel for the generation of electricity. Sovanna Phum Investment Co., Ltd, connected to the Phnom Penh System and Cambodia Energy Limited, and C.I.I.D.G. Erdos Hongjun Electric Power Co., Ltd connected to the National Grid, use coal to generate electricity. All other power plants of the licensees are diesel power plants using Heavy Fuel Oil (HFO) and/or Light Diesel Oil (LDO).

Due to the addition of Stung Tatay and the full operation of the Lower Stung Russei Chrum Hydro power plants in 2014, the energy generated by Hydropower Plants increased to 1,851.60 million kWh in 2014 compared to 1,015.54 million kWh in 2013. Similarly, due to the full operation of the coal plant of the Cambodian Energy Limited and the operation of one unit of the coal plant from C.I.I.D.G.Erdos Hongjun Electric Power Co., Ltd in 2014, the energy generated by coal power plants increased to 863.02 million kWh in 2014 compared to 168.75 million kWh in 2013.

Specifically, regarding coal power plants, the following Generation Projects are under construction and their position at the end of 2014 is stated below:

1. A 240 MW Coal Fired Power Plant in Sihanoukville: The Project consists of 2 x 120 MW (net) coal fired electric power generating facility at Sihanoukville. The project is being implemented by C.I.I.D.G.Erdos Hongjun Electric Power Co., Ltd. PPA has been signed with EDC. One unit of the project was commissioned in 2014 and the second unit is scheduled to be commissioned in 2015.
2. A 135 MW Coal Fired Power Plant in Sihanoukville: The Project consists of 1 x 135 MW coal fired electric power generating facility at Sihanoukville. The project is being implemented by C.I.I.D.G.Erdos Hongjun Electric Power Co., Ltd. PPA has been signed with EDC. The project is scheduled to be commissioned in 2017.

The Government and EDC will continuously work together to expand their power generation (see Table 2.1.2 and 2.1.3).

Table 4. Cambodia's Current and Future Power Plant Plans

| No | Project | Install Cap. MW | IA/PPA/LA | COD | Achievement |
|---|---|---|---|---|---|
| Existing Project | | | | | |
| 1 | Coal Plant | 10 | BOO | 2010 | 100% |
| 2 | Coal Power Plant | 100 | BOO | 2013 | 100% |
| Under Construction | | | | | |
| 1 | Coal Power Plant | 135 | BOO | 2016 | 45% |

Source: Cambodia Country Report, CCT Transfer Program by JCOAL, February 2016

Table 5. Cambodia's Generation Expansion Plan

| No | Generation Expansion Plan | Fuel Type | Install Capacity (MW) | COD |
|---|---|---|---|---|
| 1 | 700 MW Coal Power Plant (II) – Phase 1 | Coal | 270 | 2014-2015 |
| 2 | 700 MW Coal Power Plant (II) – Phase 2 | Coal | 100 | 2017 |
| 3 | 700 MW Coal Power Plant (II) – Phase 3 | Coal | 100 | 2018 |
| 4 | 200 MW Coal Power Plant (I) – in Sihanouk Province Phase 2 | Coal | 135 | 2016 |
| 5 | 700 MW Coal Power Plant (II) – Phase 4 | Coal | 100 | 2018 |
| 6 | 700 MW Coal Power Plant (II) – Phase 5 | Coal | 100 | 2019 |

Source: Cambodia Country Report, CCT Transfer Programme by JCOAL, February 2016

## 2.2 Indonesia

### (1) Socioeconomic Situation

Indonesia is the largest archipelagic country in the world, comprising around 17,000 islands. Its population is about 252 million, making it the fourth most populous country in the world. In terms of economic performance, Indonesia has the highest GDP in the ASEAN region with USD 983 trillion in 2015 and it is the only ASEAN member that is part of the G-20. In terms of its GDP per capita (USD 3,901), Indonesia takes fifth place among the ASEAN countries.

### (2) Energy Situation

Indonesia is a resource-rich country with a growing demand for energy. Conventional oil and gas industries continue to offer good opportunities for developers, but unconventional forms of energy also offer exciting new upstream potential. Coalbed methane, shale gas, and geothermal energy are among the sizeable and under-developed opportunities available in Indonesia.

In 2014, as recorded in the Handbook of Energy & Economic Statistics of Indonesia 2015, Indonesia's primary energy production was:

- Crude Oil: 287,902.15 Thousand Barrel;
- Natural Gas: 2,687.91 BSCF;
- Coal: 458,096.71 Thousand Tonnes;
- Hydro Power: 52,031,668.97 Million Kcal; and
- Geothermal: 73,598.03 Thousand Tonnes Geothermal Steam.

On the demand side, oil is the most consumed fuel among others, which accounted for 396.21 Million BOE from a total final energy consumption of 1,195.95 Million BOE in 2016 and the industry is counted as a major sector (see Figure 10).

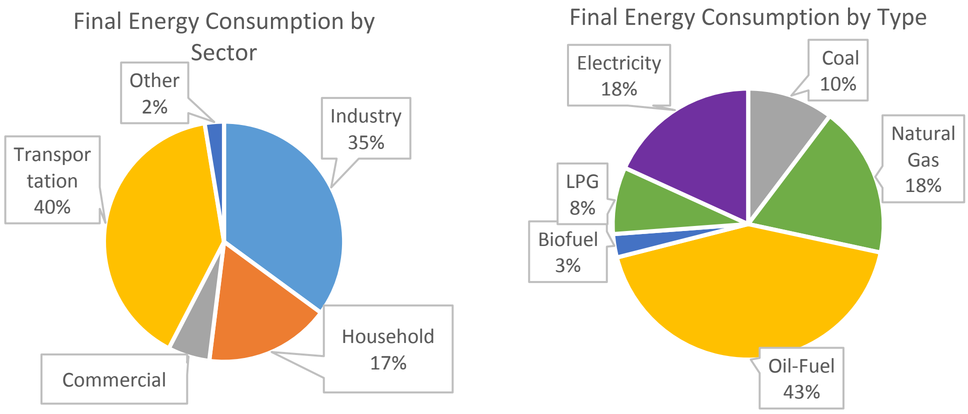



Figure 10. Indonesia's Final Energy Consumption, 2015

Source: Handbook of Energy & Economics Statistics of Indonesia 2016

- Electricity Situation

As of the end of 2014, the capacity of power systems in Indonesia was 53,065.50 MW consisting of PLN's Power Plan 37,379.53 MW and Non-PLN 15.685,97 MW. Compared with 2013 which was 50,898.51 MW, the capacity of the power system increased by 2,166.99 MW or 4.25%. As of the end of 2014, the transmission lines reached 40.331,73 km-length (see Table 6).

Table 6. Indonesia’s Installed Capacity of Power Plant, by type (MW)

| Year | Steam PP | Gas PP | Combined Cycle PP | Engine PP | Diesel PP | Hydro PP | Mini Hydro PP | Micro Hydro PP | Geothermal PP | Wind PP | Solar PP | Coal Gasification PP | Waste PP | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2011 | 16,318 | 4,236 | 8,480 | 169 | 5,471 | 3,880 | 57 | 5 | 1,209 | 0.93 | 1 | 41 | 26 | 39,898 |
| 2012 | 19,714 | 4,343 | 9,461 | 198 | 5,973 | 4,078 | 61 | 6 | 1,343 | 0.93 | 4 | 41 | 26 | 45,253 |
| 2013 | 23,812 | 4,389 | 9,852 | 448 | 5,935 | 5,058 | 77 | 29 | 1,345 | 0.6 | 9 | 6 | 26 | 50,898 |
| 2014 | 25,104 | 4,310 | 10,146 | 610 | 6,206 | 5,059 | 139 | 30 | 1,405 | 1.2 | 9 | 6 | 26 | 53,065 |

Source: PLN Annual Report 2015

The amount of each line is as follows: Extra high voltage transmission lines have reached 5.053 km, and High voltage transmission lines have reached 35.278,73 km. Total distribution lines increased to 925.311,58 km. The amount of each line is as follows: Medium voltage distribution lines reached 339.558,02 km and low voltage distribution lines reached 585.753,56 km. The sub stations increased by 5.127 MVA or 6,30%, from 81.345 MVA in 2013 to 86.472 MVA by the end of 2014, and distribution sub stations have also increased by 3.595,02 MVA or 8,32%, from 43.183,67 MVA in 2013 to 46.778,69 MVA by the end of 2014. Total distribution sub stations have also increased by 26.565 units or 7,32%, from 362.746 units in 2013 to 389.311 units in 2014.

Electricity supply in 2014 was 228.554,90 GWh, consisting of PLN’s self-production of 175.296,97 GWh and a purchase of 53.257,93 GWh. Compared to the year 2013, the electricity of PLN’s production was 163.965,74 GWh, so the increase was 11.331,23 GWh or 6,91% when compared to 2013, while the purchased electricity in 2014 was 53.257,93 GWh, an increase of 1.035,14 GWh or 1,94%. The sale of PLN electricity in 2014 was 198.601,77 GWh, which when compared to the year 2013 was an increase of 11.060,75 GWh or 5,89% consisting of sales to the industrial sector at 65.908,67 GWh, to the residential sector at 84.086,46 GWh, to the commercial sector or business enterprises at 36.282,42 GWh, and to the public sector at 12.324,21 GWh.

The number of customers in 2014 reached 57.493.234, which when compared to 2013 was an increase of 3.497.026 or 6,48%. Residential was the largest group of customers, numbering in 53.309.325 or 92,72% of all customers. PLN Energy’s losses in 2014 reached 21.423,30 GWh, the amount of each line is as follows; transmission losses at 5.224,63 GWh and distribution losses at 16.198,66 GWh. Compared to the net production of 220.712,66 GWh, these represented 2,37% and 7,52% in overall transmission and distribution losses respectively.

The electrification ratio is the ratio of the electrified household to the total households. Until the end of 2014, the electrification ratio had reached 84,35%. Compared to 2013, where the electrification ratio was 80,51%, meaning an increase of 3,84%.

(3) Policy on Energy and Electricity

Due to an aging production infrastructure and underdeveloped oil fields, the Master Plan for Economic Expansion and Acceleration (2011-2025) was introduced in order to encourage the participation of the private sector in infrastructure development including the energy sector. Furthermore, Indonesia's government aims to promote the use of coal in the electricity sector as it is domestically available and relatively cheap.

Under the Energy Law No. 30/2007, The National Energy Council (NEC) was established. It has a responsibility and authorization to plan and formulate the National Energy Policy (KEN) and the National Energy General Plan (RUEN). Indonesia's energy policy is mainly focused on the attempt to ensure the security of the energy supply. This consists of three core objectives: 1) Diversification of energy mix, 2) Conservation of energy utilisation, and 3) Establishment of energy strategic reserves.

The infrastructure in Indonesia is another issue that is aimed at being further developed, especially the national electricity grid. Under the Master Plan for Acceleration and Extension of Indonesia Economic Development (*or Master Plan Percepatan dan Perluasan Pembangunan Ekonomi Indonesia-MP3I*), the expected investment in the power and energy sector is 669 trillion IDR (69 billion USD) for energy infrastructure during the period 2014-2019.

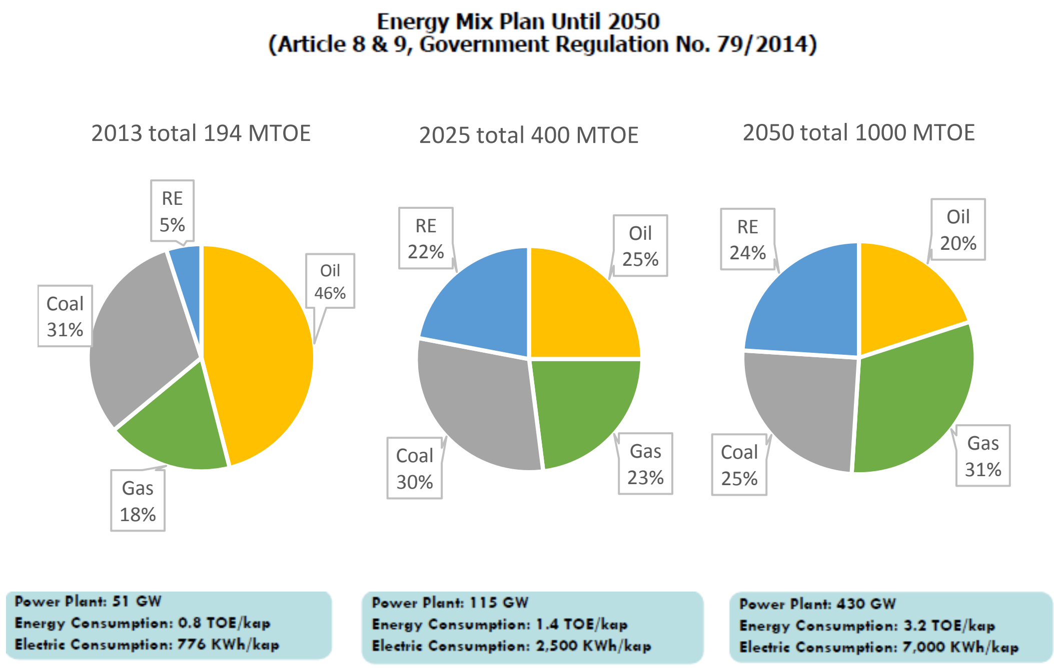



Figure 11. Indonesia's Current and Projected Energy and Power Mix

Source: Government Regulation No.79, 2014

- Challenges on Electricity Infrastructure

Through the Government Regulation No. 79 year 2014 on National Energy Policy (*Kebijakan Energi Nasional-KEN*), the Government has set the target of energy mix in the primary energy supply for the year 2025 and 2050 (see Figure 11). According to this regulation, it is expected in 2025 the share of oil should be less than 25%, coal 30%, and gas 22%. While the new and renewable energy (NRE) share should be at least 23%. As a consequence of the KEN target, the Ministry of Energy and Mineral Resources c.q. Directorate General of Electricity as the regulator of electricity in Indonesia, has integrated that target into the energy mix of power generation under the draft of the National Electricity General Plan (RUKN) 2015-2034 which was already submitted to the Commission VII of the Parliament in August 2015.

The target of power generation energy mix, which is already set in the draft RUKN, has become the government policy that should be followed and implemented by not only PLN, but also by other utilities (who have an exclusive area set by the government) in their electricity supply business plan (named as RUPTL). The target of power generation energy mix becomes a challenge for utilities into how they should transform, as before they always relied heavily on coal as a primary energy supply and now the utilisation of coal should be limited. Additionally, the NRE usage increase has created another challenge, since most of the renewable energy sources are located outside of the Java-Bali system, while the peak demand (~70%) is concentrated in the Java-Bali system.

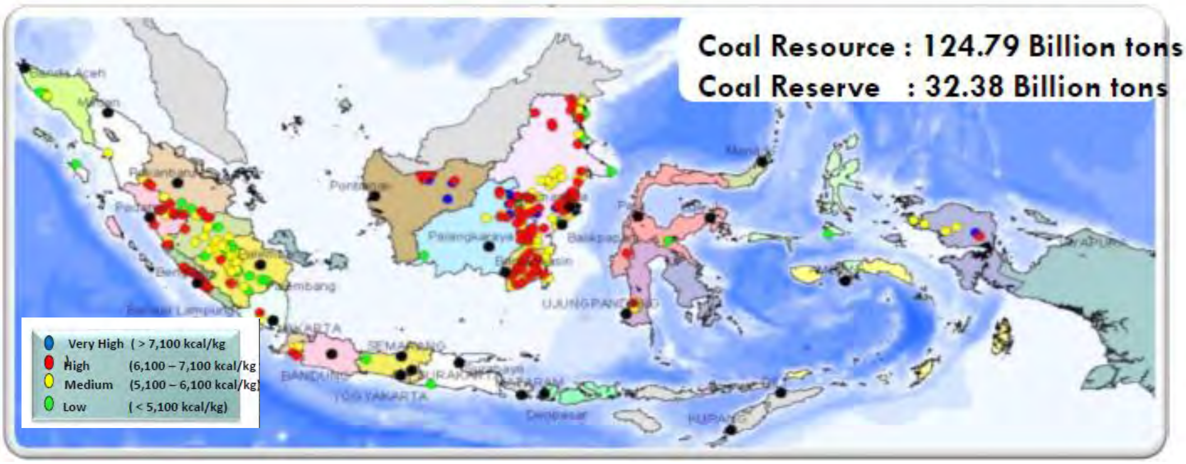
Table 7. Indonesian Electricity Planning under the 35GW Programme

| Year | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Steam PP | 3283 | 1499 | 492 | 4068 | 16497 | 3125 | 2660 | 2035 | 4275 | 4155 | 42089 |
| Geothermal PP | 30 | 85 | 240 | 320 | 485 | 1147 | 660 | 430 | 460 | 958 | 4815 |
| Combined Cycle PP | - | 750 | 3705 | 4060 | 650 | - | - | - | - | 9165 | 18330 |
| Gas PP | 400 | 1804 | 1510 | 474 | 100 | 131 | 294 | 165 | 30 | 125 | 5033 |
| Diesel PP | - | - | 10 | - | - | - | - | - | - | - | 10 |
| Mini Hydro PP | 50 | 30 | 375 | 151 | 130 | 152 | - | - | - | - | 888 |
| Hydro PP | 20 | 45 | 47 | 165 | 357 | 522 | 703 | 1537 | 931 | 2095 | 6422 |
| Solar PP | - | - | - | - | 1040 | - | - | 450 | 450 | - | 1940 |
| Other PP | 11 | - | - | - | 60 | - | 1 | - | - | - | 72 |
| Total | 3794 | 4213 | 6379 | 9238 | 19319 | 5077 | 4318 | 4617 | 6146 | 7333 | 70434 |

Source: Indonesia Country Report, CCT Transfer Program by JCOAL, February 2016

In 2015, the Government launched the 35GW program, which is designed to fulfil electricity demand growth and to achieve an electrification ratio target (see Table 2.2.2.). Under this programme, most of the projects will be offered to the private sector instead of being developed by PLN. The government has a new policy in the power sector that PLN should focus more on developing transmission and distribution lines. While the development of power plants, will be given to the private sector. The development of power plants can only be conducted by PLN, if PLN has the financial capability for equity and gets a low financing source; so the construction risk is low; and/or an isolated system development will be enhanced, as stated in the Presidential Regulation No. 4 year 2016.

- Coal Development




| Coal Quality | Resource (Mil Tons) | | | | Total | %age | Resource (Mil Tons) | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | Hypothetic | Inferred | Indicated | Measured | | % | Probable | Proves | |
| Low rank | 1755.29 | 8904.23 | 10299.52 | 11406.36 | 32365.39 | 25.93 | 5660.67 | 3532.53 | 9219.13 |
| Medium | 16808.73 | 23832.02 | 16507.93 | 24521.63 | 81670.31 | 65.44 | 16408.63 | 4289 | 20763.07 |
| High rank | 874.78 | 2485.34 | 2082.74 | 3201.87 | 1644.72 | 6.93 | 505.76 | 1047.97 | 1560.66 |
| very high rank | 13.61 | 1289.22 | 421.28 | 392.21 | 2116.32 | 1.7 | 769.85 | 175.33 | 946.88 |
| Total | 19452.41 | 36510.81 | 29311.47 | 39522.07 | 117796.7 | 100 | 23344.91 | 9044.83 | 32489.74 |

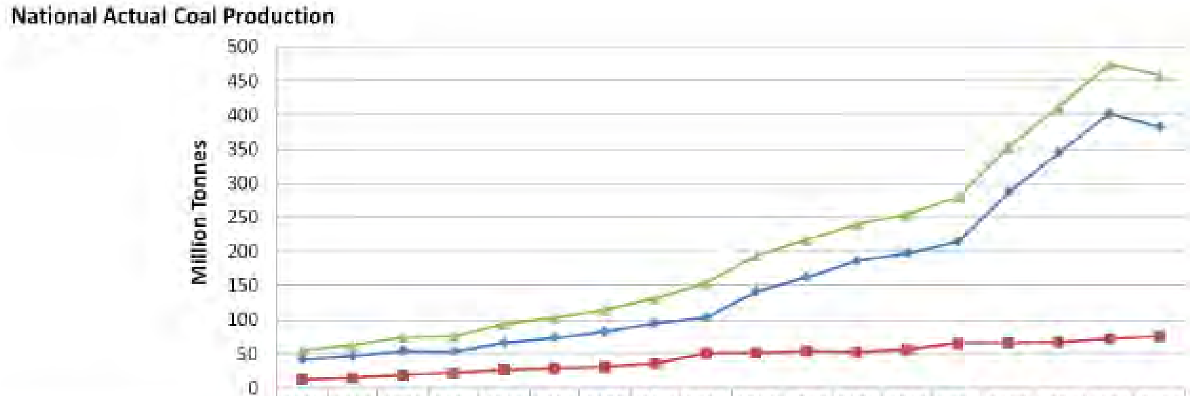
Figure 12. Indonesia's Coal Resources and Production

Source: Indonesia Country Report, CCT Transfer Programme by JCOAL, February 2016

Indonesia had 34.6 billion short tons of recoverable coal at the beginning of 2013, located primarily in South Sumatra, East Kalimantan, and South Kalimantan (see Figure 12). The quality of coal is primarily bituminous, sub-bituminous and lignite of small quantity. The low rank coal is used for domestic purposes especially in the power sector.

Approximately two thirds of Indonesia's coal production come from East Kalimantan. Coal production quadrupled over the past decade from 125 million short tons in 2003 to 538 million short tons in 2013. This increase was the result of a sharp growth in demand particularly in

Asia, where coal had a competitive advantage over higher-priced oil and natural gas. According to the Indonesian Coal Mining Association, supply began to decline in 2014 as international coal prices continued to drop, which resulted in financial losses for small operations. To ensure more transparency and reduce illegal economic gain, the government has proposed limiting exports from a total of 14 ports. Also, in October 2014, Indonesia began requiring export licenses to further manage state revenues paid through royalties and taxes and to manage the amount of exports that leave the country.




| | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Export (Million tonnes) | 42 | 47 | 55 | 54 | 66 | 74 | 83 | 95 | 103 | 142 | 163 | 187 | 198 | 215 | 287 | 345 | 402 | 382 |
| Domestic (Million tonnes) | 13 | 15 | 19 | 22 | 27 | 29 | 31 | 36 | 51 | 52 | 54 | 53 | 56 | 65 | 66 | 67 | 72 | 76 |
| Production (Million tonnes) | 55 | 62 | 74 | 76 | 93 | 103 | 114 | 131 | 154 | 194 | 217 | 240 | 254 | 280 | 353 | 412 | 474 | 458 |

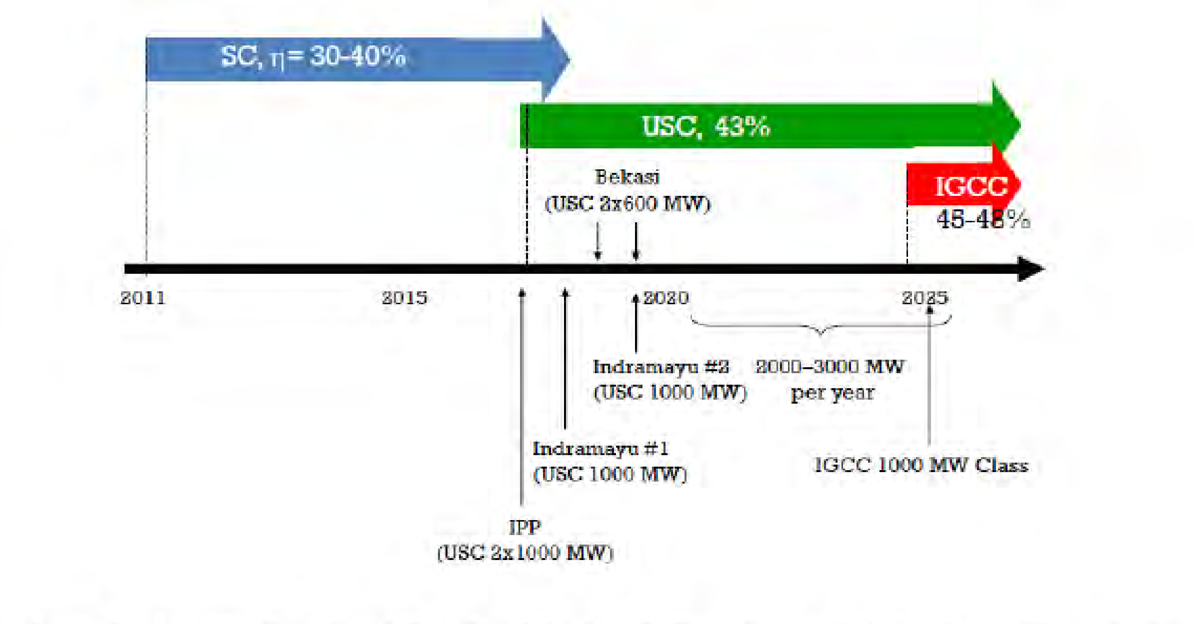
Figure 13. Indonesia Coal Production, Export, and Domestic Consumption

Source: Indonesia Country Report, CCT Transfer Programme by JCOAL, February 2016

Indonesia's coal consumption grew to 79 million short tons in 2013 (see Figure 13). The electricity sector is the largest source of domestic coal consumption. Power plants accounted for about 70% of total coal sales in recent years, while the remainder was used in industries. Electricity sector demand for coal is expected to increase in the next few years as a result of additions to coal-fired generation capacity. Unlike many other countries, Indonesia's government encourages increased use of coal in the power sector, because of the relatively abundant domestic supply. Coal use also reduces the use of expensive diesel and fuel oil to generate electricity. Although coal consumption has grown significantly in the past decade, most production has been exported. To guarantee sufficient domestic supply, the Indonesian government sets a DMO each year based on projected demand.

- CCT Roadmap

In order to fulfil the increasing electricity needs and solve the power interruptions in some systems in Indonesia, the development of coal fired power plants could be one of the solutions to be undertaken by the government due to its relatively shorter lead time to construct and also having a competitive price compared to other conventional power plants. However, the Indonesian Government is facing the challenge to reduce the $CO_2$ emission in coal fired power plants. In this regard, considerations for CCT are making headways in the development of policies to ensure greater security in electricity supply. CCT could find applications in already mature power systems such as in the Java-Bali system.




Source: *The Project for Promotion of Clean Coal Technology (CCT) in Indonesia*, JICA Study Team, with modification

Figure 14. Roadmap of CCT in Indonesia

Source: JICA Study Team for CCT Introduction

According to a CCT study report conducted in 2011 (see Figure 14), the CCT technology that can be adopted and implemented in Indonesia is Ultra Super Critical (USC) and Integrated Gasification Combined Cycle (IGCC) (JICA Study). The Central Java Power Plant with a capacity of 2 x 1000 MW will become the first USC in Indonesia and it is expected to be in operation by 2019. According to PLN's electricity business plan (RUPTL), there will be around 9 GW of USC technologies that will come online in 2019 (see Table 2.2.3 for details). While IGCC, will be introduced around 2025, by considering the development situation of this technology in the world. Both of these two technologies can use low-rank coal, utilising the resources that are abundant in Indonesia.

Table 8. Indonesia's Plan of Super Critical/USC Coal-Fired Power Plants[15]

| No | Power Plant | Capacity (MW) | COD | Developer | Location |
|---|---|---|---|---|---|
| 1 | Steam PP Lontar Exp | 1 x 315 | 2018 | PLN | Banten |
| 2 | Steam PP Jawa Tengah | 2 x 950 | 2019 | IPP | Central Java |
| 3 | Steam PP Indramayu | 1 x 1000 | 2019 | PLN | East Java |
| 4 | Steam PP Jawa 1 | 1 x 660 | 2019 | IPP | East Java |
| 5 | Steam PP Jawa 3 | 2 x 1000 | 2019 | IPP | East Java |
| 6 | Steam PP Jawa 4 | 2 x 1000 | 2019 | IPP | Central Java |
| 7 | Steam PP Jawa 5 | 2 x 1000 | 2019 | IPP | Banten/East Java |
| 8 | Steam PP Jawa 7 | 2 x 1000 | 2019 | IPP | Banten |
| 9 | Steam PP Jawa 8 | 1 x 1000 | 2018 | IPP | Central Java |
| 10 | Steam PP Jawa 9 | 1 x 600 | 2020 | IPP | Banten |
| 11 | Steam PP Sumsel 8 | 2 x 600 | 2019 | IPP | South Sumatra |
| 12 | Steam PP Sumsel 9 | 1 x 600 | 2020 | IPP | South Sumatra |
| 13 | Steam PP Sumsel 10 | 1 x 600 | 2020 | IPP | South Sumatra |

Source: RUPTL 2016-2025

Since the potential of low-rank coal is abundant in Indonesia, in order to maximise the utilisation of the resources, the development of mine-mouth power plants is encouraged by the Ministry of Energy and Mineral Resources by providing some privileges, such as the

[15] PLTU means coal fired power plants and PLTP means geothermal power plants in this table.

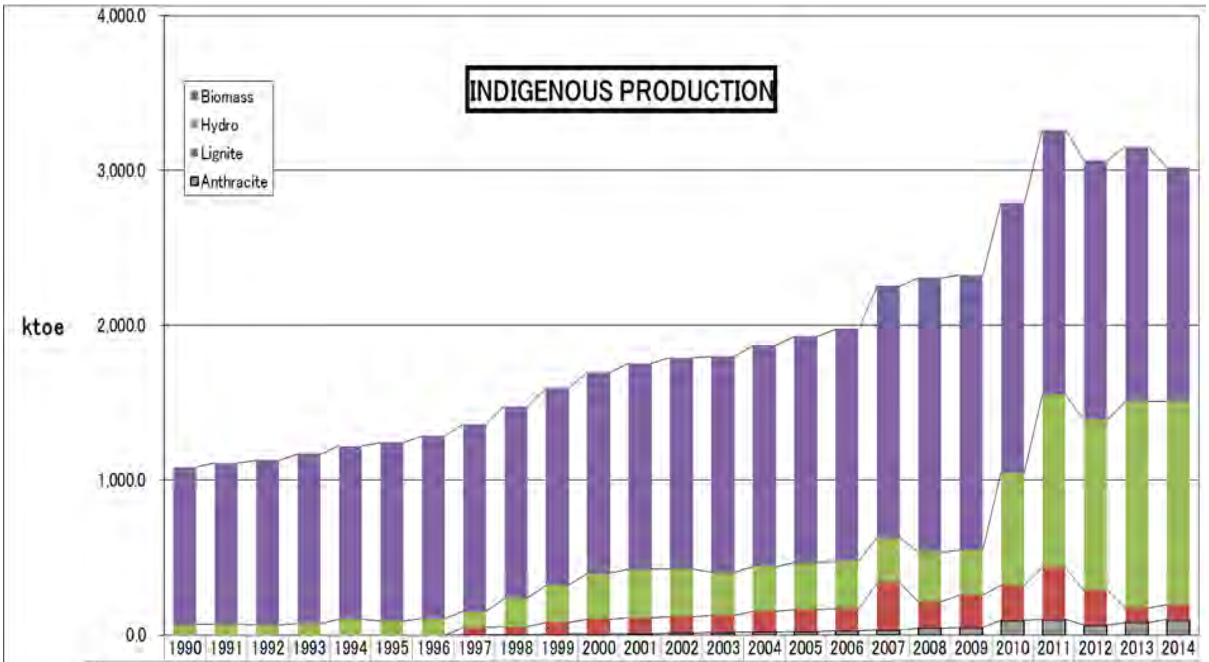
procurement process of power plants can be through direct appointment or direct selection, and the selling price of electricity can use a “cost plus margin” scheme, which will be determined every year based on the coal market condition. According to PLN’s electricity business plan (RUPTL), there will be around 4 GW of mine-mouth power plants that will be developed by 2021.

## 2.3 Lao PDR

### (1) Socioeconomic situation

Lao People’s Democratic Republic (Lao PDR) is located in the middle of the South East Asia peninsula. It has a border with five (5) countries namely; China, in the North; Vietnam, in the East, Cambodia, in the South, and Thailand and Myanmar in the West. Lao PDR has a total land area of 236,800 square kilometres and is inhabited by 6 million people. In 2015, the GDP per capita reached USD 1,730 as a consequence of a 7,6% growth of GDP in the same year. With a high level of economic growth in recent years, Lao PDR is considered one of the fastest growing economies in the East Asia and Pacific region.

### (2) Energy and Electricity Situation




| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Biomass | 1,015 | 1,039 | 1,065 | 1,091 | 1,118 | 1,151 | 1,179 | 1,208 | 1,238 | 1,269 | 1,299 | 1,330 | 1,362 |
| Hydro | 71 | 72 | 65 | 79 | 103 | 93 | 107 | 105 | 186 | 241 | 296 | 314 | 310 |
| Lignite | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 44 | 48 | 77 | 96 | 102 | 105 |
| Anthracite | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.4 | 5.9 | 6.3 | 6.9 | 8.9 | 14.1 |

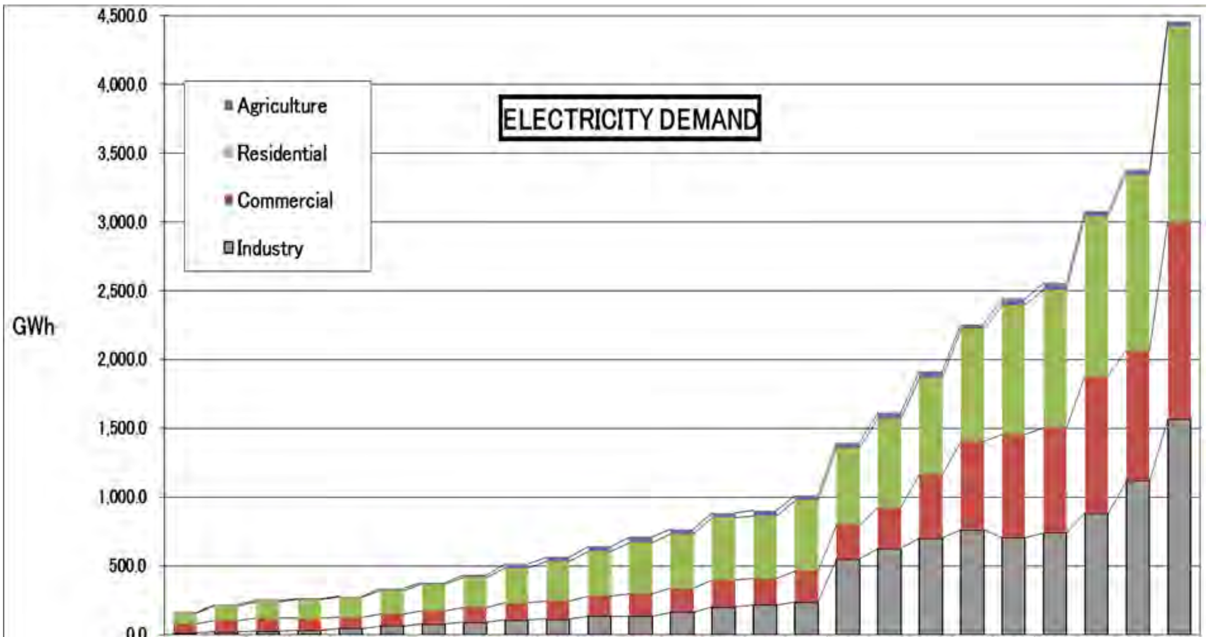
| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Biomass | 1,394 | 1,428 | 1,462 | 1,497 | 1,624 | 1,769 | 1,774 | 1,741 | 1,708 | 1,674 | 1,641 | 1,506 |
| Hydro | 273 | 288 | 302 | 309 | 290 | 320 | 289 | 727 | 1,115 | 1,097 | 1,333 | 1,313 |
| Lignite | 114 | 135 | 144 | 144 | 307 | 171 | 210 | 226 | 338 | 229 | 95 | 95 |
| Anthracite | 17.2 | 20.9 | 22.7 | 27.9 | 33.8 | 47.2 | 50.4 | 95.3 | 101.3 | 64.2 | 83.3 | 102.3 |

Figure 15. Lao PDR’s Indigenous Energy Production[16]

Lao PDR is blessed with significant indigenous energy resources. Energy use within the country is still dominated by the use of fuelwood or biomass (see Figure 15). However, this is a non-sustainable resource and the government recognises that significant logging can cause an unwanted impact on the environment. Lao PDR's indigenous energy production in 2014 was 3,016 ktoe, about 4.3% lower than the previous year as the demand was slower. Biomass is the major fuel with 49.9%, followed by Hydropower with 43.5%, while the remaining 6.5% comes from lignite and anthracite.

In 2014, the industrial sector was the largest electricity consumer accounting for 35.1% of the total, followed by the residential and commercial sectors, respectively at 32% each, while the rest came from the agricultural sector (see Figure 16).

[16] Source: Lao PDR Country Report at ASEAN-Korea Forum on Safety, April 2016.




| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture | 6 | 9 | 12 | 10 | 8 | 14 | 13 | 17 | 30 | 34 | 33 | 41 | 35 |
| Residential | 78 | 107 | 120 | 135 | 145 | 170 | 193 | 218 | 252 | 285 | 325 | 371 | 395 |
| Commercial | 67 | 85 | 96 | 87 | 82 | 89 | 94 | 108 | 124 | 132 | 147 | 163 | 173 |
| Industry | 14.3 | 20.0 | 25.4 | 32.1 | 45.4 | 64.5 | 80.0 | 91.1 | 107.6 | 114.8 | 134.8 | 134.9 | 164.0 |

| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture | 32 | 39 | 35 | 40 | 47 | 44 | 39 | 43 | 46 | 39 | 35 | 36 |
| Residential | 454 | 455 | 511 | 559 | 642 | 707 | 813 | 943 | 1,004 | 1,160 | 1,278 | 1,424 |
| Commercial | 194 | 189 | 229 | 250 | 300 | 461 | 645 | 749 | 765 | 996 | 949 | 1,432 |
| Industry | 203.4 | 218.6 | 236.5 | 549.4 | 626.2 | 703.2 | 760.2 | 707.0 | 740.4 | 882.6 | 1,118 | 1,564 |

Figure 16. Lao PDR's Electricity Demand

Source: Lao PDR Country Report at ASEAN-Korea Forum on Safety, April 2016

Hydropower is the most abundant and cost-effective energy source in Lao PDR, with a theoretical hydroelectric potential of about 26,500MW, excluding the mainstream Mekong. Of this, about 18,000MW is technically exploitable, with 12,500MW found in the major Mekong sub-basins and the remainder in minor Mekong or non-Mekong basins. Around 15% of the country's hydropower potential has been developed over the past 30 years, but under the present government policy, the rate of development will be accelerated to supply more electricity to fulfil the growing demand. In 2014, the total installed and generation capacity is summarised as follows:

- 3,294 MW have been developed with 27 plants and generate 15,887 GWh of electricity per annum.
- 6,185 MW with an annual energy output of 32,866 GWh in 44 hydro and 1 thermal (Lignite) power projects under construction;
- 1,642 MW with an annual energy output of 7,305 GWh in 24 hydro power projects under final preparation/negotiation and F/S;

Table 9. Lao PDR's Electricity Supply in 2014[17]

| Electricity(GWh)- 2014 Supply | | |
|---|---|---|
| Sectors | Consumption | %age |
| Entertainment | 9.278 | 0.21 % |
| Gov. office | 204.0 | 4.58% |
| International organization | 13.0 | 0.29% |
| Educ. and sport business | 540.0 | 12.12% |
| Industry | 1,564.0 | 35.1% |
| Commercial | 666.21 | 14.9% |
| Residential | 1,424.0 | 31.9% |
| Agriculture | 35.6 | 0.8% |
| Total Consumption | 4,456.1 | 100% |
| Total Export | 14,624.97 | |
| Total Import | 1,214.91 | |

By 2020, Lao PDR's total installed capacity will have reached 11,121 MW, with an annual energy output of 56,058 GWh.

Table 10. Lao PDR's coal production data

| Coal Production | | Coal Export | | Consumption | |
|---|---|---|---|---|---|
| Total production | 438,250 | Total Coal Export | 308,762 | Total Coal Consumption | 168,553 |
| Industry anthracite | 227,250 | Anthracite | 54,462 | Lignite | 157,780 |
| Lignite | 211,000 | Lignite | 254,300 | Anthracite | 10,773 |

(3) Policy on Energy and Electricity

[17] Clean Coal Technology Sharing Knowledge, Tokyo, Japan, Lao PDR PPT

The first Power Sector Policy in Lao PDR was formulated in 1990. The objectives were: 1) earn foreign exchange through electricity export; 2) increase access to electricity by grid extensions and off-grid rural electrification; 3) maintain an affordable tariff to promote economic and social development; and 4) replace dependence on imported fuels for energy generation. The Lao Government is serious in accelerating small-scale power development, which is suitable for rural electrification, by utilising the resources of various fuels. The objective is to achieve 90% electrification by 2020 and 98% by 2030 through grid extensions.

The current major energy policies of Lao PDR are as follows:

1) Development of relatively low cost indigenous fuel, such as coal, to reduce import of expensive petroleum products and reduce the consumption of fuelwood;
2) Development of hydropower to meet most of the country's energy needs as well as to provide greater export earnings from electricity sales to neighbouring countries;
3) Implementation of an appropriate pricing policy that will positively influence consumption patterns and assist the government in achieving its fuel substitution and conservation objectives; and
4) Strengthening institutional capacity in the energy sector particularly in the field of training, policy formulation, and project implementation and financial management.

In Lao PDR, the power sector serves two vital national priorities:

1) To promote economic and social advancement by providing a reliable and affordable domestic power supply; and
2) To earn foreign exchange from electricity exports.

Since the year 2008, the export of electricity amounted to approximately 30% of all of Lao PDR export levels. The Lao Government is committed to supply 7,000MW to Thailand, 5,000MW to Vietnam and 1,500MW to Cambodia by 2020. To date, the Government has signed an MoU and is undertaking research studies on a total of more than 70 hydropower projects.

- Coal Development

Coal mining activities in Lao PDR are at an early stage compared with many other AMS. The coal data and information are quite inadequate including the relevant specific rules and regulations. Most of the coal activities are in the exploration phase and involve mainly small to medium size mining operations. Almost all coal mines in Lao PDR are open cast. So far, there is not any research and development for coal upgrading. The increased utilisation of coal for domestic consumption (i.e. cement industry) and the demand of a coal-fired power plant have led to more coal consumption and the demand for a higher coal production. Due to the recent developments regarding the coal demand and supply situation, the Government has amended the Decree on the Expert of Minerals from June 2008. Coal is now regarded as one of those commodities that the Government does not allow to be exported.

Furthermore, the Government has ongoing cooperation with Thailand to conduct coal exploration in the Nakheng and Namon villages in the Feuang District, Vientiane province. According to a report from the Ministry of Planning and Investment, the Government approved the investment in the mining sector from 2000 to 2010 to build several dams and coal-fired power plants. The investments were intended to enable the trade of electricity with the neighbouring counties.

- Clean Coal Initiative

In Lao PDR, there is no concrete policy and planning on the development of clean coal technology. However, the Government is continuously embarking its plan to improve knowledge and experience from developed countries through various capacity building activities, as well as technical and financial assistance.

## 2.4 Malaysia

### (1) Socio-economic Situation

Malaysia is located in the South-Eastern part of the East Asia peninsula and the Northern part of Borneo Island. Malaysia has a total land area of 330,290 square kilometres with its total population of 30 million people. During the period 2011-2015, the Malaysian economy expanded at a steady pace despite mixed performance globally. Real Gross Domestic Product (GDP) is estimated to expand by 5.3% per annum with nominal per capita Gross National Income (GNI) expected to increase by 5.8% from RM27,819 (US$8,636) in 2010 to RM36,937 (US$10,196) by 2015. Between 2009 and 2014, the average monthly household income expanded faster at 8.8% per annum. Growth was driven by strong domestic demand, particularly from the increased private investment, and a diversified economic base which softened the impact of a challenging external environment. Due to the steady expansion of the economy, people enjoyed improvements in income distribution and low unemployment at 2.9%.

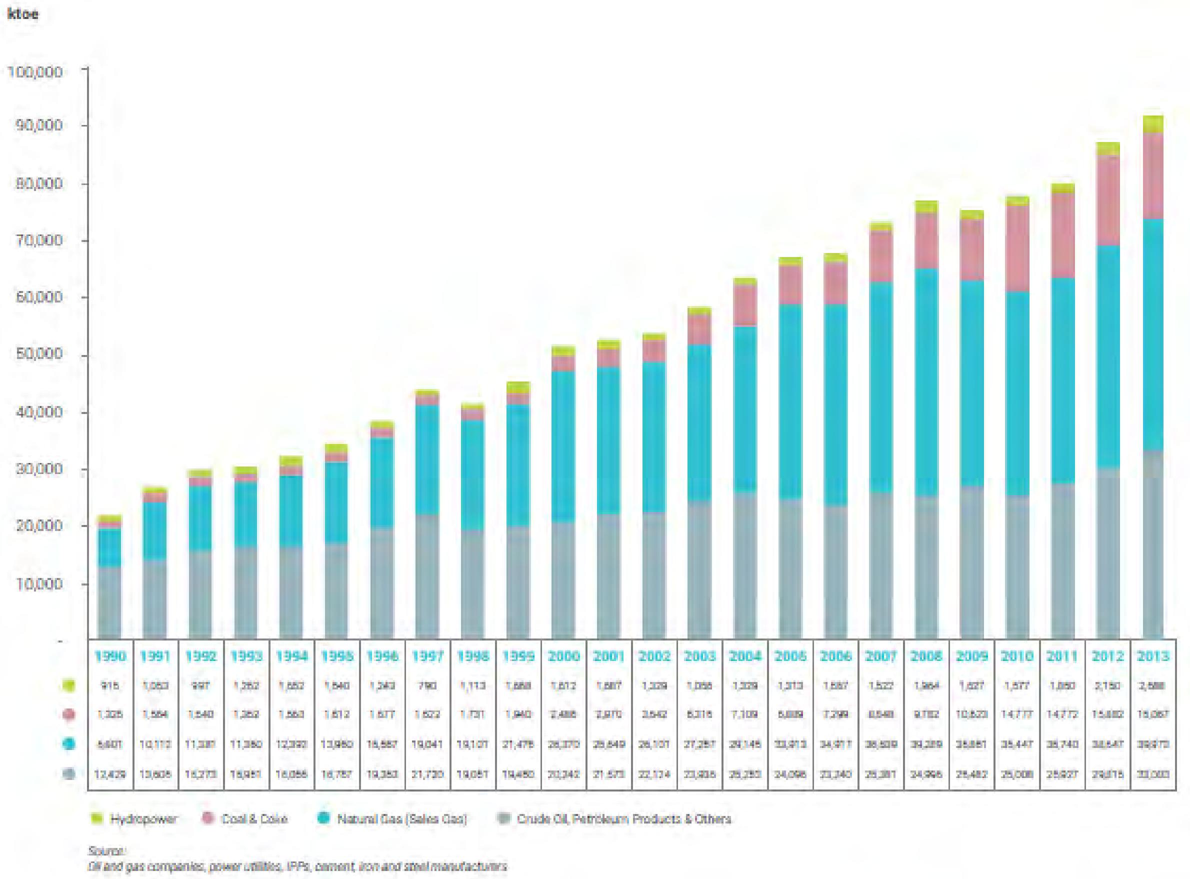
Malaysia, like many countries across the world, is grappling with the challenge of balancing a growing population and demand, with a natural environment that is increasingly under stress. In the global context of increasing intensity and frequency of extreme weather events, adopting green growth has now become an imperative for Malaysia. It represents Malaysia’s commitment to renew and, indeed, increase its commitment to the environment and long-term sustainability.

(2) Energy and Electricity Situation

Malaysia's electricity generation mix has always been highly dependent on fossil fuels. More than 12,000MW of new capacity will be commissioned between 2015 and 2020 in addition to the recently commissioned TNB power plant Janamanjung U4 of 1,010MW of generation capacity[18]. Malaysia's energy supply and consumption posted a strong growth. The total primary energy supply continued to increase at 4.9% (2012: 9.1%) due to higher production and imports especially from natural gas and petroleum products. Total final energy consumption recorded a 4.6% growth, contributed by a higher level of fuel consumption in the transportation sector.

The total primary energy supply in 2013 increased by 4.9% to register at 90,730 ktoe (see Figure 17). The increase was a result of higher natural gas production in 2013. Total natural gas production increased by 2.9% to settle at 64,406 ktoe (2012: 62,581 ktoe). The higher production of natural gas was due to higher production from the Sarawak gas fields and resulted in an increase of 6.8% compared to the previous year. The production of crude oil, however, decreased by 1.8% to register at 28,576 ktoe.

[18] Peninsular Malaysia Electricity Supply Industry Outlook 2016




| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydropower | 915 | 1,053 | 997 | 1,262 | 1,652 | 1,540 | 1,243 | 790 | 1,113 | 1,668 | 1,612 | 1,687 |
| Coal & Coke | 1,326 | 1,564 | 1,540 | 1,262 | 1,563 | 1,612 | 1,677 | 1,622 | 1,731 | 1,940 | 2,486 | 2,970 |
| Natural Gas (Sales Gas) | 6,601 | 10,112 | 11,381 | 11,360 | 12,392 | 13,960 | 16,567 | 19,041 | 19,101 | 21,476 | 26,370 | 25,849 |
| Crude Oil, Petroleum Products & Others | 12,429 | 13,605 | 15,273 | 15,951 | 16,056 | 16,757 | 19,353 | 21,720 | 19,051 | 19,450 | 20,242 | 21,573 |

| | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydropower | 1,329 | 1,058 | 1,329 | 1,313 | 1,587 | 1,522 | 1,864 | 1,627 | 1,577 | 1,850 | 2,150 | 2,588 |
| Coal & Coke | 3,542 | 6,316 | 7,109 | 6,889 | 7,299 | 8,848 | 9,782 | 10,623 | 14,777 | 14,772 | 15,882 | 15,067 |
| Natural Gas (Sales Gas) | 26,101 | 27,257 | 29,145 | 33,913 | 34,917 | 36,539 | 39,229 | 35,851 | 35,447 | 35,740 | 38,547 | 39,973 |
| Crude Oil, Petroleum Products & Others | 22,124 | 23,936 | 25,253 | 24,096 | 23,240 | 25,381 | 24,996 | 25,482 | 25,008 | 25,927 | 29,815 | 33,003 |

Figure 17. Malaysia's Primary Energy Supply

The analysis showed that natural gas still had the largest share of the total primary energy supply, with 44.1%. The natural gas share dropped compared to the previous year's share at 44.7%. The share of crude oil, petroleum products, and others remained strong with a share of 36.4%. The total primary supply of coal and coke constituted 16.6% of the total. While the hydropower's share was at 3.0% compared to only 2.5% during the previous year. Malaysia's crude oil reserves stood at 5.850 billion barrels as of 1st January 2013 compared to 5.954 billion barrels in the previous year. The reduction was caused by a lower reserve mainly coming from Peninsular Malaysia with a negative growth rate of 3.2%. Malaysia's natural gas reserves as of 1st January 2013 increased to 98.320 trillion standard cubic feet (tscf), an increase of 6.7% from the 2012 level of 92.122 tscf. The major increase of the natural gas reserves was observed in Sarawak, as the reserves increased by 16.4%.

Table 11. Malaysia's Installed Capacity in 2013

| | | Hydro | Natural Gas | Coal | Fuel Oil | Diesel | Biomass | Others | Total |
|---|---|---|---|---|---|---|---|---|---|
| Peninsula Malaysia | TNB | 1911 | 4955 | - | - | 0 | - | - | 6866 |
| | IPPS | 20 | 8069 | 7200 | - | - | - | - | 15289 |
| | Co-Generation | - | 806 | - | - | 3 | 84 | - | 893 |
| | Self-Generation | - | 31 | - | - | 577 | 370 | 1 | 979 |
| | SREP | 9 | - | - | - | - | 2 | 67 | 78 |
| | Subtotal | 1940 | 13861 | 7200 | 0 | 580 | 456 | 68 | 24105 |
| Sabah | SESB | 70 | 112 | - | - | 394 | - | - | 576 |
| | IPPS | 7 | 529 | - | 152 | - | 40 | - | 728 |
| | Co-Generation | - | 42 | - | - | 48 | 108 | - | 198 |
| | Self-Generation | - | - | - | - | 526 | 123 | - | 649 |
| | SREP | 7 | - | - | - | - | 30 | - | 37 |
| | Subtotal | 84 | 683 | 0 | 152 | 968 | 301 | 0 | 2188 |
| Sarawak | SEB | 108 | 588 | 480 | - | 163 | - | - | 1339 |
| | IPPS | 1800 | - | - | - | - | - | - | 1800 |
| | Co-Generation | - | 289 | - | - | - | - | - | 289 |
| | Self-Generation | - | - | - | - | 9 | 10 | - | 19 |
| | Subtotal | 1908 | 877 | 480 | 0 | 172 | 10 | 0 | 3447 |

Source: National Energy Balance 2015, Suruhanjaya Tenaga

In terms of electricity, Malaysia has three independent systems, namely Peninsular Malaysia, Sabah, and Sarawak. While the biggest share is in Peninsular Malaysia, in total, Malaysia has 29,748 MW installed capacity in 2013. Natural gas is the main fuel source for its power generation as it contributed more than 50% of the installed capacity in 2013, or about 15,421 MW (see Table 2.3.1). Industry is the main consumer of electricity in Malaysia. From a total of 123,076 GWh of electricity consumption in 2013, industry accounted for 45.4%. The commercial sector was second, followed by the residential sector with a 32.7% and 21.4% share respectively (see Figure 18).

Electricity Consumption in 2013, by Sector

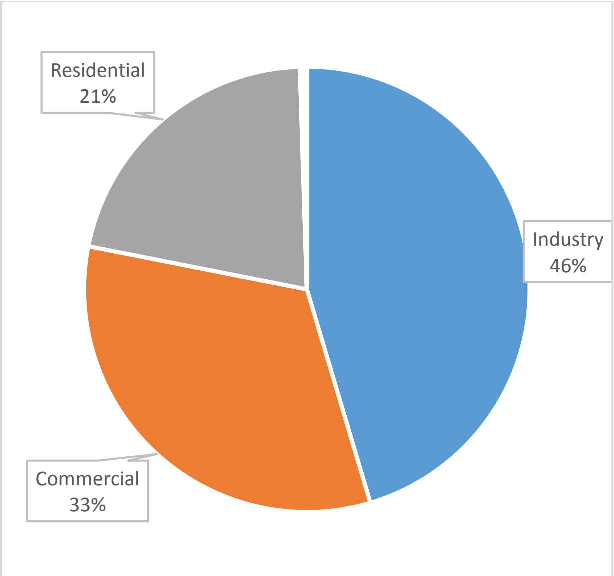



Figure 18. Malaysia's Electricity Consumption in 2013, by Sector

Source: National Energy Balance 2013-2015, Suruhanjaya Tenaga

(3) Policy on Energy and Electricity

The most important policy on coal is the Four Fuel Policy of 1981 which aimed to avoid over-dependence on oil products, and spread the risk of energy supply across gas, hydroelectricity, coal, and oil. In 2001 renewable energy was introduced as the fifth fuel of choice. Interestingly, the reduction in oil dependence has been at the expense of a massive shift to gas; the country is now dependent on gas-fired power for its electricity.

Under the Tenth Malaysia Plan 2011-2015, in the light of the global economic turmoil, the key driver for this plan is to ensure economic growth, income generation, and social development, and so the emphasis on energy and environment seems less prominent than in previous plans, but the aims of previous plans still stand. The tenth plan merely enhances the aspirations of the government in past plans. Some of the economic reforms will also go some way to tackle sustainability issues. Fossil fuels, notably oil products, and gas are all under-priced.

The new energy policy aims to move towards market pricing, in the case of gas this could happen by 2015. The expected withdrawal of subsidies in the Malaysian end user market would help ease the government's funding burden on fossil fuels, but also promote energy efficiency at the same time, helped by the country's own energy efficiency programme, especially in the building sector. Larger electricity users of greater than 2000 kWh per year (some 44% of users) will also face a withdrawal of subsidies. A move to greater market pricing is expected to reduce wastage and in doing so, help Malaysia in its longer-term aim of reducing carbon emissions.

(4) Climate Change Policy

According to national policy, Malaysia adopts a ‘precautionary principle’ and ‘no regret’ policy that allows for justified action to be taken to mitigate or adapt to climate change. Malaysia’s national policy on sustainable development is based on a balanced approach, whereby the environment and economic development complement each other. Some of the strategies adopted by Malaysia to address climate change are as follows:

- The energy sector has been identified as a major contributor of GHG to the atmosphere;
- To reduce the heavy dependence on oil, the Government has identified hydropower and gas, as well as oil and coal, as the primary sources to meet increasing energy demands;
- Promotion of energy efficiency among industries and private sectors;
- Introducing the ‘Guidelines for energy efficiency in Buildings’ which sets minimum standards for energy conservation in the design of new buildings;
- Implementation of public awareness programmes by government agencies and non-government organisations to promote energy efficiency, recycling and use of public transport; and
- Maintenance of an effective forest management and conservation programme to preserve biodiversity and sinks for GHG.

(5) Coal Development

Malaysia’s rising demand for coal for its power plants has posed new challenges in sourcing the required tonnage and quality for the future as global demand is expected to increase. There have been concerns that the traditional suppliers might not be able to supply the preferred coal needs in order to minimise downtime as experienced in 2014. The total consumption in Malaysia is 27.5 mtpa (see Table 2.4.2.).

Table 12. Coal Consumption for Malaysia's CFPP[19]

| Coal – Fired Power Plant | Coal Consumption |
|---|---|
| Kapar Energy ventures GF3 (U3 & U4) | 1.5 |
| Kapar Energy ventures GF3 (U5 & U6) | 2.5 |
| TNB Jamanjung U1-U3 | 6 |
| Tanjung Bin Power | 5.9 |
| Jimah Energy Ventures | 3.6 |
| TNB Jamanjung U4 | 4 |
| Manjung Five | 4 |

Source: Peninsular Malaysia Electricity Supply Industry Outlook 2016

Coal usage will mostly dominate generation due to its price advantage. New technologies such as high efficiency CCGT, clean coal technologies and improved RE technologies will be given priority in determining a future energy mix. Malaysia is a regular participant in world coal trade. Coal production is a modest 1 Mt/y but, as an importer, the country trades some 30 Mt/y. As one of ASEAN's most prosperous economies, the expected growth in electricity demand is inevitable. For many years the country has been dependent on gas-fired power, much of which is in the form of expensive single cycle gas turbines. However, coal-fired power has emerged as an important provider of power in a country desperate to improve its energy security. Currently, there are four locations of the coal-fired power plants and another three are expecting to be online in the near future (see Figure 19). Malaysia requires about 39.5 Million Tonne per Annum (Mtpa) of coal for its power plants in operation, the scale of which now is 12,200 MW in terms of installed capacity (see Table 2.4.3.).

[19] Peninsular Malaysia Electricity Supply Industry Outlook 2016

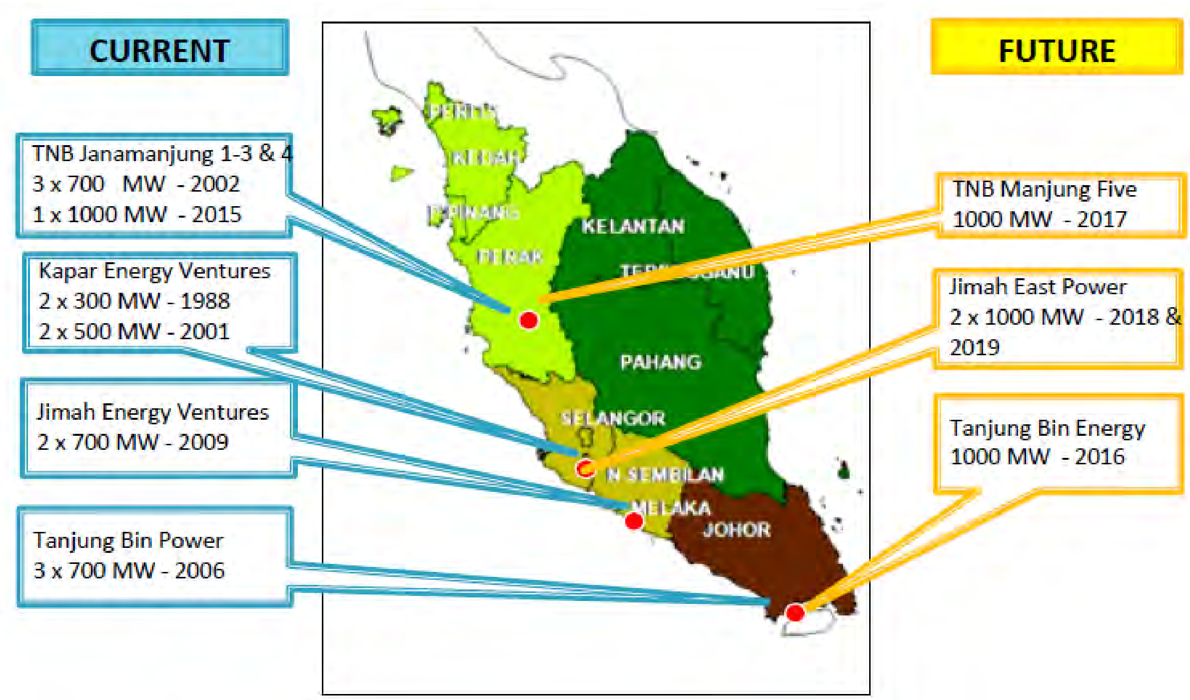



Figure 19. Coal-Fired Power Plants in Malaysia

Source: Malaysia Country Report, CCT Transfer Programme by JCOAL, February 2016

In 2015, coal was the second largest in the fuel mix with a share of 28%, but under the Government's projections it will reach 66% in 2024 and stay around 54% by 2034 (see Figure 20). To comply with the concern regarding the environment, development of new coal power plants in Malaysia must be the supercritical or ultra-super critical, with high efficiency, and utilising clean coal technology.

Table 13. Coal Demand for Coal-fired Power Plants in Malaysia

| Plant | Capacity (MW) | Commissioned | Coal Requirements (mtpa) |
|---|---|---|---|
| TNB Kapar Ph. 2 | 2 x 300 | 1988 | 1.5 |
| TNB Kapar Ph. 3 | 2 x 500 | 2001 | 2.5 |
| TNB Janamanjung | 3 x 700 | 2002 | 6 |
| IPP Tg. Bin | 3 x 700 | 2006 | 5.9 |
| IPP Jimah | 2x 700 | 2009 | 3.6 |

| | | | |
|---|---|---|---|
| TNB Janamanjung 4 | 1000 | 2015 | 4 |
| IPP Tg. Bin Energy | 1000 | 2016 | 4 |
| TNB Manjung Five | 1000 | 2017 | 4 |
| IPP Jimah East Power | 2 x 1000 | 2018 & 2019 | 6 |
| Total Capacity of Coal | 12200 | | 37.5 |

Source: Malaysia Country Report, CCT Transfer Program, February 2016

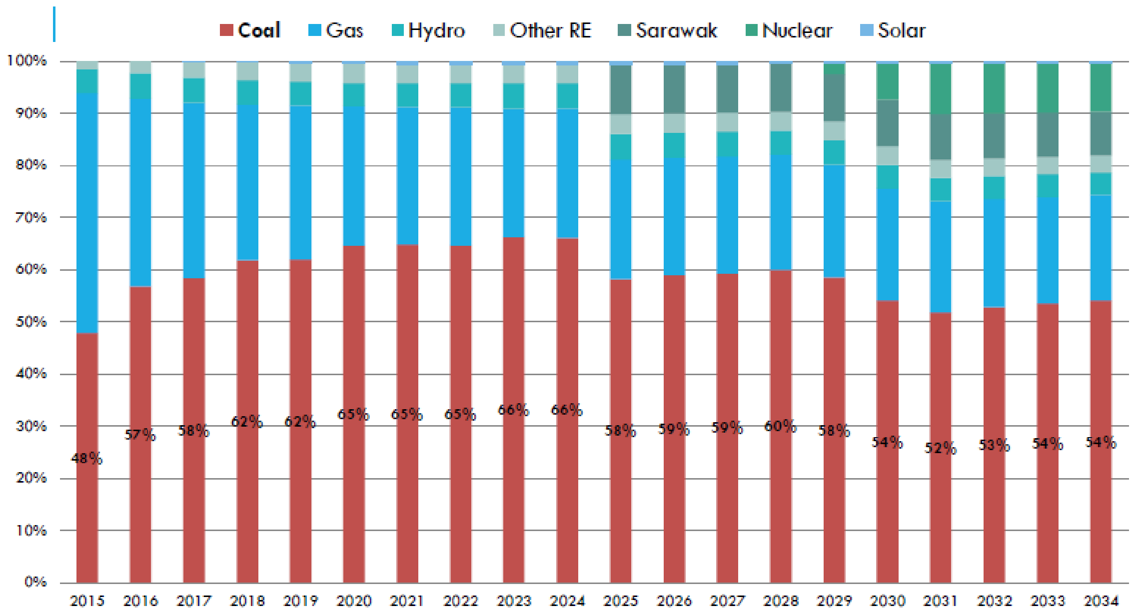



Figure 20. Projected Fuel Mix in Malaysia

Source: Malaysia Country Report, CCT Transfer Program, February 2016

## 2.5 Myanmar

### (1) Socio-economic Situation

Myanmar is located in the Mekong area with a total land area of 676,577 $km^2$ and a 2,800-kilometer coastline along the Eastern side of the Bay of Bengal. Myanmar's population is approximately 51 million or about 76.1 people density per $km^2$.

The per capita gross domestic product (GDP) is about $1278. With recent development on national politics, in Fiscal Year 2014/15, the GDP growth rate reached 8.5%. The economy is predominantly agriculture based, with rice being the main crop and staple food. Liberalization of the economy and opening up to foreign direct investment has prompted rapid growth in the industrial sector, notably with the export of natural gas.

### (2) Energy and Electricity Situation

Myanmar has abundant energy resources, particularly hydropower and natural gas. The hydropower potential of the country's rivers, which drain the four main basins of Ayeyarwaddy, Chindwin, Thanlwin, and Sittaung, is estimated to be more than 100,000 MW. Myanmar has identified 92 potential large hydropower projects with a total installed capacity of 46,101 MW. Proven gas reserves total 11.8 trillion cubic feet (tcf) with huge potential for discovery. Offshore gas is the country's most important source of export revenues, currently supplying Thailand with a new gas pipeline planned to the PRC. A third of the country's $13.6 billion in foreign direct investment is in the oil and gas sector (as of September 2011). Myanmar is one of the five major energy exporters in the region; particularly natural gas. Energy is seen as the central key for Myanmar in re-entering the global economy system, not only because it holds significant reserves of oil and natural gas, but also because the development of the sector will require a major transformation of the basic institutions and infrastructure that will underpin the country's future economic growth.

In the Fiscal Year 2012-13, Total Primary Energy Demand reached 17,988 ktoe, 54% of which came from biomass (see Figure 21). As more than 70% of the population is living in rural areas, this sector consumed most energy, with about 63% of the total consumption in the same FY (see Figure 22).

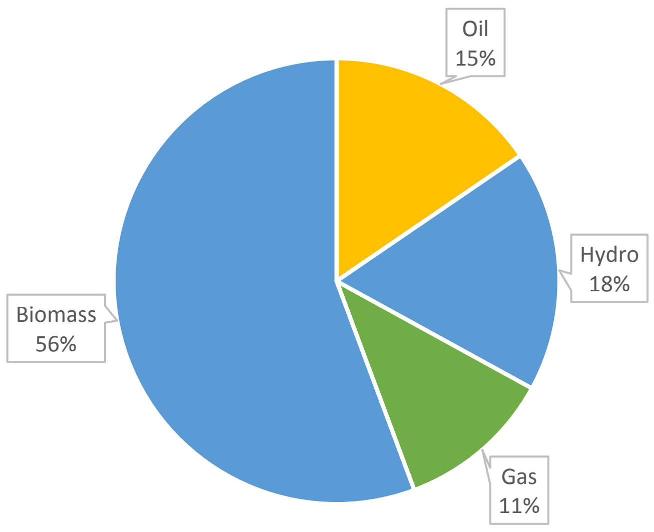



Figure 21. Myanmar Primary Energy Supply 2012-13

Source: Myanmar Country Presentation for AEO4

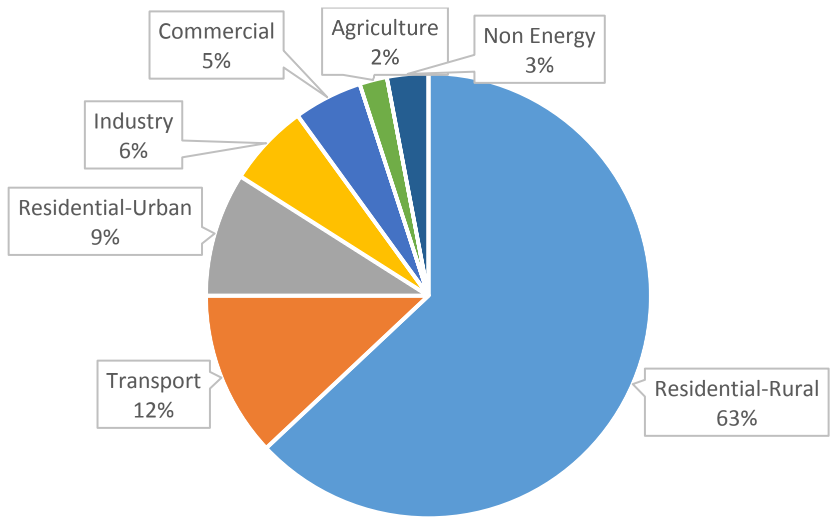



Figure 22. Myanmar's Energy Consumption by Sectors

Source: Myanmar Country Presentation for AEO4

Electricity consumption in Myanmar has doubled during the last 10 years, in FY 2012-13, total electricity consumption was 8,450 GWh (see Figure 23). With a population of about 60 million, Myanmar's per capita electricity consumption was considered as the lowest among other ASEAN Member States. The low national average per capita electricity consumption is due to the low electrification rate, low industrial development, and also a lack of investment. The country's average electrification grew from about 16% in 2006 to 26% in 2011. Yangon City has the highest electrification ratio (67%), followed by Nay Pyi Taw (54%), Kayar (37%), and Mandalay (31%). The remaining rural areas are still poorly electrified; averaging at about 16%.

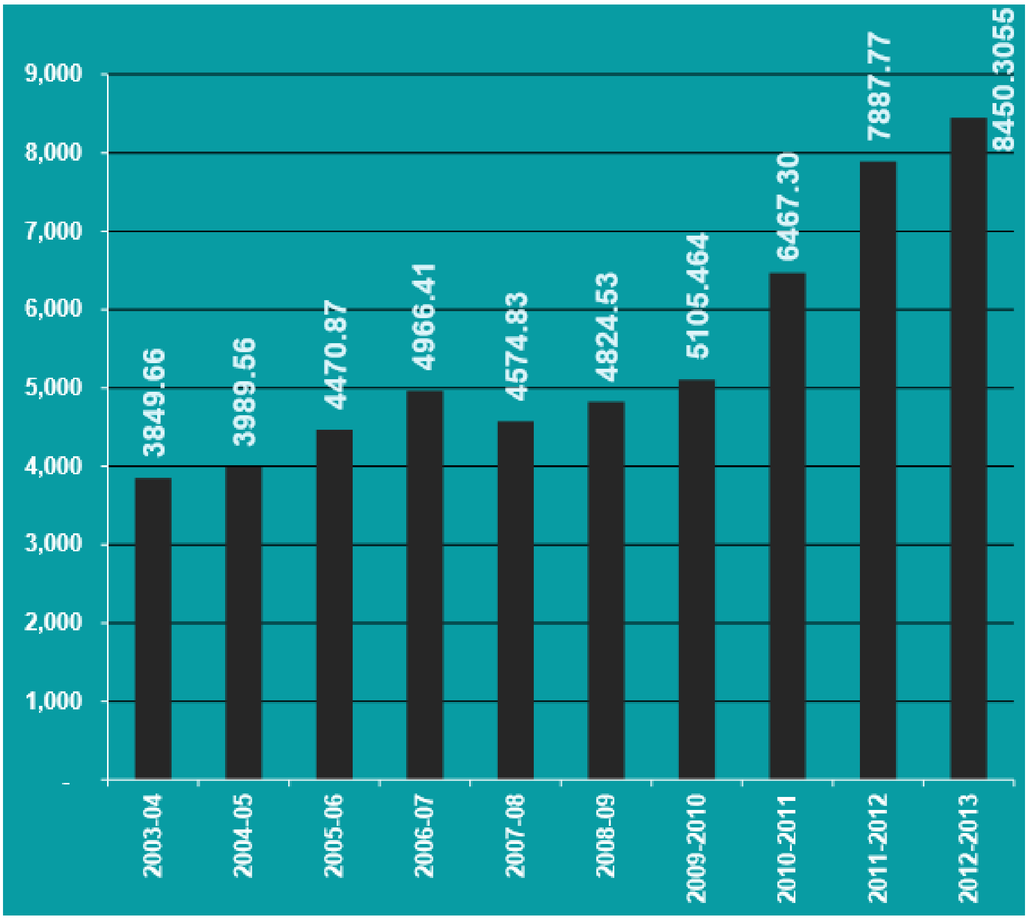



Figure 23. Myanmar's Electricity Consumption

The total system installed capacity in 2011 was 3,361 MW consisting of 2,520 MW (76%) hydropower capacity, 715 MW (21%) gas-fired capacity, and 120 MW (4%) coal-fired capacity. Although the installed capacity exceeds the 2011 peak load of 1,533 MW, the availability capacity of the gas and coal power plants were low due to poor maintenance. Particularly, during the dry season, the hydropower plants cannot generate at full capacity due to a lack of water. Hence, Myanmar's power grid is experiencing significant load shedding during the dry season of up to 400–500 MW. Myanmar Electric Power Enterprise (MEPE) is responsible for the development and implementation of transmission network, covering the voltage levels of 66 kV, 132 kV, and 230 kV. Distribution systems consist of lower voltage levels—33 kV, 11 kV, 6.6 kV, and 0.4 kV. Two distribution enterprises operate the distribution systems in the country. The Yangon City Electricity Supply Board (YESB) is responsible for the supply of electricity to consumers in Yangon City. The Electricity Supply Enterprise (ESE) covers the rest of the country comprising 13 states and regions, including off-grid generation and distribution. It was reported that technical and non-technical losses of the transmission and distribution system were as high as 30% in 2003, but reduced to 27% in 2011. These high losses and low electrification ratio will require the improvement of the transmission and distribution network in Myanmar.

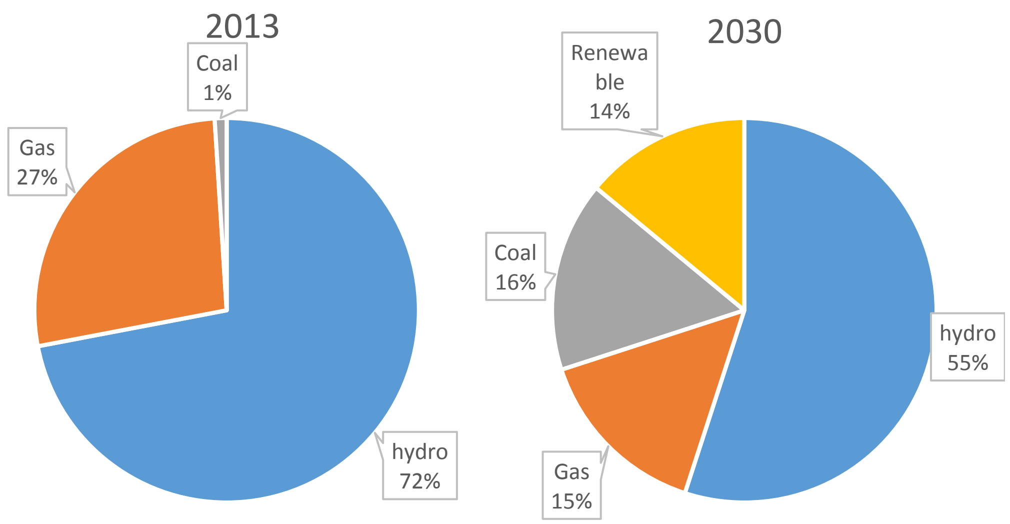



Figure 24. Myanmar's Current and Projected Power Mix

Source: Myanmar Country Report, CCT Transfer Program, 2016

In 2013, hydro and natural gas were major fuels for power generation with a share of 72% (2,259 MW) and 27% (866 MW) respectively (see Figure 24). The coal power plant capacity is only 1% (30 MW) - a quarter of the planned capacity of the 120 MW in Tigyt, Shan state. However, the Government is expecting to see an increase in the coal share to around 16% in 2030, or about 2,620 MW, becoming the second major fuel in power mix. As part of this target, the Government is already preparing future plans for the coal power plant in Myanmar, namely: 400 MW in Kyaingtone, Shan state, 235 MW in Kalewa, Sagaing region, 235 MW in

Mandalay region and also a plan for the Yangon and Dawei region, which is still in the planning stage.

- Energy Policy

Recognising the critical importance of energy for sustainable economic development and the wellbeing of the people, the Government on 9th January 2013 established the National Energy Management Committee (NEMC), with the Vice President of the Government of the Union of Republic of Myanmar as the Patron and the Union Minister for Energy as the Chairman. The implementation and the execution of the Myanmar Energy Policy will be under the guidance and coordination of the National Energy Management Committee and with the support of all concerned organizations/agencies as well as the civil society. The Government has also constituted an Energy Development Committee (EDC) to support the activities of NEMC.

There are nine Energy Policies to be implemented by the National Energy Policy framework consistence with a national energy plan.

1. Implement a short term and long term comprehensive energy development plan based on systematically investigated data on the potential energy resources which are feasible and can be practically exploited, considering the minimum impact on the natural and social environment;
2. Promote private sector participation through Institute laws, rules and regulations and to privatize State Energy Organizations in line with State Economic Reform Policy;
3. Compile systematic statistics on domestic demand and supply of various different kinds of energy resources of Myanmar;
4. Implement programmes by which the local population could proportionally enjoy the benefit of energy reserves discovered in the areas;
5. Implement programmes on a wider scale, utilisation of renewable energy resources such as wind, solar, hydro, geothermal, and bioenergy for the sustainable energy development in Myanmar;
6. Promote Energy Efficiency and Energy Conservation;
7. Establish R, D, D & D (Research, Development, Design and Dissemination) Institution in order to keep abreast of international practices in energy resources exploration and development works and also to produce international standard products in order to manufacture quality products and conduct energy resources exploration works in accordance with international standards;
8. Promote international collaboration in energy matters; and

9. Formulate the appropriate policy for energy product pricing, meeting the economic security of energy producers and energy consumers.

Myanmar identified four main drivers for its energy policy framework: to maintain energy independence, to promote utilisation of renewable energy, to promote energy efficiency, and the use of alternative fuels.

- Electricity Policy

The Electricity Act of 1948 (with amendment in 1967), the Myanmar Electricity Law, and the Electricity Rules (1985) are major regulations for the electricity sector in Myanmar. There are several points highlighted by Myanmar regarding the policy on the electricity sector:

1. Employ the available energy resources in power generation for the sufficient supply of electricity;
2. Promote the effective and efficient use of electricity for future energy sufficiency, reserves and sustainability in our nation;
3. Conduct a reliable power quality to be supplied safely;
4. Enhance the electricity distribution system to be developed in accordance with the advanced technologies;
5. Adopt environment-friendly methods of electricity generation, transmission, and distribution;
6. Encourage the expansion of power transmission and distribution throughout the country and the Public-Private-Participation in each sector;
7. Obtain millennium achievements, besides constructing thermal power plants, need to construct more hydro power plants yearly by the EIA and SIA, whereas hydro power is the clean and renewable energy.

In responding to the growth of economy, the Government has calculated the need of the installed capacity on electricity (see Figure 25).

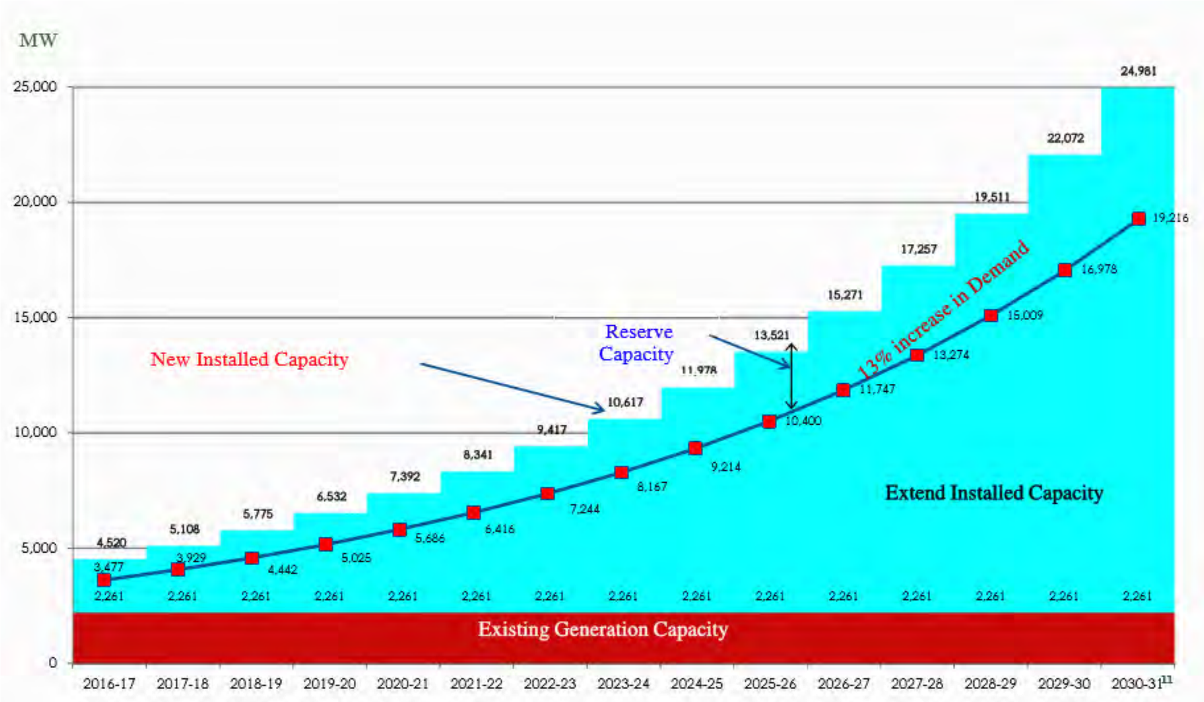



Figure 25. Myanmar's Long-Term Demand Forecast and Required Generating Capacity

Source: Myanmar Country Presentation at JICA Tokyo International Center Training Program, 23rd June – 13th July 2013

- Coal Development and Policy

Some 500 coal occurrences have been identified in Myanmar with the most notable occurrences in the Ayeyarwaddy and Chindwin river basins, as well as in the southern part of Myanmar and the intra-mountain basins, including in Shan State. Coal exploration began in 1965 with a total 200 deposits of coal discoveries with total reserves of 540.317 million tons (see Figure 26). However, Only 1% of this estimated potential, however, has been confirmed. The biggest deposit was found in the Sagaing area. From a geological perspective, most of Myanmar's coal resources were formed during the Tertiary period, mostly lignite to sub-bituminous. Coal found in Shan State tends to be of a lower quality (sub-bituminous).

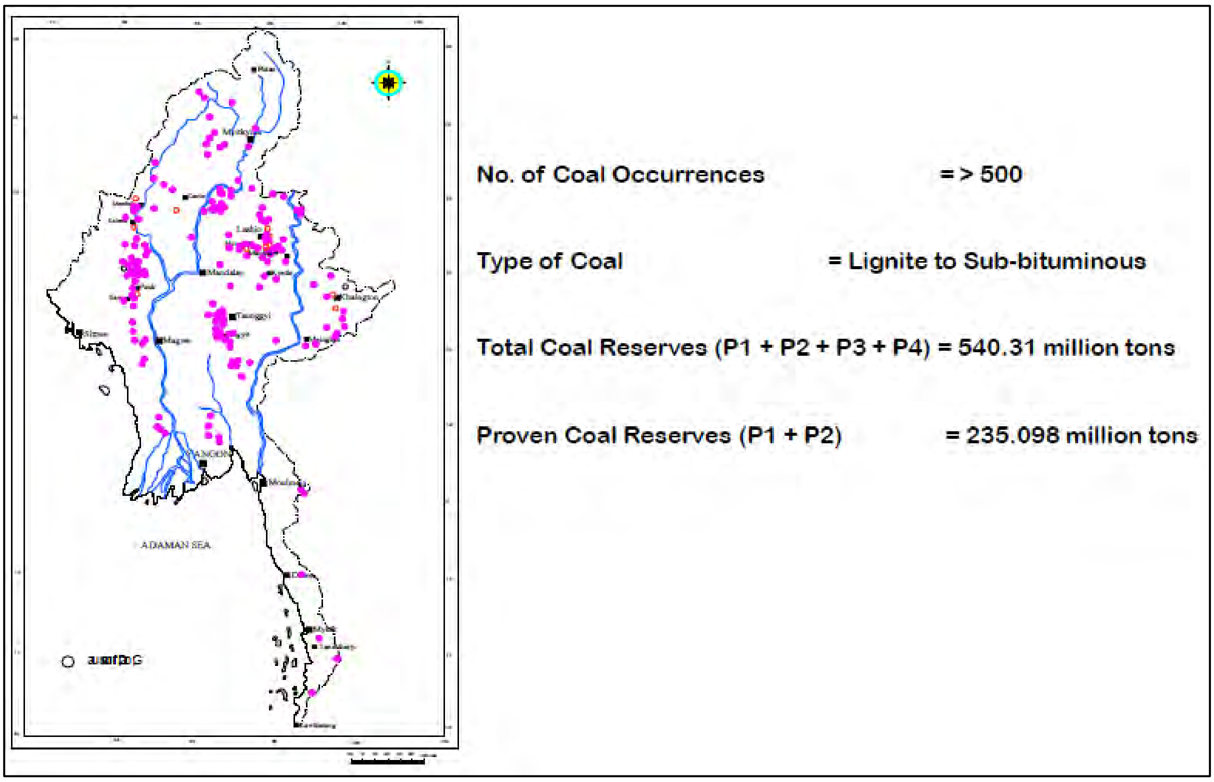



Figure 26. Myanmar's Coal Reserves

Source: Myanmar, CCT Transfer Program by JCOAL, February 2016

The Government implements several related policies on the coal sector, namely:

1) Expanding exploration:
    - Increasing exploration for finding new coal resources.
    - Field studies with international organisations.
    - Planning projects targeting the energy sector.
2) Systematic production of coal:
    - Ground surveying.
    - Production of coal with systematic mine design using modern machineries and technologies to obtain maximum coal tonnage with least waste production.
    - Giving directions to joint-ventured companies.
3) Effective utilisation of coal:
    - Supply of raw materials to make coal briquettes using high technology.
    - Make a policy to use coal in industrial needs.
    - Make a domestic-use-only policy for coal.

- Cooperate with the ministry of energy, cement factories, and coal using industries.
- Allow exportation of coal only with the approval of Union Government.
- Cooperate with ASEAN membership countries in the activities relating to the utilisation of coal.
- Provide assistance in the fulfilment of coal demand to coal-fired power plants.

4) Minimization of environmental impact through promoting the development of CCT:
    - Invite local and foreign investments and technologies.
    - Assist government staff as well as private entrepreneurs and company staff to attend international seminars and workshops held in foreign countries including ASEAN countries.
    - Study the CCT technology for low-grade coal (lignite and sub-bituminous) and its upgrading technology.
    - Encourage coal-fired power plants to use CCT.
    - Send staff to seminars and workshops on CCT.
    - Long-term cooperation with private joint-venture companies working with the Ministry of Energy.
5) Establishment of Research and laboratories:
    - Study of photo-geology and satellite images.
    - Study of sedimentary basin.
    - Study of previous geological reports.
    - Discussion with the expert team for possible sites.
    - Formation of working committee on energy in the ministry.
    - Collection of coal data.
    - Teaching and providing training on coal production, safety, reduction of environmental impacts and mine reclamation.
    - Providing technological needs.
    - Study of coal policies of ASEAN countries.
    - Comparing the conditions of coal resources, demand, and usage of the ASEAN member countries.
6) Allocation of coal reserves for future generations:
    - Only issue mining permits to local companies after detail checking all coal reserves that have been explored.
    - Allocate and reserve some coal deposits for future generations.

2.6 The Philippines

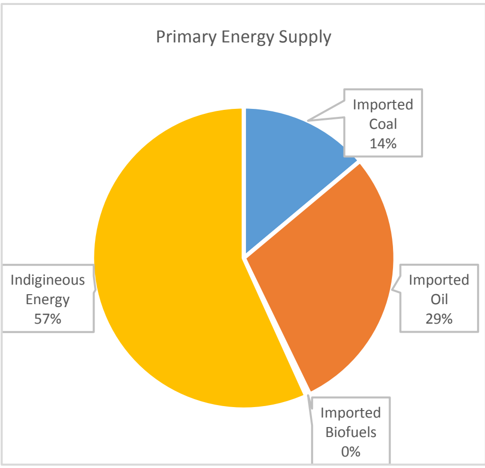
(1) Socioeconomic Situation

An archipelago of 7,107 islands, the Philippines stretches from the South of China to the Northern top of Borneo. With a total land area of approximately 343,448.32 km$^2$. The Philippine archipelago is one of the largest islands in the world, divided into three major island groups, namely; Luzon, Visayas, and Mindanao.

The Philippines has a total population of about 101 million people. Its' Gross Domestic Product (GDP) has Purchasing Power Parity of US$285 billion.

(2) Energy and Electricity Situation

The country's supply of energy increased to 45 Mtoe in 2013 from the 2012 level of 43.75 Mtoe. Preliminary data for 2013 showed that the self-sufficiency level, or the share of indigenous energy, decreased to 56.7% in 2013, from 60.2% in 2012 (see Figure 27).



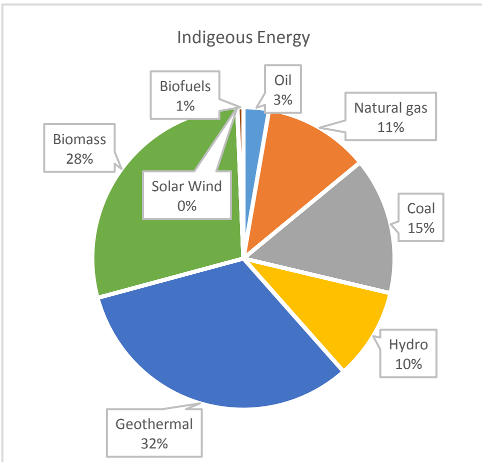




Figure 27. Philippines' Primary Energy Supply

Source: Department of Energy, 2015

Total installed and dependable capacity in the country as of 31st December 2014 slightly increased to 17,944 MW and 15,633 MW respectively, due to the entry of new power plants in the three grids; adding 557 MW to the installed capacity and 153 MW in dependable capacity.

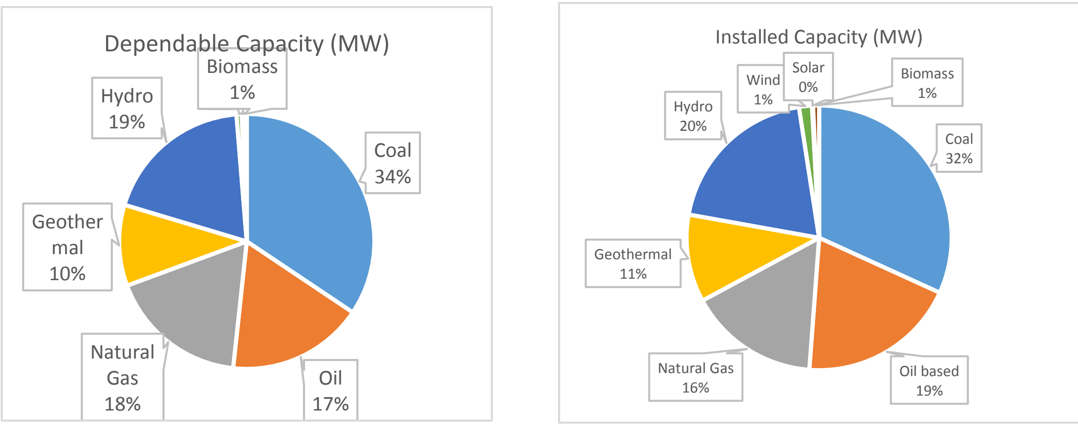



Figure 28. Philippines' Installed and Dependable Capacity

Source: Department of Energy, 2014

The total Installed capacity in Luzon is 13,213 MW or 73.6% of the total installed capacity, followed by Visayas with 2,520 MW or 14%. Mindanao has 2,211 MW or 12.3%. As of the breakdown of dependable capacity, 11,622 MW or 74.3% is accredited to the Luzon grid, 2,160 MW or 13.8% is from Visayas, and 1,851 MW or 11.84% is from Mindanao.

In Luzon, new plants were commercially operational such as 18.9 MW Northwind Phase 3, 81 MW UPC Caparispisan wind, 150 MW EDC Burgos wind farm in the Ilocos region and the 12 MW SCJI power Biomass plant in Nueva Ecija. In addition, the inclusion of the 140 MW Petron Refinery Solid Fuel - Fired Boiler (RSFFB) power plant in Bataan, 12.7 MW Lafarge diesel power plant and the 1.8 MW Communal hydro plant in Nueva Ecija resulted in an increase in installed capacity by 421 MW.

The adjustments made in the dependable capacity of plants such as GN Power in Mariveles, Bataan, resulted in an increase from 125 MW to 132 MW. The unavailability of the Botocan hydroelectric power plant in Laguna due to transmission line issues resulted in a 103 MW net increase in the dependable capacity of Luzon (see Table 2.6.1.).

Table 14. Installed and Dependable Capacity, Luzon

| FUEL TYPE | LUZON | | | | | |
|---|---|---|---|---|---|---|
| | Installed Capacity (MW) | | | Dependable Capacity (MW) | | |
| | Dec-14 | Mar-14 | Difference | Dec-14 | Mar-14 | Difference |
| Coal | 4,671 | 4,531 | 140 | 4,391 | 4,219 | 172 |
| Oil Based | 2,033 | 2,020 | 13 | 1,507 | 1,736 | (229) |
| Natural Gas | 2,861 | 2,861 | 0 | 2,759 | 2,759 | 0 |
| Geothermal | 844 | 844 | 0 | 692 | 607 | 85 |
| Hydro | 2,471 | 2,464 | 7 | 2,131 | 2,147 | (16) |
| Wind | 283 | 33 | 250 | 103 | 17 | 86 |
| Biomass | 50 | 38 | 12 | 39 | 34 | 5 |
| TOTAL | 13,213 | 12,792 | 421 | 11,622 | 11,519 | 103 |

Source: Department of Energy, 2014

The installed and dependable capacity in Visayas (see Table 2.6.2), increased by 59MW and 47MW, respectively due to the commercial operation of the additional 9 MW SACASOL solar farm in San Carlos City and the 50 MW Nasulo Geothermal Power plant, both located in Negros Occidental.

Table 15. Installed and Dependable Capacity, Visayas

| FUEL TYPE | VISAYAS | | | | | |
|---|---|---|---|---|---|---|
| | Installed Capacity (MW) | | | Dependable Capacity (MW) | | |
| | Dec-14 | Mar-14 | Difference | Dec-14 | Mar-14 | Difference |
| Coal | 806 | 806 | 0 | 777 | 777 | 0 |
| Oil Based | 670 | 670 | 0 | 505 | 505 | 0 |
| Geothermal | 965 | 915 | 50 | 817 | 777 | 40 |
| Hydro | 11 | 11 | 0 | 11 | 11 | 0 |
| Biomass | 44 | 44 | 0 | 32 | 32 | 0 |
| Natural Gas | 1 | 1 | 0 | 1 | 1 | 0 |
| Solar | 22 | 13 | 9 | 17 | 10 | 7 |
| *TOTAL* | *2,520* | *2,461* | *59* | *2,160* | *2,113* | *47* |

Source: Department of Energy, 2014

In Mindanao, 124 MW and 102 MW were added to the installed capacity of oil and hydroelectric power plants (see Table 2.6.3.). The grid additional capacity for oil-based capacity are from the 15 MW Mapalad Power Corporation (MPC) ‐ 19 MW In Digos, 15 MW of Mapalad Energy Generation Corporation (MEGC) Diesel plant, 15 MW of Panaon Diesel plant and 8 MW of Tandag Diesel plant of King Energy Generation Inc. (KEGI). There are also two hydroelectric power plants in Davao del Sur in Mindanao. The 37.1 MW thermal plant from the directly - connected industry Philippine Sinter Corporation (PSC) also augmented the existing plants in Mindanao that supplies power to the grid.

Table 16. Installed and Dependable Capacity, Mindanao

| Fuel Type | Mindanao | | | | | |
|---|---|---|---|---|---|---|
| | Installed Capacity (MW) | | | Dependable Capacity (MW) | | |
| | Dec 2014 | Mar 2014 | Difference | Dec 2014 | Mar 2014 | Difference |
| Coal | 232 | 232 | 0 | 210 | 210 | 0 |
| Oil Based | 773 | 663 | 110 | 693 | 605 | 88 |
| Geothermal | 108 | 108 | 0 | 98 | 98 | 0 |
| Hydro | 1061 | 1047 | 14 | 840 | 826 | 14 |
| Solar | 1 | 1 | 0 | 0 | 0 | 0 |
| Biomass | 36 | 36 | 0 | 10 | 10 | 0 |
| TOTAL | 2211 | 2087 | 124 | 1851 | 1749 | 102 |

Source: Department of Energy, 2014

(3) Policy on Energy and Electricity

The Government of the Philippines considers energy as the life-blood of the economy. It is indispensable in achieving economic growth and critical in sustaining a nation's progress and prosperity. Energy is an instrument for poverty reduction and social equity as it serves as an enabling factor to channel grassroots development with the delivery of the much-needed public services to the marginalised and disadvantaged sectors of the society.

Along these lines, the energy sector underscores its guiding vision of "Energy Access for more" to mainstream access of the larger populace to reliable and affordable energy services to fuel, most importantly, local productivity and countryside development. With "Energy Access for more", the Government hopes to resonate a national commitment to move energy access up to higher levels of political and development agenda to become a key priority of the government.

The energy sector has outlined three major pillars as its overall guidepost and direction (see Figure 29), as follows: (a) Ensure energy security; (b) Achieve optimal energy pricing; and, (c) Develop a sustainable energy plan. The foregoing plan is phased into short- (2010-2011), medium-(2011-2013) and long-term (2013-2016) timelines.

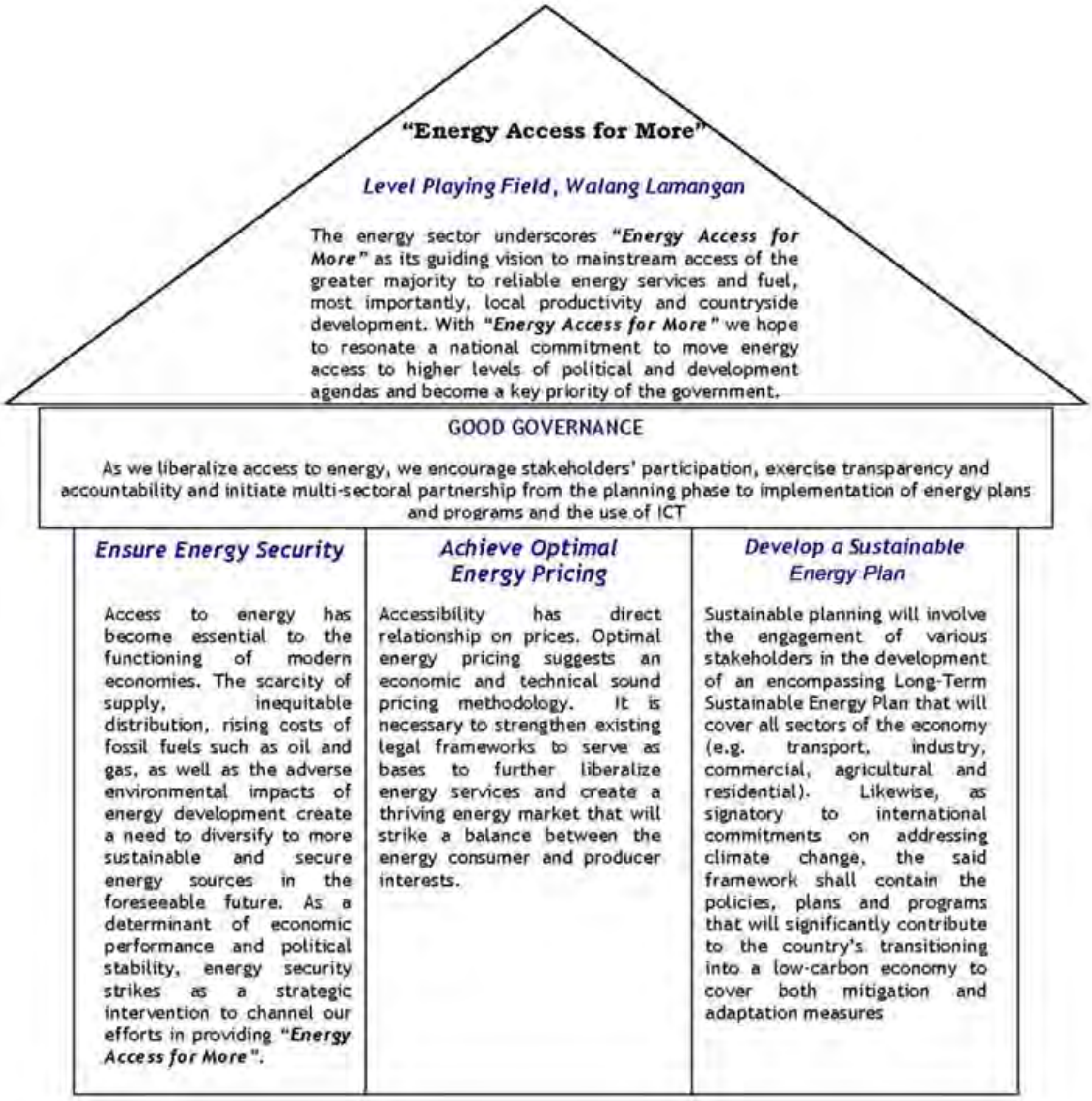



Figure 29. The Philippines' Three Pillars on Energy Reform Agenda

Source: 2012-2030 Philippine Energy Plan, Department of Energy

An over-arching strategy to achieve these three major pillars is the principle of good governance of the energy policy. The government liberalises access, and sets the transparency and accountability in the energy project.

To enhance the energy development, the government set an integrated Information and Communication Technology (ICT) infrastructure that will enable various stakeholders to access energy-related information and services in real time. The online energy data and information will assist policy makers to make intelligible decisions, and guide investors to provide the best options in the initiation stage.

- Electricity Reform

The Philippines had a strong history of successful independent power producer (IPPs) implementations. One of the first successful IPPs was the 735 MW Pagbilao coal-fired plant in Quezon. The formation of the Public-Private Partnership (PPP) framework under the Build-Operate-Transfer (BOT) Law enacted amid the power crisis in the early 90s led to a number of IPPs being set up to meet the power demand in the country. This resulted in investments from foreign companies (AES, Tokyo Electric, and Marubeni) as well as the development of domestic power companies (Aboitiz, Ayala, Energy Development Corporation, Mirant, Meralco, SMC Global Power, etc.).

The country started to involve the private sectors in the 90's. The big push for privatisation and restructuring in the Philippine power sector came with the 1994 World Bank study proposing radical reforms in the industry. Pursuant to the Electric Power Reform Act 2001 (EPIRA), Power Sector Assets and Liabilities Management Corporation (PSALM) was mandated to reform and restructure the sector. Since its formation, PSALM has successfully privatised 26 generating plants and the National Grid Corporation of the Philippines (NGCP) through a 25-year concession while it appointed IPP administrators for five generating plants. Thus, by liquidating all of the financial obligations of the National Power Corporation (NPC), the stage is now set for the introduction of a competitive power market in the country.

- Coal Development and Policy

The Presidential Decree No. 972 of the Coal Development Act of 1976 aims to expand exploration and development of coal production and consumption. Coal mines would come under an operating autonomy for producers but with the rights issued by the Government. Coal production also falls under a number of contractual and environmental regulations. The contract system encourages avoidance of pollution to air, ground, and water, maximising cost effectiveness and ensuring health and safety measures are practised. Environmental Impact Assessments must also be carried out under the Environmental Policy Act of 1997 (PD 1151), which applies to mines, power plants and industrial users.

The Philippines appears to take environmental solutions seriously especially in the combustion of coal for power generation. Under the Environment code (PD 1152), tax exemptions are provided for the purchase and expenses associated with pollution control equipment, spare parts, devices and accessories. Additionally, the Clean Air Act of 1999 (RA 8749) s19(2) requires all coal-fired power stations and industrial users of coal to mitigate SOx and NOx emissions, as well as to ensure the reduction of CO2 emissions. While the latter is more dependent on ensuring high efficiency and the deployment of the cleanest technology that is practicable, the DENR Administrative Order 14, s60 (2) requires the sulphur content of the coal to not exceed 1%, unless appropriate emission control equipment is installed.

In December 2011, the government announced a $600 million investment for coal exploration projects. It shows that the government is keen to expand the utilisation of coal fuel in the country. The government is unlikely to withdraw its support for fossil fuels, which provide a more predictable supply of electricity.

Electricity generation has grown from just 10 TWh in the 1970s to 67 TWh in 2010. Almost all forms of power generation have increased over the decades, led by natural gas fired power plants since 2001. Coal has contributed around 17% of the power generation, although some later data suggests coal accounted for more than 20% in 2010. According to Almendras (2012), coal-fired power increased market share in 2011, accounting for 34% of total generation, while natural gas provided 29%, with renewable (mainly geothermal and hydro) energy at 27%.

In 2013, the Philippines had 17.235 GWe of power generating capacity in operation. Although there has been high growth in natural gas-fired power, coal still has the largest share of the generating capacity. Thermal power also provides more of the 'dependable' power that the Philippines requires. There are nine operating coal-fired power plants with a combined capacity of 4213 MWe (Jemiras.net). The plant list consists entirely of subcritical stations with several small sized circulating fluid bed combustion (CFBC) plants.

The coal-fired power plants are distributed across the country with five in Luzon Island, three in the Visayas and one in Mindanao[20]:

i) Sual Power Plant, the largest coal-fired power plant is operated by Team Energy Corporation which is located in the Pangasinan, Luzon area. It has a total capacity of 1,218 MWe (2 x 609 MWe units) and has been in operation since 1999 using bituminous coal. This was the first plant to install wet limestone flue gas desulphurisation (FGD) scrubbers that has a 226m tall stack.

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[20] DOE of the Philippines 2014

ii) Pagbilao IPP, also operated by Team Energy Corporation has been in operation since 1996. The 734 MWe (2 x 367 MWe) plant is located in Manila on the South-western tip of Pagbilao Grande Island.

iii) The Mindanao plant is 232 MW (2x116 MW) using bituminous coal from Indonesia. The plant is operated by Steag State Power Incorporation located at the Phivdec Industrial Estate near Cagayan de Oro City with a total of 25-years PPA.

iv) The Calaca plant is 600 MWe (2x300 MWe) located at Batangas and operated by SEM-Calaca Power Corporation. It is designed to use local bituminous and subbituminous coal, which have been in operation since 1984 and 1995, respectively. The power plant was the first 300 MWe power plant in the Philippines.

v) The Masinloc power plant is a pulverised coal fired power plant that operated in 1998 to reduce the power shortage in the area. The plant is located in the Zambales province, Luzon. Its capacity is 2 x 300 MWe, which was built by the Mitsubishi Corporation of Japan.

Policymakers, specialists, and scientists point out that the expansion of coal usage faces a number of environmental barriers. To address the challenges, the need for CCT implementation is required to reduce the emissions. In this regard, the Philippines is increasing the use of CFBC, improving the power plants efficiency, and utilising CCS technology. A further option that could be investigated, is the use of large supercritical coal-fired power in the highest demand areas; such as Luzon.

The legislation for coal-fired power stations is stringent with newer coal-fired power stations equipped with FGD and ESP. Nearly all the planned coal-fired power stations are CFBC and small in size at up to 300 MWe. Recently, the government planned to build a coal-fired power plant in Visayas with a total of 1.6 GWe capacity.

## 2.7 Thailand

### (1) Socioeconomic Situation

Thailand is located in Southeast Asia with borders along the Andaman Sea, the Gulf of Thailand and the Southeast of Myanmar. The total area is 514,000 km$^2$ including the land 511,770 km$^2$ and water 2,230 km$^2$. It is bordered by Myanmar, Cambodia Lao PDR, and Malaysia.

The population of Thailand is 68,657 with GDP per capita at 5,436 USD. Based on the total land area and the total population, the population density of Thailand is estimated to be about 127 people per km$^2$.

### (2) Energy and Electricity Situation

In 2015, the total primary commercial energy consumption in Thailand was 2.08 million barrels per day. Natural Gas has the biggest share, accounting for about 44%, followed by oil with 37% (See Figure 30). The consumption of fossil fuels is growing except coal (lignite) consumption which declined from 101,000 barrels per day (kbd) of crude oil equivalent in 2013, to only 78 kbd crude oil equivalent in 2015. For the final commercial energy consumption, the value reached 1,420 kilo barrels per day of crude oil equivalent in 2015, consisting of 4% oil, 21% electricity, and 12% natural gas (see Figure 31).

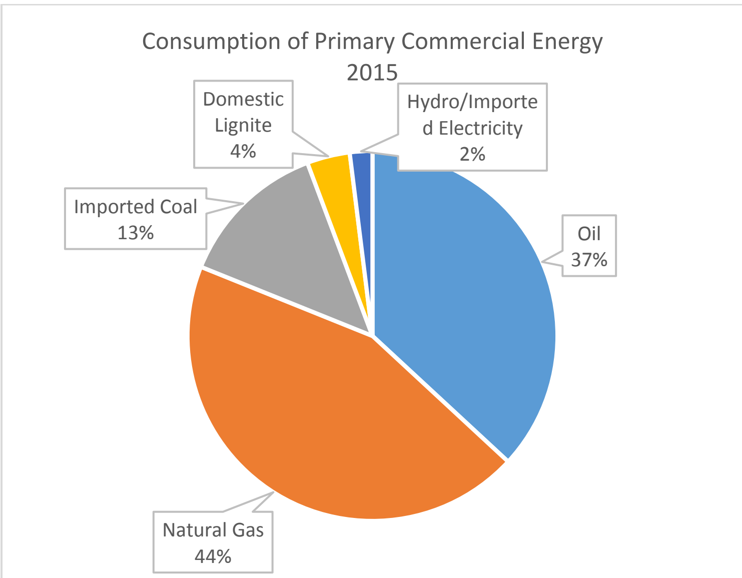



Figure 30. Thailand's Consumption of Primary Commercial Energy

Source: Thailand Country Report at ASEAN＋3 Oil Forum 2016

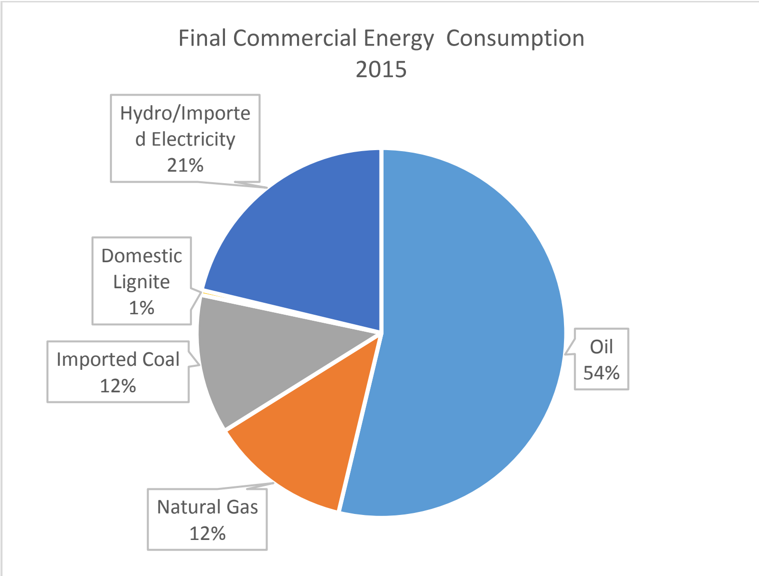



Figure 31. Thailand's Final Commercial Energy Consumption

Source: Thailand Country Report at ASEAN＋3 Oil Forum 2016

The electricity generation trend in Thailand has been on the rise for decades. In 1998, and 2007-2009, no major surge of electricity demand was observed and the production of electricity was stable accordingly. In 2014, the generation was at a level of 180,945 gigawatt-hours (GWh), which increased by 2.0%, compared with that in the previous year, with the use of the following fuels: natural gas, 66%; coal/lignite, 21%; electricity import/exchange and others, 9%; hydropower, 3% and oil, 1% (see Figure 32).

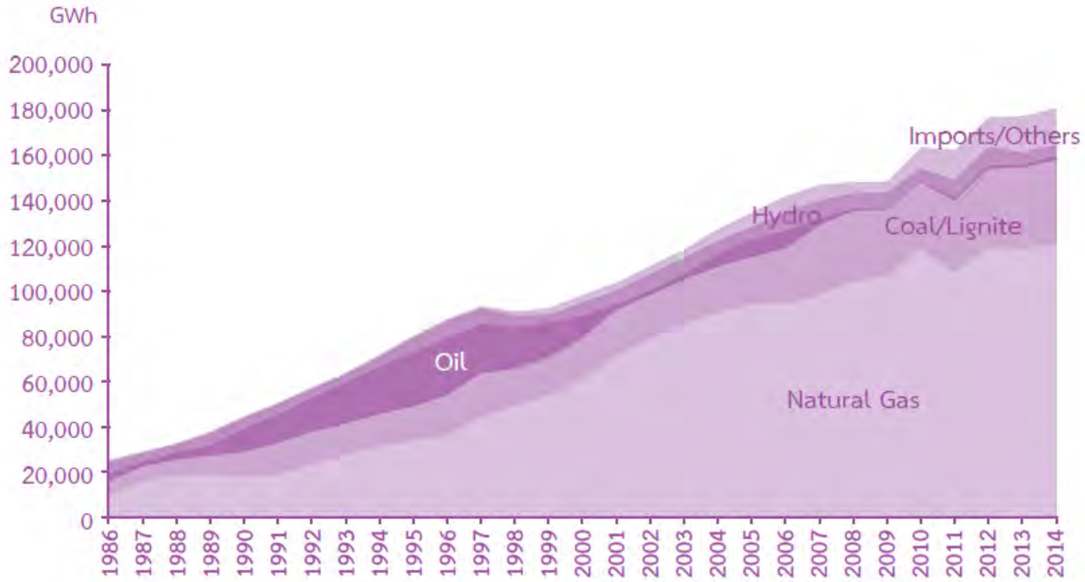



Figure 32. Thailand's Electricity Generation

Source: Energy Statistics of Thailand 2015

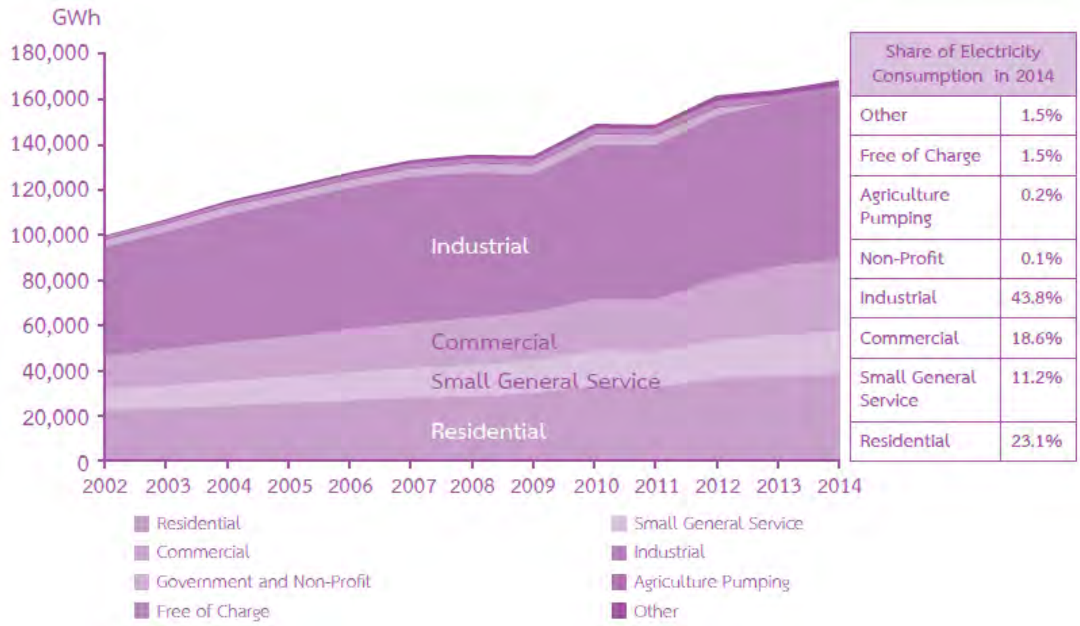



Figure 33. Thailand's Electricity Consumption

Source: Energy Statistics of Thailand 2015

In 2014, the total consumption of the country increased by 2.6%, compared with that in 2013, reaching the amount of 168,620 GWh, due to a recovery in national economic growth (see Figure 33). The highest share of national electricity consumption was the industrial sector, holding a share of 44%; while the household, commercial, and small general service sectors accounted for a share of 23%, 19% and 11% respectively.

### 3. Coal Statistics

#### i) Domestic Coal Production

In 2014, total domestic lignite coal was at 17,981,722 tonnes, 95% was produced at the Mae-Moh mine, and the remaining 5% was produced from private sector mines.

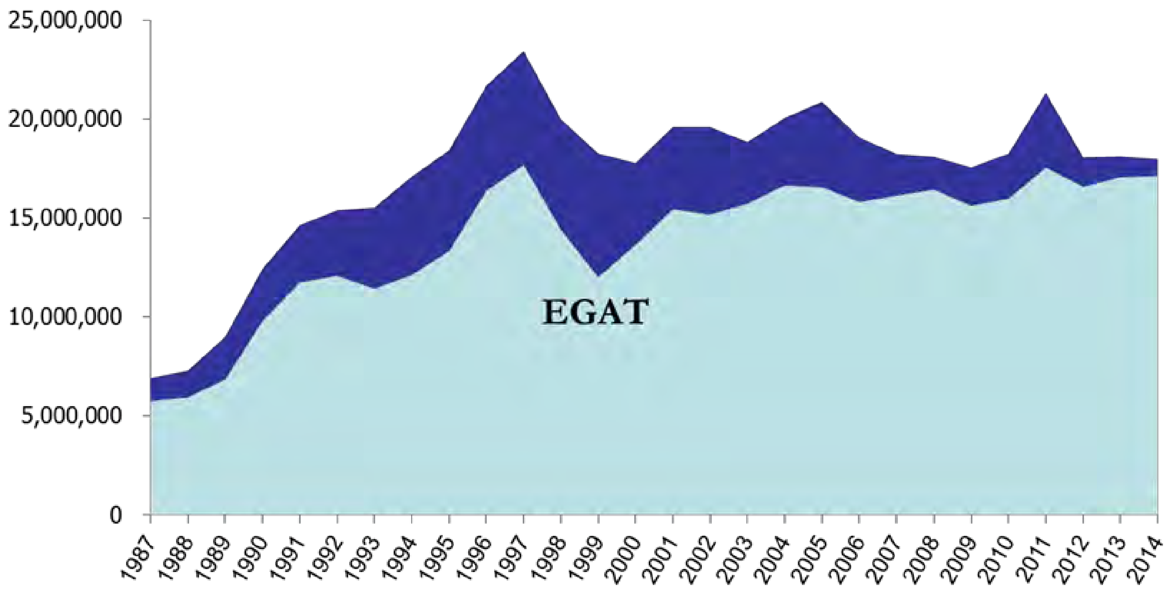



Figure 34. Thailand's Total Domestic Lignite Coal from 1987-2014

Source: Department of Mineral Fuels Thailand, 2016

#### ii) Coal Imports

Most of the imported coal in Thailand is of sub-bituminous and bituminous coal; only a small amount is anthracite and briquette. The number of coal imports increased continuously because domestic lignite concessions began to expire and because the price of coal was cheaper when compared to other fuel types (See figure 35).

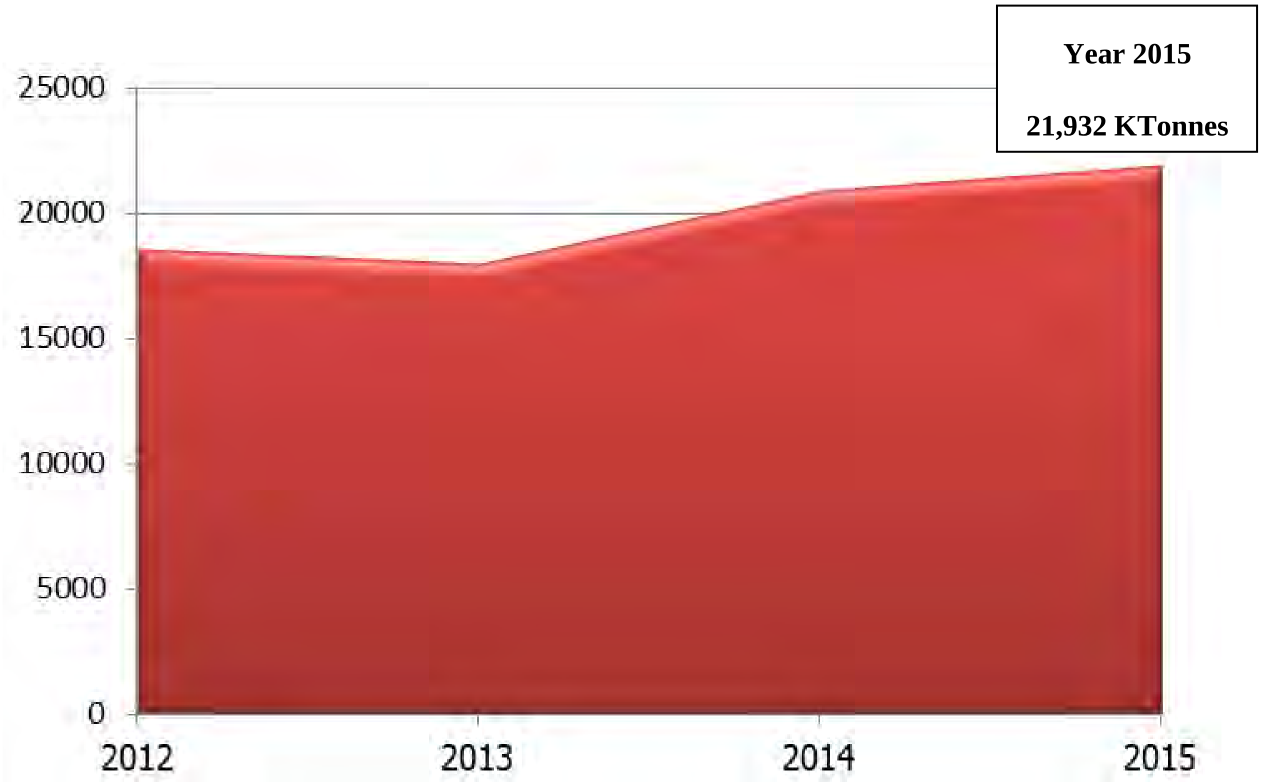


Figure 35. Total Amount of Imported Coal in Thailand from 2012-2015

Source: Department of Mineral Fuels Thailand, 2016

## Coal Utilisation

In 2016, Domestic Lignite coal and Imported Coal consumptions had 52% and 48% of shares in the power generation sector and the industrial sector (based on the calorific value), respectively. Coal demand in the industrial sector was growing, mainly by clinker production and boilers for paper and food industries.

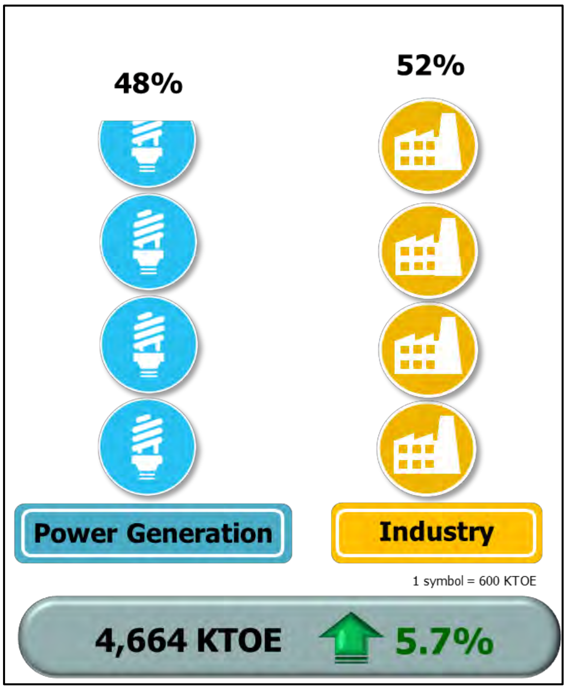



Figure 36. The Growing Demand for Electricity in Thailand

Source: Department of Mineral Fuels Thailand, 2016

## 4. Clean Coal Technologies (CCTs) Situation in Thailand

i) CCT in Coal Fired Power Plants (CFPP)

Now, most of the CFP in Thailand that were installed were Subcritical, with one Supercritical unit and some units of Fluidised Bed Combustion. Other CCTs are Flue Gas Desulfurisation and Electrostatic precipitator. Thailand expects to install an Ultra Supercritical in a new Coal fired Power Plants after a short time.

ii) CCT in the Industrial sector

Normally Thailand uses a stoker for a small boiler and a Fluidised Bed Combustion for a medium size boiler.

- Policy on Energy and Electricity

Recently, Thailand developed its Energy Development Plans Integration which consists of five Major Plans (see Figure 37): (1) Power Development Plan (PDP 2015), (2) Energy Efficiency Development Plan (EEDP), (3) Alternative Energy Development Plan (AEDP), (4) Gas Procurement and Management Plan, and (5) Oil Management Plan.

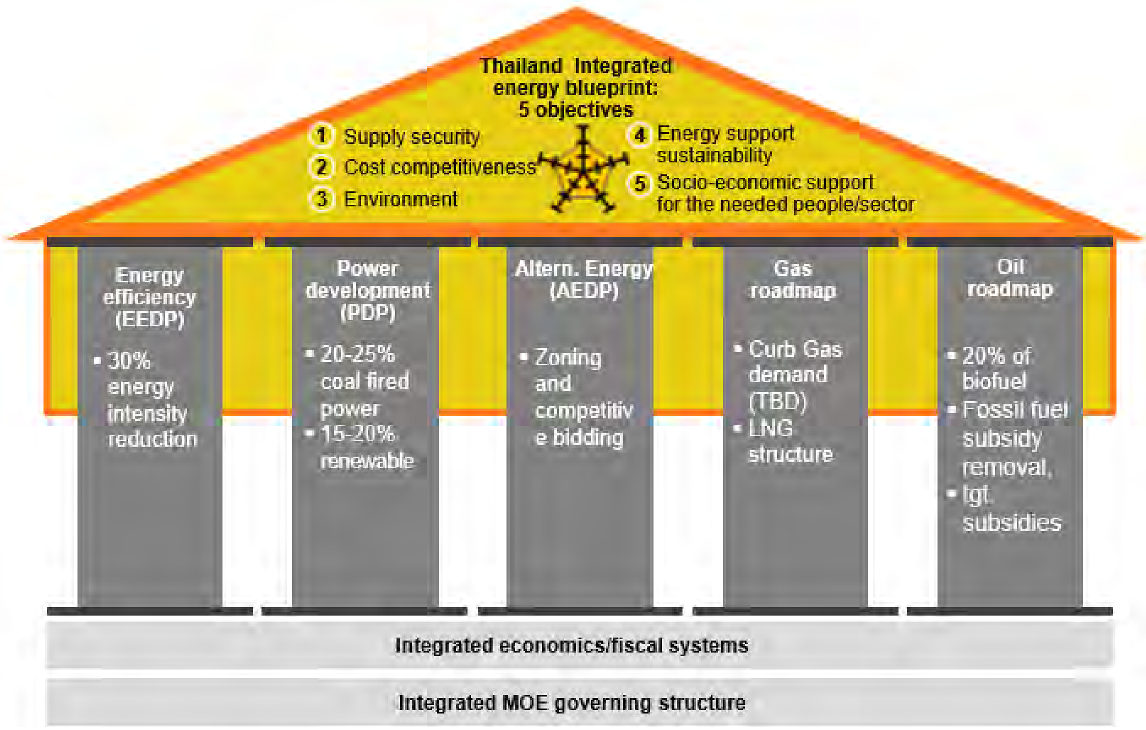



Figure 37. Thailand's Integrated Energy Blueprint

Source: Energy Statistics of Thailand 2015

As part of the integrated plan, the revised power development plan (PDP) 2015 states the following objectives to embrace the following actions:

1. Security of Electricity Supply in both Generation and Transmission Systems, at both National and Regional Levels;
2. Fuel Diversification: Reduce Share of Natural Gas in generation mix, Increase Coal share for power generation, Limit Power Import from neighbouring countries to 20% of generation mix by 2036, Promote Renewable for Power Generation, and Promote Nuclear for Power generation; and
3. Maintain Reserve Margin to be at least 15% of annual peak demand.

Consequently, there is a change on the fuel requirements to fulfil its electricity demand (see Table 2.7.1.).

Table 17. Thailand's Fuel Share Target under PDP 2015

| Fuel | Percentage in 2014 | Percentage in 2026 | Percentage in 2036 |
|---|---|---|---|
| Imported hydro power | 7 | 10 - 15 ↑ | 15 – 20 ↑ |
| Clean coal including lignite | 20 | 20 - 25 ↑ | 20 – 25 ↑ |
| Renewable energy including hydro | 8 | 10 - 20 ↑ | 15 – 20 ↑ |
| Natural gas | 64 | 45 - 50 ↓ | 30 – 40 ↓ |
| Nuclear | - | - | 0 – 5 ↑ |
| Diesel/Fuel oil | 1 | - ↓ | - ↓ |

Source: Thailand Country Report, CCT Program by JCOAL, February 2016

PDP 2015 also figured out that from the total installed capacity of 27,612 MW, as of December 2014, this number will reach 70,335 MW by the end of 2036; including the contribution of 7,390 MW of coal (see Figure 38) for the composition on installed capacity and power generation, and Table 2.7.2. for details of each new and retired power plants).

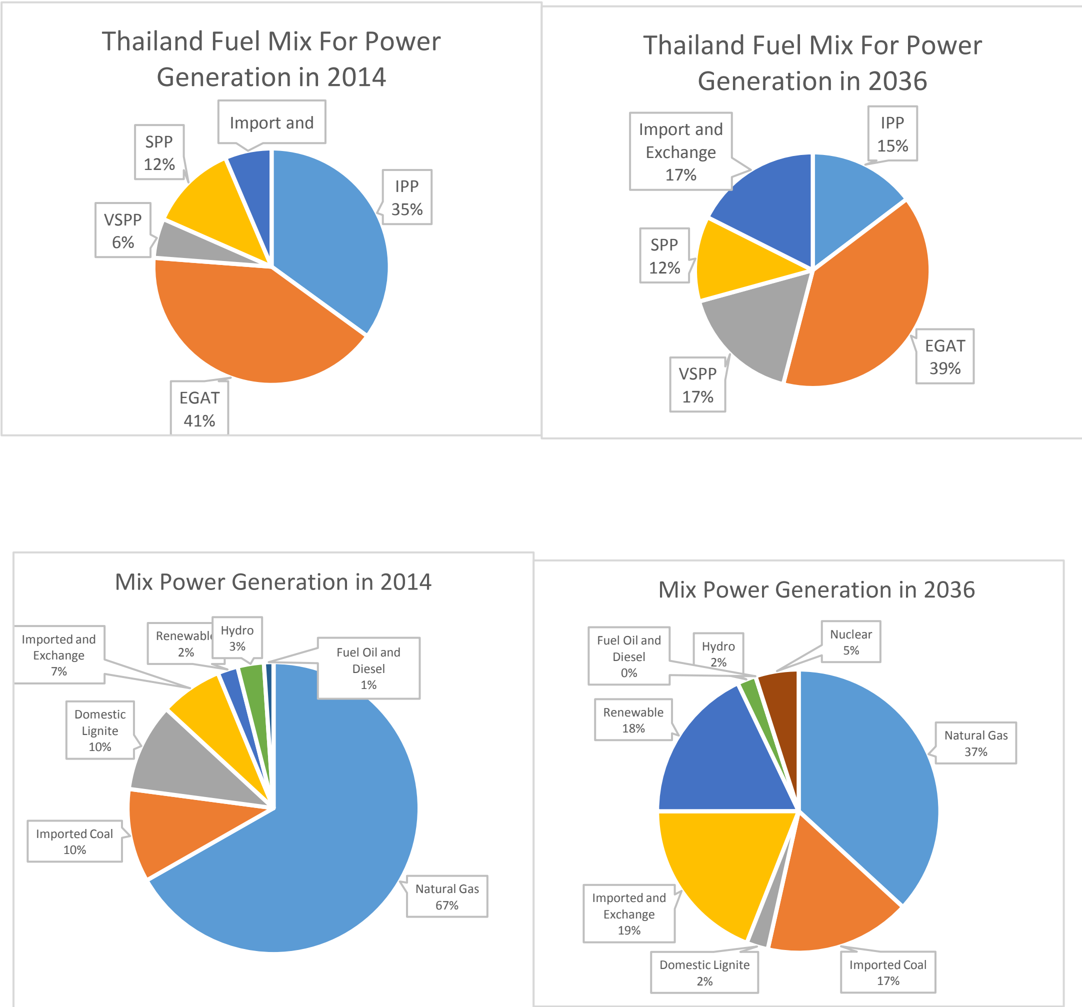



Figure 38. Thailand's Fuel Mix for Power Generation under PDP 2015

Source: Thailand Country Report, Korea-ASEAN Energy Safety Policy Forum, 2016

Table 18. Thailand's PDP 2015: Plan for New and Retired Coal-Fired Power Plants

| COD/Retirement Year | Project | Net Capacity (MW) |
|---|---|---|
| | Mae Moh #4-13 | 1,080 |
| 2006 | BLCP #1 | 673 |
| 2007 | BLCP #2 | 673 |
| 2012 | GHECO-ONE | 660 |
| 2016 | National Power Supply #1, #2 | 270 (2x135) |
| 2017 | National Power Supply #3, #4 | 270 (2x135) |
| 2018 | Mae Moh Retirement #4-7 | -560 |
| | Mae Moh Replacement #4-7 | 600 |
| 2019 | EGAT Clean Coal #1 (Krabi) | 800 |
| 2021 | EGAT Clean Coal #2 (Thepha 1) | 1,000 |
| 2022 | Mae Moh Retirement #8-9 | -540 |
| | Mae Moh Replacement #8-9 | 450 |
| 2024 | EGAT Clean Coal #3 (Thepha 1) | 1,000 |
| 2025 | Mae Moh Retirement #10-13 | -1,080 |
| 2032 | BLCP Retirement #1, 2 | -1,346 (2x673) |
| 2033 | EGAT Clean Coal #4 | 1,000 |
| 2034 | EGAT Clean Coal #5 | 1,000 |
| 2035 | EGAT Clean Coal #4 | 1,000 |
| | EGAT Nuclear #1 | 1,000 |
| 2036 | EGAT Nuclear #2 | 1,000 |

| Year 2036 | Net Capacity (MW) |
|---|---|
| Lignite | 1,050 |
| Coal | |
| EGAT | 4,800 |
| IPP | 1,200 |
| Nuclear | 2,000 |

Source: Thailand Country Report, Korea-ASEAN Energy Safety Policy Forum, 2016

Part of the diversification under PDP 2015 is to increase the use of coal, nuclear and renewables, as well as increase end-use energy efficiency. The prospects for clean coal technology (CCT) could be strengthened by improving the public perception of CCTs and also with the establishment of a central CCT centre. The CCT implementation has already started in Thailand with the first supercritical coal-fired power station to be commissioned in 2011 by the Independent Power Producer (IPP) Glow Energy. This power plant could act as a model for future supercritical plants to use less coal more efficiently, improve air quality, and reduce CO2 emissions.

The BLCP subcritical 1400 MW station at Rayong FGD technology, low NOx burners and an electrostatic precipitator as well as importing low sulphur coal from Indonesia and Australia. Since the plant was commissioned in 2007, it has consistently been operating with low emissions. BLCP established the Kiang Saket Energy Center at the plant in Rayong to both inform and educate people about the clean coal technology in the power plant.

In 2015, the Department of Mineral Fuels and the AFOC National committee of Thailand prepared the CFPP development plan 2015-2016, whereby Thailand aims to construct a total of 2.3 GW for the period 2015-2016 in order to meet the increasing demand for electricity (Table 2.7.3.).

Table 19. Demand for Electricity in Thailand from 2015-2018

| Year | Name of CFPP | Capacity |
|---|---|---|
| 2015 | Lao PDR (Hong Sa) TH #1-2 (Jun, Nov) | 2x491 MW |
| 2016 | Lao PDR (Hong Sa) TH #3 (Mar) | 491 MW |
| 2017 | National Power Supply TH #3-4 (Mar) | 270 MW |
| 2018 | Replacement of Mae Moh TH #4-7 (Nov) | 600 MW |

Source: http://www.egat.co.th/2015

## 2.8 Vietnam

### (1) Socioeconomic Situation

Vietnam has recorded a remarkable level of economic development over the past 30 years. Reforms have been made in both the economic and political arena that have spurred rapid economic growth and development, and transformed Vietnam into a lower middle-income country. Vietnam has had strong economic growth since 1990. The country's GDP per capita growth was 6.4% a year during the 2000s. In 2015, the GDP growth rate increased to 6.7% and in the first half of 2016, Vietnam's economic activity moderated with GDP expanding by 5.5%.

The Vietnamese population is calculated as 90 million inhabitants with a total GDP per capita of 2,053 USD. The Vietnamese have a better education than most countries with a similar per capita income. Access to basic infrastructure has improved substantially, with an example being the reduction of electricity shortages in rural areas. The development was rapidly equitable since 1993. Vietnam enjoys good economic growth with an average level recorded at 7.3% per year during period 1990-2010 and it reached 6.68% in 2015. The Government has set a target to continue the GDP growth at 6-7% per year during the period 2016-2020 in order to increase the GDP per capita from USD 2,100 in 2015 to USD 3,000 by 2020.

### (2) Energy and Electricity Situation

Vietnam's energy demand has risen rapidly in line with robust economic expansion. During the last decade, Vietnam was one of the fastest-growing energy consumers among the AMS, with an average annual growth exceeding 6% from 200-2010. The per capita primary energy consumption of Vietnam was 0.77 toe in 2010. Power consumption in Vietnam has continued to increase, fuelling the socio-economic development of the country. Industry continued to take the biggest share at 47.4% to 52% in total consumption in 2006 and 2010, respectively (see Table 2.8.1). Household consumption occupied the second largest share, but was slightly reduced due to the fast level of industrialization in Vietnam, from 42.9% in 2006 to 38.2% in 2010. Altogether the service, agriculture and other sectors occupied approximately 10% of the total level of electricity consumption.

Table 20. Vietnam's Electricity Consumption by Sector during 2006-2010

| No | Item | 2006 (%) | 2007 (%) | 2008 (%) | 2009 (%) | 2010 (%) |
|---|---|---|---|---|---|---|
| 1 | Agriculture | 1.1 | 1.0 | 1.0 | 0.9 | 1.1 |
| 2 | Industry | 47.4 | 50 | 50.7 | 50.6 | 52.5 |
| 3 | Services (Commerce, Hotels and Restaurant) | 4.8 | 4.8 | 4.8 | 4.6 | 4.5 |
| 4 | Household consumption | 42.9 | 40.6 | 40.1 | 40.1 | 38.2 |
| 5 | Others | 3.8 | 3.7 | 3.5 | 3.7 | 3.7 |

Source: GIZ Vietnam based on Master Plan VII

In 1995-2005, the annual growth rate of power consumption was over 14.9%, while the GDP growth rate was only 7.2%. The highest growth of power demand was found in the industrial sector (16.1%), followed by the residential sector (14%). In the future, according to the National Power Development Master Plan VII, the electricity demand of the country will continue to grow by 14 - 16% per year in the period 2011-2015 and then slow down to 11.15% per year in the following period 2016-2020, and then reduce further to 7.4 – 8.4% per year in 2021-2030.

- Policy on Energy and Electricity

The key aim of Vietnam's energy policy is to attract foreign investment, especially in the electricity sector and to create a competitive market, as stated in the Law on Electricity from 2005 (last update: Decree 137/2013/ND-CP on 10th December 2013). Vietnam aims for the diversification of its energy mix, while minimizing its dependency on oil.

The central document constitutes the Vietnam Power Development Plan for the 2011-2020 Period (with an outlook to 2030) approved by the Prime Minister on 21st July 2011. In the development plan, Vietnam aims to create efficient energy sources, by sustaining the energy supply through enhanced energy security. Specifically, the targets include, namely: (1) increase in electricity supply (through both domestic production and imports); (2) prioritisation of renewable energy sources, to reach a 4.5% share of total electricity production in 2020 and 6.0% in 2030; (3) reduction of electricity elasticity coefficient / GDP from the current average 2.0 to 1.5 in 2015 and 1.0 in 2020; as well as (4) rural electrification of remote and rural areas.

To satisfy this power demand, the Government of Vietnam has set specific production and import targets for the power sector. In the Master Plan VII for the period 2010-2020, with an outlook to 2030, the targets include:

1) Produce and import a total of 194-210 billion kWh by 2015, 330-362 billion kWh by 2020, and 695-834 billion kWh by 2030;
2) Prioritize generating electricity from renewable resources by increasing the renewable electricity yield from 3.5% of total electricity generation in 2010 to 4.5% in 2020 and 6% in 2030;
3) Reduce the electricity-over-GDP elasticity from the present value of approximately 2.0 to the value of 1.5 in 2015 and 1.0 in 2020;
4) Speed up the rural and mountainous electrification programme to ensure that almost all rural households will have electricity by 2020.

The strategies that will be applied to achieve the said targets are also lined out encompassing:

1) Diversification of domestic resources for power generation using both traditional resources (such as coal and gas) and new sources (such as renewable and nuclear power);
2) Balancing the development of power generation in different regions of the country to reduce transmission losses, effectively share the electricity yield and utilize the seasonal electricity yield of hydropower;
3) Develop new power sources, while simultaneously updating the technology used in existing power plants; and
4) Diversification of investment sources to overcome the lack of financial and technical resources and also to improve economic efficiency.

Table 21. Vietnam’s Structure of Power Sources

| No. | Power source | 2020 | | | 2030 | | |
|---|---|---|---|---|---|---|---|
| | | Installed Capacity (MW) | Share in total installed capacity (%) | Share in total electricity yield (%) | Installed Capacity (MW) | Share in total installed capacity (%) | Share in total electricity yield (%) |
| 1 | Coal thermal power plants | 36,000 | 48.0 | 46.8 | 75,000 | 51.6 | 56.4 |
| 2 | Gas turbine thermal power plants | 10,400 | 13.9 | 20.0 | 11,300 | 7.7 | 10.5 |
| 3 | LNG turbine thermal power plants | 2,000 | 2.6 | 4.0 | 6,000 | 4.1 | 3.9 |
| 4 | Integrated hydropower plants | 17,400 | 23.1 | 19.6 | N/A | 11.8 | 9.3 |
| 5 | Pumped-storage hydropower plants | 1,800 | 2.4 | | 5,700 | 3.8 | |
| 6 | Biomass power plants | 500 | 5.6 | 4.5 | 2,000 | 9.4 | 6.0 |
| 7 | Wind power plants | 1,000 | | | 6,200 | | |
| 8 | Nuclear power plants | N/A | N/A | 2.1 | 10,700 | 6.6 | 10.1 |
| 9 | Import | 2,200 | 3.1 | 3.0 | 7,000 | 4.9 | 3.8 |
| | **Total** | **75,000** | **100** | **100** | **146,800** | **100** | **100** |

Source: GIZ Vietnam based on Master Plan VII

The structure of power sources for the period 2010-2020, with outlook to 2030, is outlined in the Master Plan VII (see Table 2.8.2.). At all times, the most important power source is coal and gas thermal power. Nuclear and renewable electricity shares are insignificant during 2010-2020, but will become relatively important during 2020-2030. The hydropower share will remain almost the same between the two periods of 2010-2020 and 2020-2030. Specifically, by 2020, shares of power sources in terms of electricity yield are expected to be 46.8% for coal thermal power, 19.6% for integrated hydropower and pumped-storage hydropower, 24% for gas and LNG turbine thermal power, 4.5% for renewable power, 2.1% nuclear power, and 3.0% imported from other countries.

- Electricity Market

The Electricity Corporation of Vietnam (EVN), a state company, owns more than 71% of all electricity generation capacity, all transmission lines, electricity operation systems, distribution, and retail. To mobilize investments for electricity development the government adopted a market-based electricity price approach and pursue environmental protection. The Government of Vietnam has set a target to develop a competitive electricity market in order to improve the economic efficiency of the power supplies and uses in the country. According to the draft plan to develop a competitive electricity market, the power sector development is expected to undergo three phases:

1) Competitive power generation market (2005-2014) where power plants could offer to sell electricity to single buyers;
2) Competitive wholesale market (2015-2022) where wholesale companies could compete in buying electricity before selling to distributors;
3) Competitive retail market from 2022: consumers could choose their own power suppliers.

The electricity prices would be adjusted annually with fully monitored consideration to minimise the socio-economic issues.

Currently, the main holdings in electricity generation in Vietnam are mostly the state-owned companies such as 53% owned by Electricity Corporation of Vietnam (EVN), 10% owned by Petroleum Corporation of Vietnam (PVN), 3.7% owned by Vietnam National Coal and Minerals Corporation (VINACOMIN) and 10.4% from other Independent Power Producers (IPPs) and foreign BOT.

- Development of Coal and CCT

In January 2003, the government issued a decision (No 20/2003/QD-TTg of 29 January 2003) by the Prime Minister regarding the development of the coal industry. The plan included a number of commitments that aimed to modify and improve coal industry practice and productivity in the period 2003-2010. The decision had an important contribution upon coal mining activities in Vietnam. Subsequently, the revision on coal decision was issued in 2008 under No 89/2008/QD-TTg of July 7 2008. The basic platform for development is essentially the same, but extends the plans to 2015, and has a greater degree of emphasis on shifting the coal market to a more competitive regime.

The agreed plan on coal is as follows, namely:

1) Speeding up coal exploration and estimating coal resource and volume.
2) Coal business will be active in complying with the market mechanism under state regulations.

3) Meeting the maximum domestic consumption, while exporting only domestic coal that is not required for domestic consumption.

4) Protecting the ecology and environment is the primary goal for the sustainable coal sector development.

In 2016, Vietnam's energy economy is largely served by traditional biofuels and oil products. Within the power generating sector, hydropower and gas-fired power plants are the dominant fuel source. Meanwhile coal fired power plants still maintain supply at 40 Mt/y.

Coal plays a crucial role in energy policy, since the coal export activities are considered as one of the major factors in increasing economic growth. The government planned to add coal fired power plants to help address the power shortage issue. New coal-fired power projects are being encouraged by the government in order to maintain a stable supply of electricity for the Northern and Southern areas of the country. According to Vietnam's total investment for power development to 2030, the CFPP has a lion share of 47.9% in 2014-2015 with a projected decrease to 34.7% in 2016-2020 (Table 22).

Table 22. Vietnam's Total Investment for Power Development to 2030

| No. | Items | 2014-2015 | 2016-2020 | 2021-2025 | 2026-2030 | 2014-2030 |
|---|---|---|---|---|---|---|
| I | Power sources | 71.5% | 70.0% | 71.5% | 67.1% | 69.6% |
| | - Coal-fired power | 47.9% | 34.7% | 22.8% | 17.4% | 26.5% |
| | - Hydropower | 16.2% | 6.4% | 0.4% | 1.3% | 3.8% |
| | - Pumped storage | 0.0% | 0.5% | 2.4% | 2.8% | 1.8% |
| | - Gas-oil fired | 0.0% | 9.9% | 5.9% | 11.9% | 8.4% |
| | - Nuclear | 0.0% | 4.5% | 26.3% | 19.1% | 15.7% |
| | - Renewable | 7.4% | 13.9% | 13.6% | 14.6% | 13.4% |
| II | Power Network | 28.5% | 30.0% | 28.5% | 32.9% | 30.4% |
| *1* | *Transmission Network* | *44.7%* | *47.6%* | *47.0%* | *52.0%* | *48.8%* |
| | - 500kV transmission lines | 11.7% | 15.0% | 12.9% | 23.8% | 17.3% |
| | - 500kV Substations | 5.0% | 6.6% | 7.9% | 7.4% | 7.1% |
| | - 220kV transmission lines | 16.2% | 11.0% | 10.3% | 9.3% | 10.7% |
| | - 220kV Substations | 11.9% | 15.0% | 15.9% | 11.4% | 13.7% |
| *2* | *Distribution network* | *49.6%* | *46.5%* | *47.0%* | *41.9%* | *45.3%* |
| *3* | *IDC network* | *5.7%* | *5.8%* | *6.0%* | *6.1%* | *6.0%* |
| | Total | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

| Period | 2014-2015 | 2016-2020 | 2021-2025 | 2026-2030 | 2014-2030 |
|---|---|---|---|---|---|
| I- Total power generation plants - billion USD per year on average | 8.10<br>4.05 | 21.36<br>4.26 | 25.63<br>5.13 | 26.39<br>5.28 | 84.43<br>4.79 |
| II- Total power network - billion USD per year on average | 3.23<br>1.62 | 9.13<br>1.83 | 10.23<br>2.05 | 12.93<br>2.59 | 35.53<br>2.09 |
| Total power sector- billion USD per year on average | 11,34<br>5,67 | 30,43<br>6,09 | 35,86<br>7,17 | 39,33<br>7,87 | 116,96<br>6,88 |

Source: Vietnam Energy Policy, MOIT, 2015

Table 23. Vietnam's Planned Coal-Fired Power Plants in 2016 in MW

| Coal-fired Power Plants | Capacity | Investor |
|---|---|---|
| Mong Duong I | 500 | EVN |
| Thai Binh I | 300 | EVN |
| Hai Duong | 600 | Jak Resource–Malaysia/BOT |
| Anh Khanh II | 150 | CTCP NĐ An Khánh |
| Long Phu I | 600 | PVN |
| Vinh Tan I | 1200 | CGI/BOT |
| Duyen Hai III | 600 | EVN |

Source: Vietnam's Report of the CCT Transfer Programme by JCOAL, February 2016

Vinacomin will endeavour to expand exploration, surveys and production, since coal which is intended for the export market, will be utilised for domestic consumption in the power sector and to fulfil the burgeoning demand for coal as shown in the Table below (Table 24).

Table 24. Vietnam's Projected Coal Demand

| Item | 2016 | 2017 | 2018 | 2019 | 2020 | 2025 | 2030 | 2015-2030 |
|---|---|---|---|---|---|---|---|---|
| Domestic coal demand (for Power Plants) | 26.8 | 29.1 | 33.2 | 35.9 | 37.5 | 44.5 | 48.0 | 639.9 |
| Other Sectors' demand | 9.8 | 9.8 | 9.8 | 10.3 | 10.8 | 10.8 | 10.8 | 170.9 |
| Import Coal | 1.1 | 3.4 | 5.5 | 11.0 | 17.4 | 43.9 | 78.3 | 516.9 |

Source: Vietnam's Report of the CCT Transfer Program by ACE and JCOAL, February 2016

## Chapter 3 - Features, Advantages, and Applicability of CCT

## (Coal Fired Power Generating Technologies)

## 3.1 Introduction to the Technology Chapters

The overall situation of the ASEAN region, as well as of each individual ASEAN member state, is well described in the preceding policy chapters; i.e. Chapter I and Chapter II based on AEO4.

ASEAN needs coal fired power generation, as well as other energy and fuel options, to bolster its fast-growing economy. Under the current circumstances where joint global efforts are expected to help address climate change issues, and also where an increased environmental awareness of the people in every country is observed, introducing and utilizing CCT for environmental compliance is required for any ASEAN country that is going to utilize coal for power generation.

The Technology Chapter (Chapter III and Chapter IV) is to serve as an updated technical reference by providing ideas insights for relevant policy makers, as well as utility officers and engineers of ASEAN countries.

Chapter III covers coal fired power plant systems, Japan's previous experience in pursuing better environmental management with coal power generation, introduction to typical clean-coal fired power plants in Japan, and IGCC (Integrated coal Gasification Combined Cycle) as the next generation and established technology.

Meanwhile, Chapter IV highlights a wide range of CCTs, from RBM, combustion optimization, to upgrading technologies. It is to be noted that all technologies that are introduced in the following chapters are technologically established and well applicable globally.

The directory of CCTs as an Appendix, though placed at the end of this book, is of equal importance as the preceding chapters. Each technology is individually highlighted with further technical details. An excellent feature of the Directory of this Version 2 is that the records of projects with the technology are provided, where such records are available, so that ASEAN stakeholders may refer to the information in the course of deliberating their introduction of the CCT.

This handbook does not in any way try to define or confine either the role or meaning of CCT. The term CCT or HELE is used to indicate a form of technology, which, either individually or when combined with other technology, is effective in realizing cleaner coal utilisation in the power sector and other industrial sectors. As the title of the Handbook suggests, the focus of this book is CCT for power generation (Figure 39).

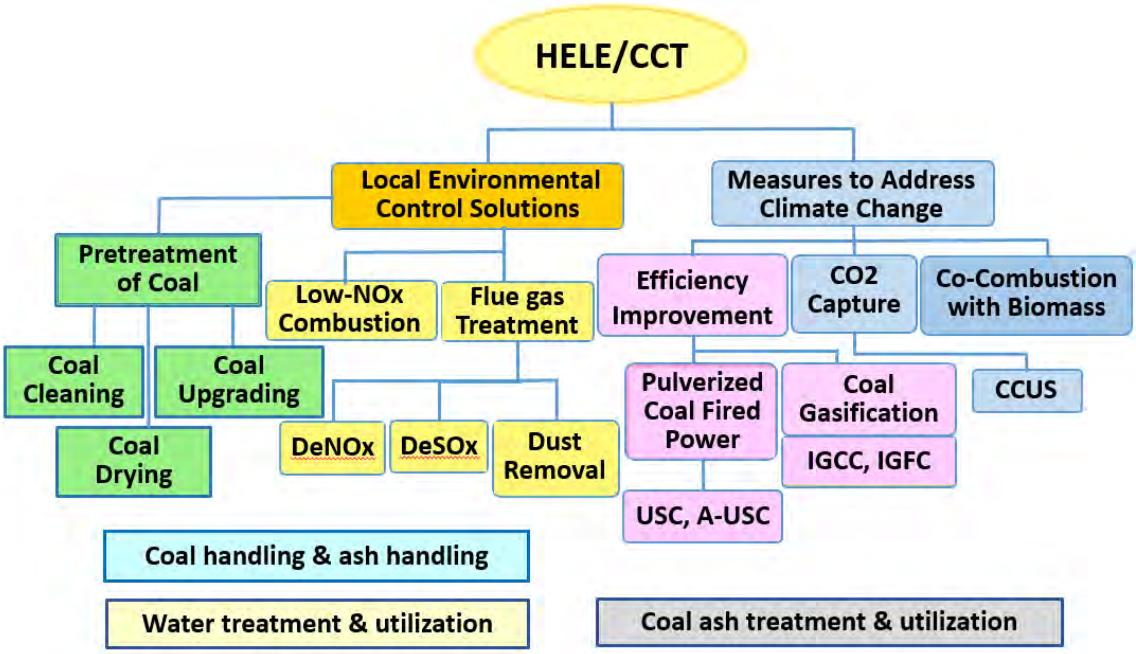



Figure 39. Overview of Clean Coal Technology

3.2 Coal Fired Power Plants

Fig.3.2.1. shows a schematic overview of a typical and current coal fired power plant constructed in Japan. The application of low NOx burner, De-NOx, De-SOx and Electrostatic Precipitator (ESP) are essential. Gas-gas heater (GGH) is equipped to avoid white smoke from the stack, by the warming-up of the flue gas exhausted from wet type De-sulfurization equipment. Ancillary equipment is introduced in Chapter 4.

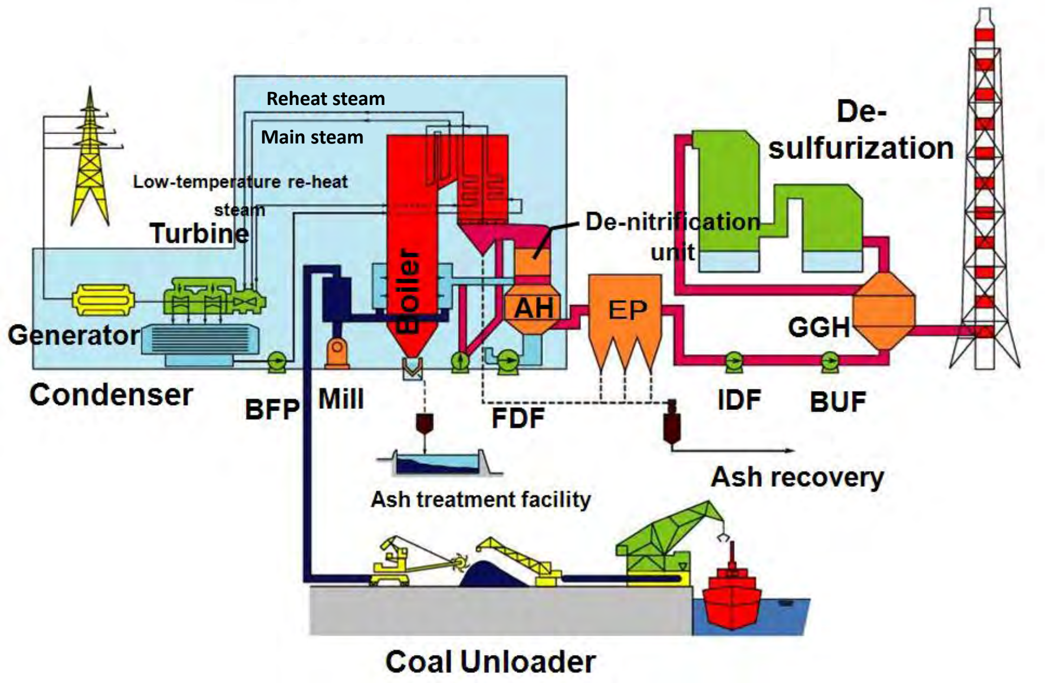



Figure 40. Schematic Overview of a Typical Coal Fired Power Plant Installed in Japan[21]

3.3 History of Steam Condition Improvements for Coal-fired Power Plants

The development history of steam conditions for power plants in Japan is shown in Figure 41. Persistent efforts have been made to increase steam pressure and steam temperature to ensure the improvement of power generation efficiency.

[21] Japan Coal Energy Center

Firstly, in 1967, a supercritical thermal power plant with an oil and gas fired boiler was introduced (Steam pressure in 24.1MPa, main steam temperature in 538℃ and re-heater steam temperature in 566℃). In 1981, a coal fired supercritical power boiler created 24.1 MPa and 538℃ steam (both superheated and reheated steam). While, in 1993, the ultra-supercritical power unit started at 24.1 MPa and 538℃ of main steam and 593℃ of re-heater steam. Recently, in 2016, the highest steam condition was a coal fired power plant measured at 25 MPa and 600℃ main steam and 620℃ reheated steam, which started commercial operation in 2009.

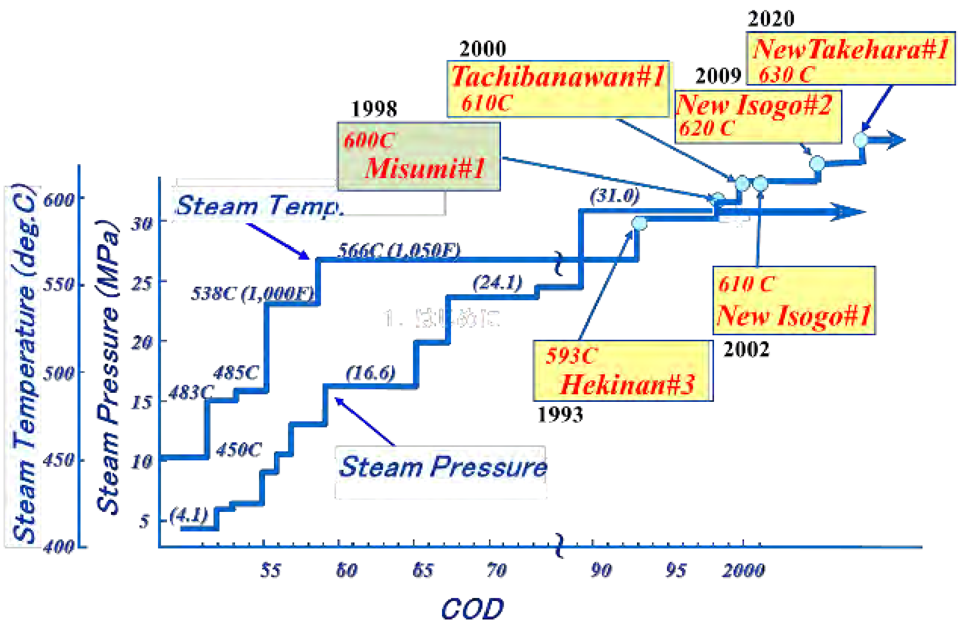



Figure 41. Development of Steam Temperature and Pressure.[22]

3.4 Why Japan Affirms the Value of Coal Fired Power Generation

Today Japan enjoys good air and water quality, while coal still accounts for 26% of its generation source, and some power plants are situated quite close to major cities. Such a situation is not a total surprise; the world-highest efficiency, the world best practices, and

[22] Japan Coal Energy Center

know-how were all obtained through years of strenuous effort made by the government, the industry, and the people themselves.

An impressive level of high economic growth in 1950's incurred serious degradation of the environment in the 1960's. The deterioration of the air quality was quite noticeable at that time, while in the early 1970's there was still an extremely high urban ozone concentration in Japan, which led to the government issuing a series of new and revised environmental standards and policy directives. Most of the currently available environmental technologies were developed through the same period.

All these factors have contributed to a massive improvement of the environment in Japan with a focus on the air and water quality; as you can see in the following graph.

| Year | 1960 | 1965 | 1970 | 1975 | 1980 | 1985 | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1st. Oil shock | | | | | | | | | |
| | | Photochemical smog | | | The first coal fired SC plant in Japan | | | | | | | |
| Topics | ▼ | | ▼ ▼ | ▼ | ▼ | ▼ | ▼The first coal fired USC plant in Japan | | | | | |
| | Serious pollution problem | | | 2nd. Oil shock | | Recommendations of global environmental issues | | | | | | |
| | | | | | | | | | | | | |
| Air Pollution Control Act | ▼ | | ▼▼▼▼▼▼ | | | ▼ | | ▼▼▼▼▼▼ | ▼▼▼▼▼▼ | ▼▼▼▼▼▼ | ▼▼▼▼▼▼ | ▼ |
| | Enactment | | Revision | | | Revision | | Revision | | | | |
| | | Low NOx Burner | | SCR(Oil) | SCR(coal) | | | | | | | |
| NOx Reduction | | | ▼▼ | ▼ | ▼ | ▼ | | | ▼ | | | |
| | | Two-staged Combustion, | | | | In Furnace De-NOx(Coal) | | | SCR(η=90%) | | | |
| | | Exhaust Gas Mixture | | | | | | | | | | |
| | | | | | | | | | Dry De-SOx | | | |
| SOx Reduction | | | ▼ | | | | ▼ | | ▼ | | | |
| | | | Wet FGD | | | | Nonleak GGH | | | | | |
| | | | | | | | | | | | | |
| PM Reduction | | | | | ▼ | | | ▼ | | | | |
| | | | | | MEEP | | | Low-Low Temp. EP | | | | |

Figure 42. Japan's Experience in Coping with Energy and Environmental Issues[23]

The other turning point in the history of coal power generation in Japan is the emergence of USC. Construction of the first USC in Japan started as early as 1993, prior to the world's first get together at COP1 in 1995 to discuss climate change issues.

In summary, what Japan has achieved from this time until now, and what ASEAN envisions for the future are the same. Coal power development should involve clean technology, best practices, and optimal O&M technique in order to achieve the three essentials-$CO_2$ emissions reduction, prevention of environmental degradation, and sustainable energy supply.

[23] Japan Coal Energy Center

Japan's experience in coping with the energy and environmental situation by energy diversification

Each and every coal fired power plant in Japan operates at designed efficiency, for decades, regardless of the technology it employs, which should be of great interest to ASEAN power sector stakeholders.

In this context, figures in the table of emission values at J-POWER's Isogo that is located adjacent to Yokohama city, which has a population of 3.7 million people, may be surprising for those who believe that coal and coal power is not clean.

3.5 Ultra-supercritical Coal Fired Power Plants

In the 90's, a national project was started to develop 600℃-class coal fired power plants to improve the thermal efficiency. First, a USC (≥24.1 MPa and 593℃) in Japan with 700MW capacity was built in 1993. Since then, the steam conditions of USC have been applied to almost all coal fired power plants in Japan. Thereafter technology for higher steam temperature has been developed in a phased manner. As of 2016, the highest super-heater and re-heater steam temperatures are 600℃ and 620℃ respectively.

All of the technology has been operating with a high efficiency and high availability. A new coal fired USC unit is planned to operate with a higher steam condition at 25MPa and 600℃, 630℃ main and reheated steam in 2020.

Figure 43 shows power generation efficiency and $CO_2$ reduction rates for various steam conditions of SC/USC units. Efficiency improvements from 538℃ class to 625℃ is roughly +5% and the $CO_2$ reduction is -4.5%. Fig. 3.3.2. is a view of Isogo Power Station.

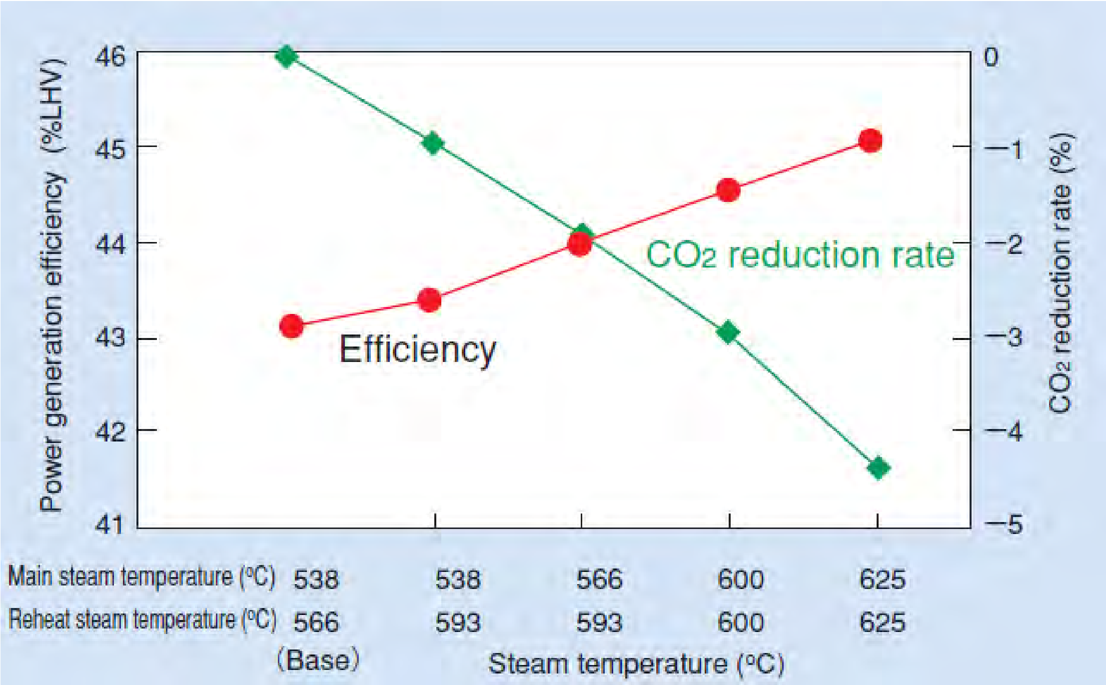



Figure 43. Efficiency and $CO_2$ Reduction Rate[24]

Figure 44. Up-to-date USC, Isogo No. 1, and No. 2 Units

[24] Japan Coal Energy Center

(600MW respectively, From J-POWER Homepage)

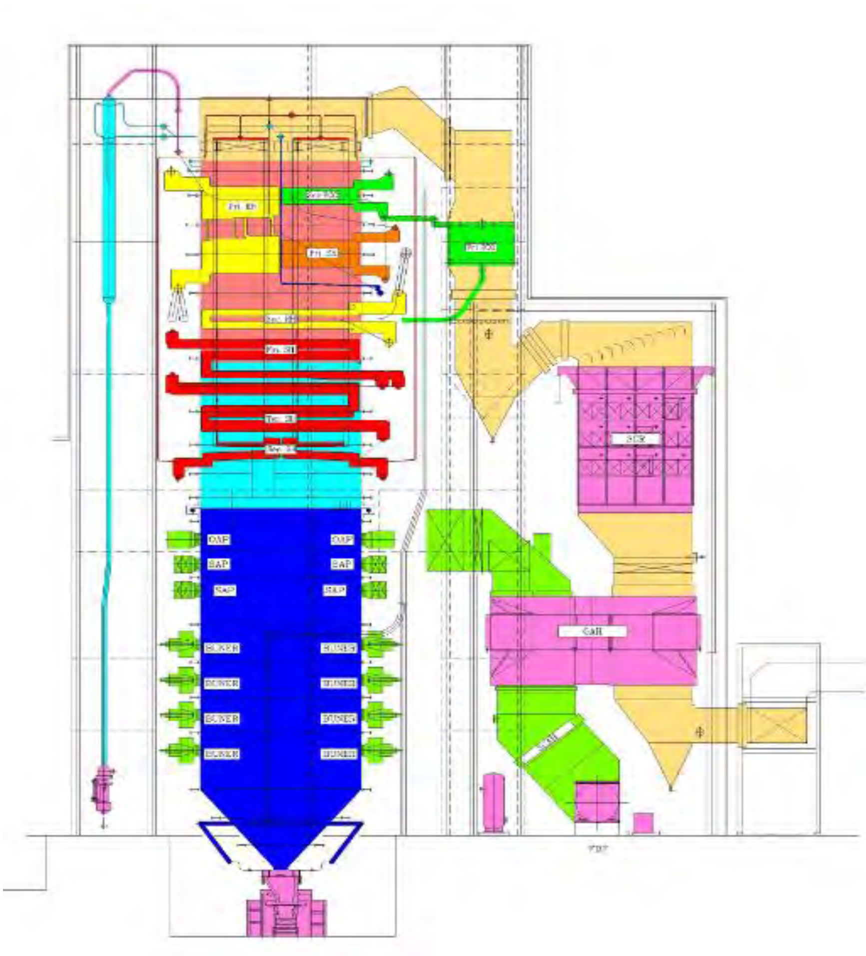


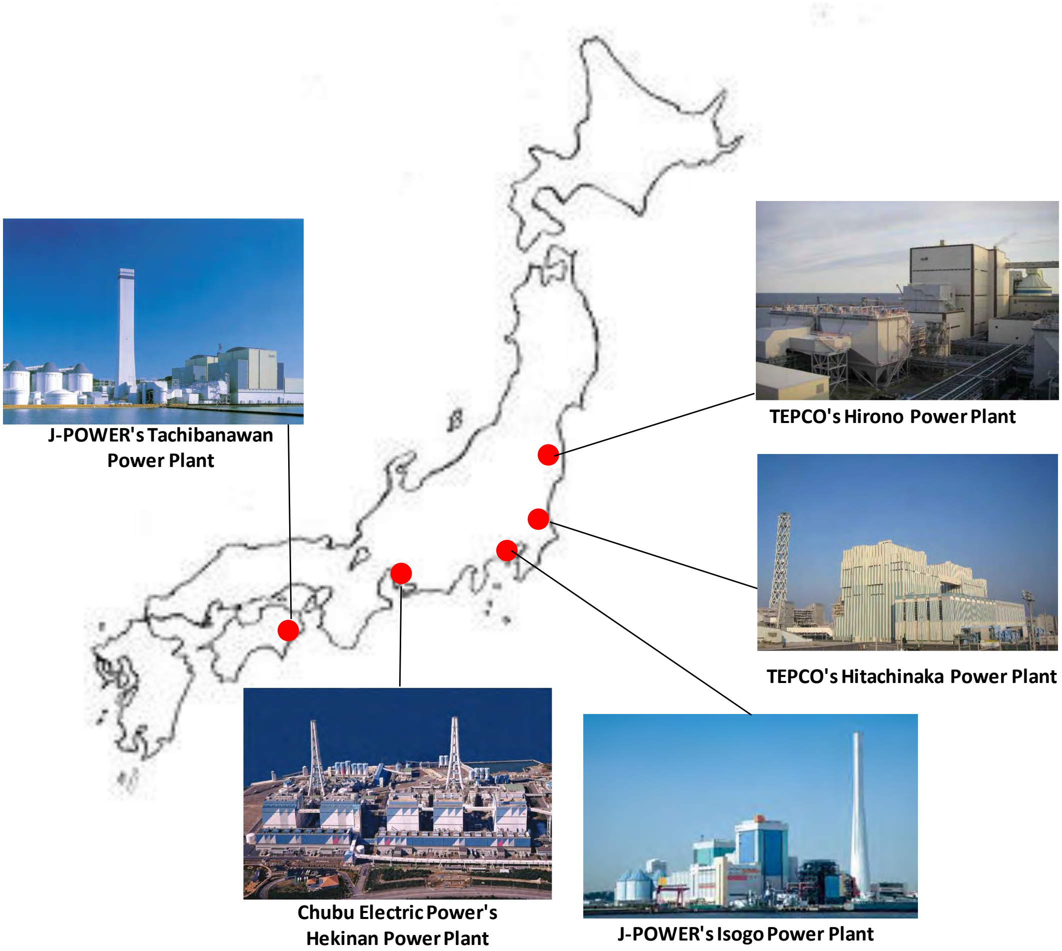

Figure 45. Boiler Side View of Ultra-supercritical Unit

(Isogo Unit No.1; 600MW)

For the next step, the study for a 700 ℃ class USC power plant started in 1998. It is called an A-USC (Advanced USC), with a targeted net efficiency of around 50% (LHV basis).

A demonstration test at the actual plant began operations with 700℃ in May 2015, and will be finished by 2016.

## 3.6 Japan's Typical Coal Fired Power Plants




### (1) Tokyo Electric Power Co., Inc.

#### 1) Hirono Coal fired Power Plant (Space: 1,320,000M$^2$)[25]

With an installed capacity of 4,400 MW, the plant is the largest thermal power plant (excl. GTCC) in Japan. Unit 5 (600MW) and Unit 6 (600MW) run on coal, while Unit 1 to 4 run on oil.

a) Unit Specification

---

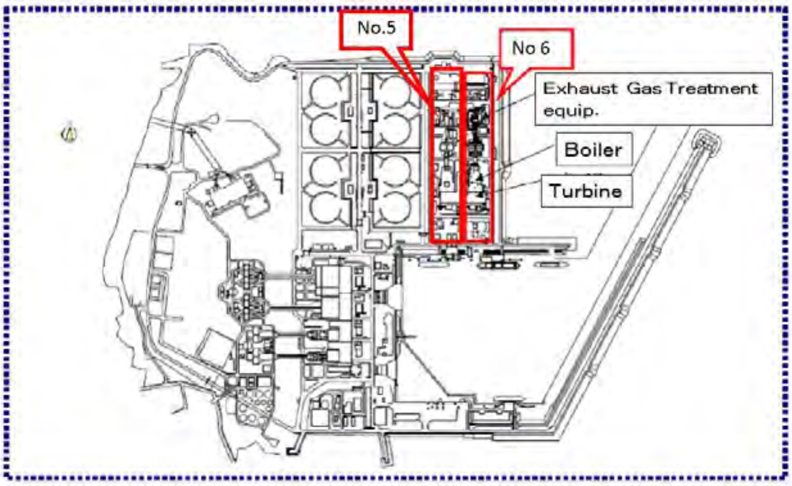
[25] Reference: Material was supplied by Tokyo Electric Power Co.,Inc. and Tokyo Electric Power HP http://www.tepco.co.jp/cc/press/betu13_j/images/131203j0101.pdf , Jcoal Coal Data Bank

| No. | Nominal Output(MW) | Steam condition | | Efficiency (LHV) | COD |
|---|---|---|---|---|---|
| | | Temp. | Pressure | | |
| #5 | 600 | 600/600℃ | 24.5MPa | 45.2% | June/2004 |
| #6 | 600 | 600/600℃ | 24.5MPa | 45.2% | Dec./2014 |

Unit 1, 2, 3, 4 are oil-fired Units.

b) Overview of CFPP (Unit 6)

c) Layout of CFPP



2) Hitachinaka Coal fired Power Plant (Space:1,410,000M²)[26]

The plant, with 1,000MW x 2 units, is situated the closest to the Tokyo metropolitan area. Unit 2 achieved a significant milestone in the history of coal-fired power generation in Japan.

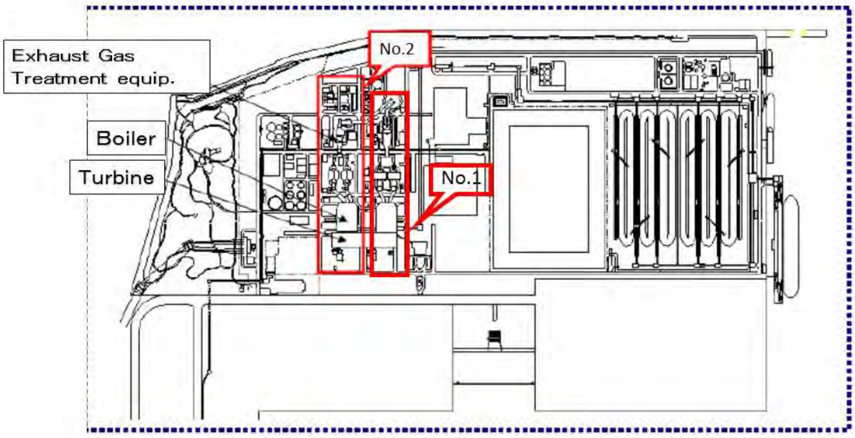
a) Unit Specification

| No. | Nominal Output(MW) | Steam condition | | Efficiency (LHV) | COD |
|---|---|---|---|---|---|
| | | Temp. | Pressure | | |
| #1 | 1000 | 600/600℃ | 24.5MPa | 45.2% | June/2003 |
| #2 | 1000 | 600/600℃ | 24.5MPa | 45.2% | Dec./2013 |

b) Overview of CFPP

c) Layout of CFPP

[26] Reference: Material was supplied by Tokyo Electric Power Co.,Inc. and Tokyo Electric Power HP http://www.tepco.co.jp/cc/press/betu13_j/images/131218j0101.pdf, Jcoal ,Coal Data Bank




(2) Chubu Electric Power Co., Inc.

Hekinan Coal Fired Power Plant (Space: 1,600,000M$^2$)[27]

The plant is the largest coal - fired power plant in Japan and one of the largest in Asia with an installed capacity of 4,100MW (700MW x 3, 1,000MW x 2).

Unit 3 is defined as the forerunner in the development path of USC plants in Japan, as it first adopted a primary temperature of 593℃.

a) Unit Specification

| No. | Nominal Output(MW) | Steam condition | | Efficiency (LHV) | COD |
|---|---|---|---|---|---|
| | | Temp. | Pressure | | |
| #1 | 700 | 538/566℃ | 24.1 MPa | 43% | Oct./1991 |
| #2 | 700 | 538/566℃ | 24.1 MPa | 43% | June/1992 |
| #3 | 700 | 538/593℃ | 24.1 MPa | 44% | Apr./1993 |

[27] Reference: Material was supplied by CHUBU Electric Power Co. Inc.

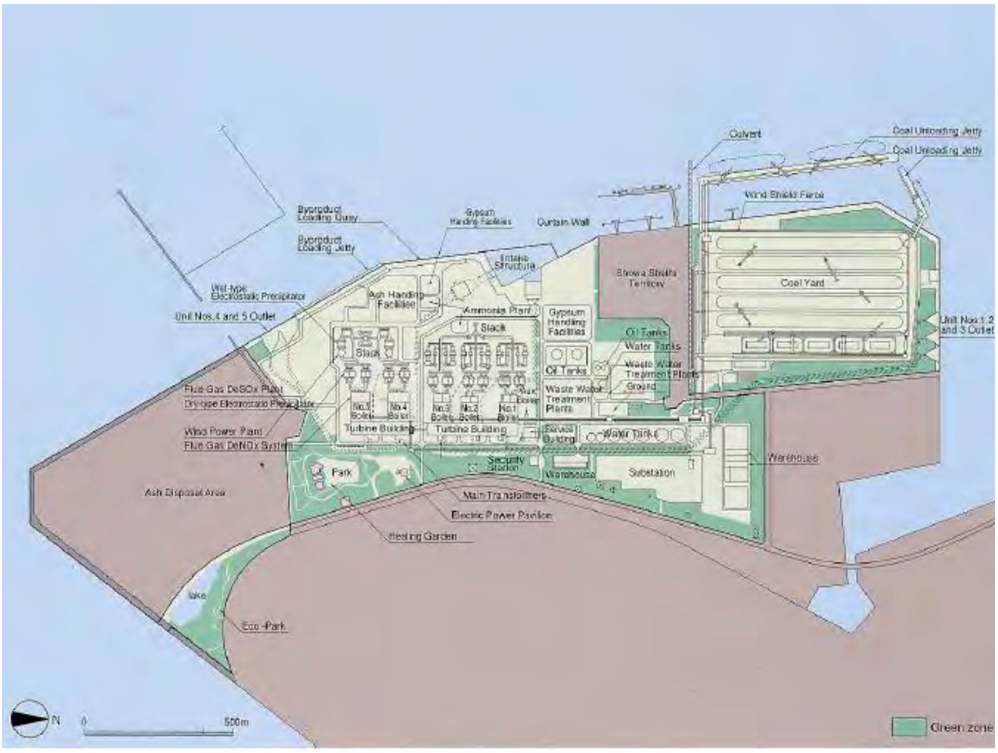
| | | | | | |
|---|---|---|---|---|---|
| #4 | 1000 | 566/593℃ | 24.1 MPa | 44% | Nov./2001 |
| #5 | 1000 | 566/593℃ | 24.1 MPa | 44% | Nov./2002 |

b) Environmental Value

| No. | NOx<br>（ppm：O2=6%） | SOx<br>（ppm） | PM<br>（mg/m3N：<br>O2=6%） |
|---|---|---|---|
| #1,2,3 | 30 | 28 | 5 |
| #4,5 | 15 | 25 | 5 |

c) Overview of CFPP

d) Layout of CFPP



(3) Electric Power Development Co., Ltd (J-POWER)

1) New Isogo Coal fired Power Plant (Space: 120,000M$^2$)[28]

Isogo, now synonymous as the world-cleanest power plant and is a model for all who pursue the environmentally-sustainable coal-fired power generation, stands out from the crowd by undergoing a very unique 'Build, dismantle and build' method that was introduced to ensure uninterrupted power supply and environmental compliance throughout the years of the replacement process from subcritical (conventional)-type to tower-type USC Boiler. Unit 1 commenced its operation in 2002, while Unit 2 with COD in 2009, has set another benchmark by reaching a 620℃ reheat.

a) Unit Specification

| No. | Nominal Output(MW) | Steam condition | | Efficiency (LHV) | COD |
|---|---|---|---|---|---|
| | | Temp. | Pressure | | |
| #1 | 600 | 600/610℃ | 25MPa | 45% | Apr./2002 |
| #2 | 600 | 600/620℃ | 25MPa | 45% | July/2009 |

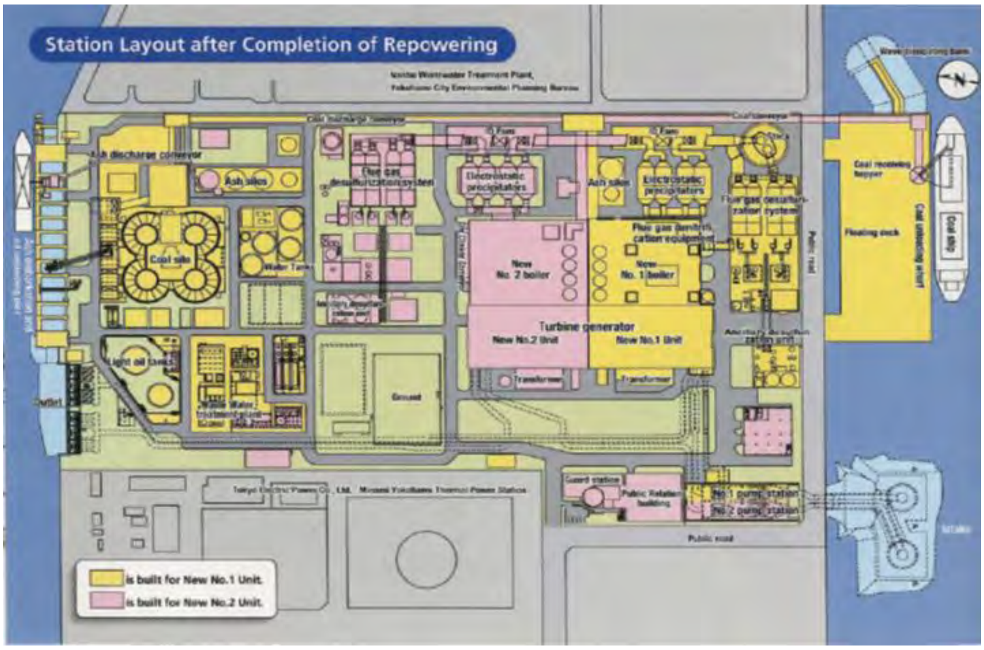
b) Environmental Values

| No. | NOx (ppm：O2=6%) | SOx (ppm：O2=6%) | PM (mg/m3N) |
|---|---|---|---|
| #1 | 20 | 20 | 10 |
| #2 | 13 | 10 | 5 |

c) Overview of CFPP

[28] Reference: Material was supplied by Electric Power Development Co.,Ltd. and the guidebook of Isogo Thermal Power Station published by Electric Power Development Co.,Ltd.

d) Layout of CFPP



2) Tachibana-wan Coal fired Power Plant (Space: 360,000M$^2$)[29]

The plant with COD in, is one of the most efficient and cleanest with two 1,050MW units, which is the largest unit in Japan. The plant set a benchmark for steam condition at 25MPa x 600/610℃.

a) Unit specification

| No. | Nominal Output(MW) | Steam condition | | Efficiency (LHV) | COD |
|---|---|---|---|---|---|
| | | Temp. | Pressure | | |
| #1 | 1,050 | 600/610℃ | 25MPa | 45% | July/2000 |
| #2 | 1,050 | 600/610℃ | 25MPa | 45% | December/2000 |

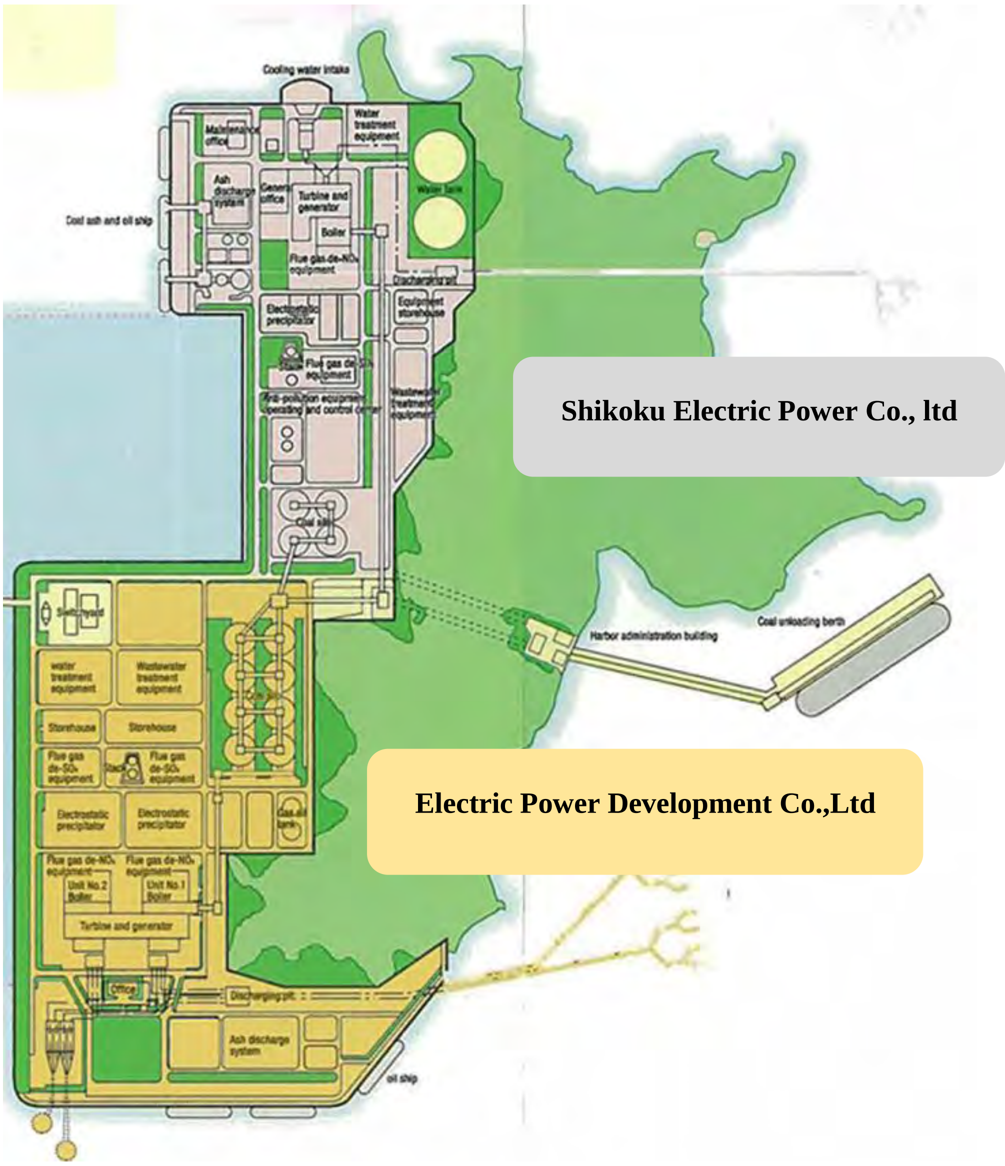
b) Environmental values

| No. | NOx （ppm：O2=6%） | SOx （ppm：O2=6%） | PM （mg/m3N） |
|---|---|---|---|
| #1, 2 | 45 | 50 | 10 |

[29] Reference: Material was supplied by Electric Power Development Co.,Ltd. and the guidebook of Tachibana-Wan Thermal Power Station published by Electric Power Development Co.,Ltd.

c) Overview of CFPP

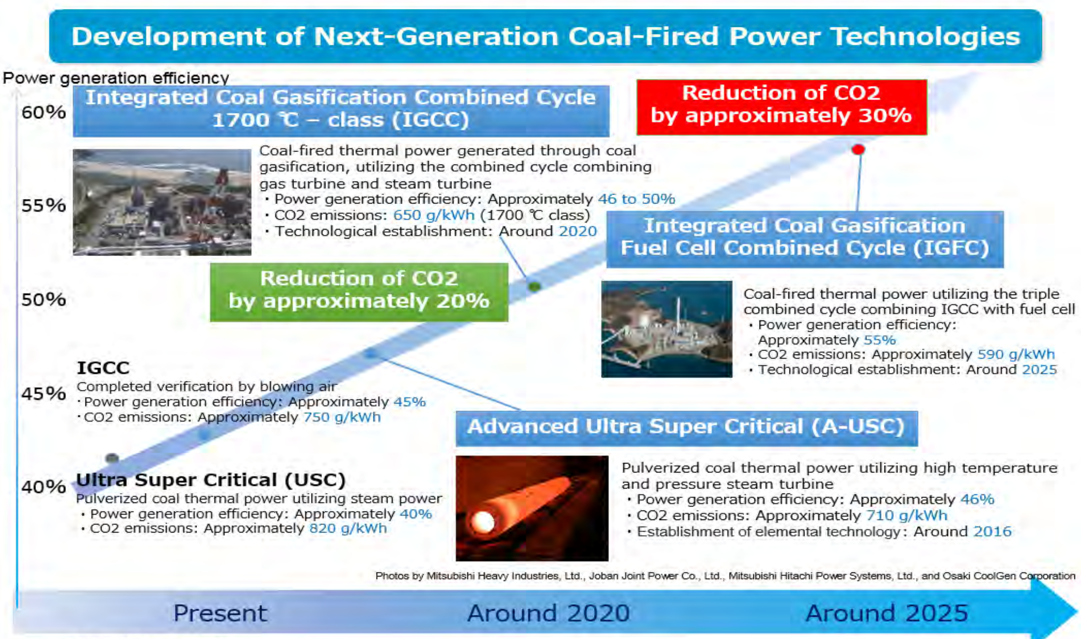
d) Layout of CFPP



3.7 Integrated Coal Gasification Combined Cycle (IGCC)

(1) Introduction

Coal-fired power plants play an important role in providing energy at low prices because coal is abundant, efficient, and less expensive than most other energy options and will remain an important part of the future energy of the globe. In the meantime, it is also recognised that coal fired power plants without CCT, may cause environmental impacts by emitting a considerable quantity of carbon dioxide ($CO_2$) and greenhouse gases (GHG), into the atmosphere compared to other power generation plants. In an era when the global community is working together to achieve low or near-zero emissions, Japan is not exempted from the required efforts towards the further enhancement of environmental compliance through beyond-USC technology development (Figure 46).




SOURCE : METI

Figure 46. Development of Next-Generation CCTs

IGCC has been developed to improve the power generation efficiency using gasifier technology to turn coal into synthesis gas (syngas) for gas turbine power generation. The plant is integrated because the syngas produced in the gasification section is used as fuel for the gas turbine in the combined cycle, while the steam produced by the syngas cooler in the gasification section and heat recovery steam generator (HRSG) installed gas turbine exhaust section is used by the steam turbine in the combined cycle. Figure 47 shows the outline of IGCC.

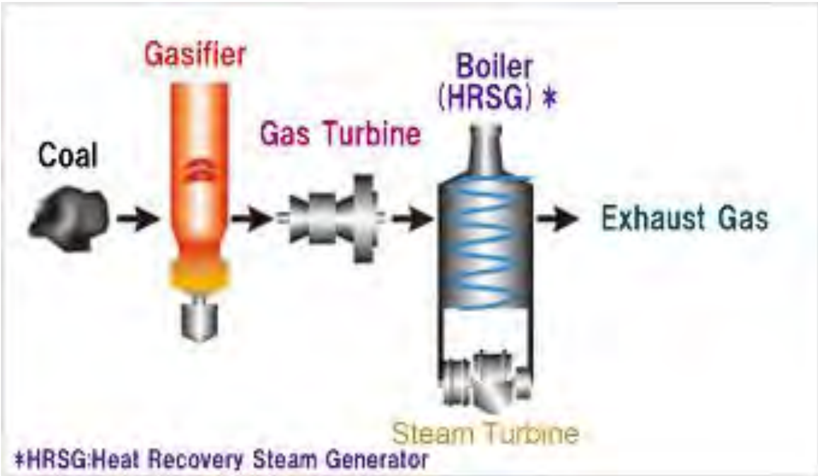



Figure 48. Outline of IGCC .

[30] Joban Joint Power Co., Ltd.

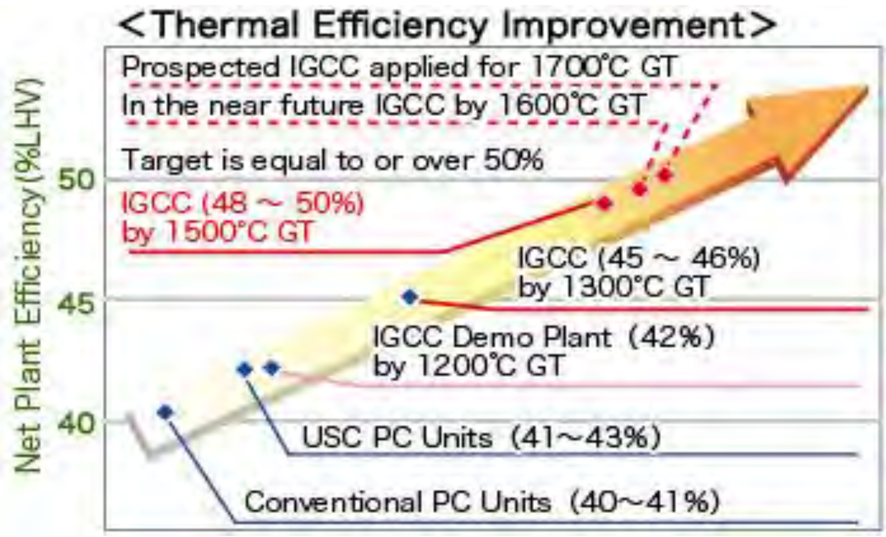



Figure 49. Thermal Efficiency of a Typical Power Generation Plant[31]

(2) Demonstration Plant

Figure 49 shows a 250MW demonstration plant installed at Nakoso Power Plant of Joban Joint Power supplied by Mitsubishi Hitachi Power Systems (MHPS).

The plant had successfully completed its demonstration operation under Clean Coal Power R&D Co., Ltd. and has started its commercial operation since April 2013 under Joban Joint Power, the new owner of 250MW Nakoso IGCC plant as Nakoso #10 Unit.

[31] Japan Coal Energy Center


Figure 50. 250 MW IGCC Demonstration Plant [32]

(3) Salient features

An IGCC system has the following features compared with conventional coal fired power generation systems:

1) High plant efficiency: 42% (Net, LHV)
2) Low emissions of NOx, SOx, $CO_2$ and PM
3) Reduction of ash volume and protection from heavy-metals elution after landfill by melting of ash in gasifier and exhausted as vitric slag.
4) Coal with low ash melting temperature, ill-suited for pulverized coal fired boiler, can be used.

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[32] Joban Joint Power Co., Ltd.

(4) Forthcoming commercial projects

The next commercial IGCC units that are currently at the detailed design phase are one 540MW unit at the Nakoso Power Plant in 2020, and the other 540MW at the Hirono Power Plant in 2021.

# Chapter 4 - List of other Available and Applicable CCTs

## 4.1 Boiler Technology

### (1) Comparison of Subcritical units and Supercritical units

Since the steam conditions are changed from subcritical pressure to supercritical pressure, both the structure and characteristics of the boiler will be different.

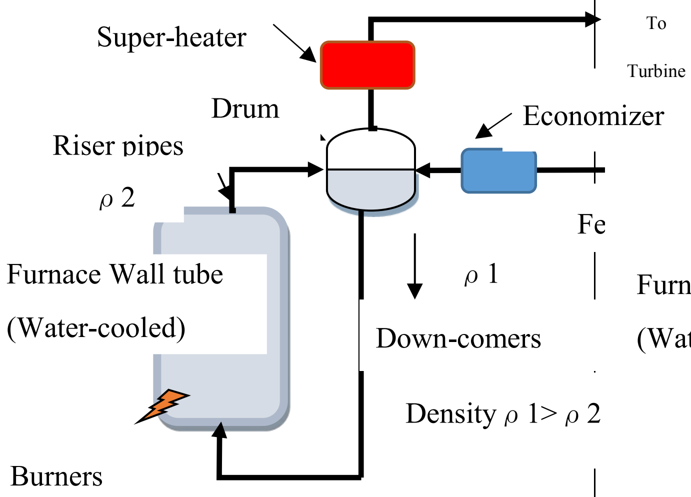
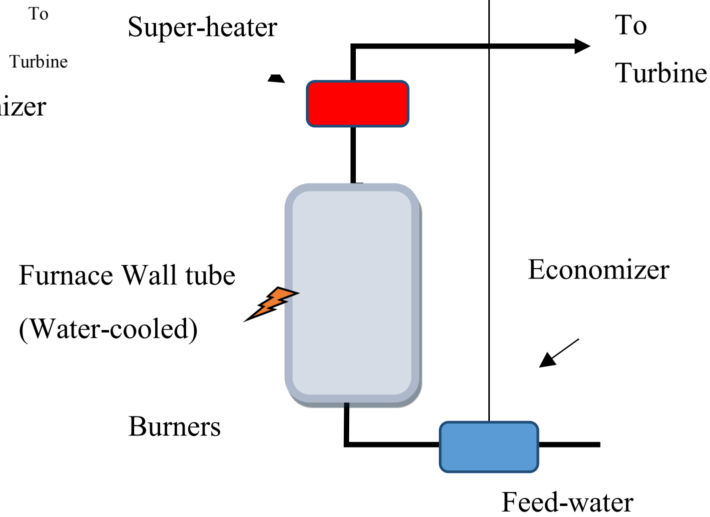
The table below shows the main comparative features of a boiler designed by new technology (supercritical pressure / ultra-supercritical pressure) compared with an old one (subcritical pressure). Figure 50 shows the typical side view of a subcritical boiler, and shows a typical side view of a supercritical boiler (ultra-supercritical boiler).

### (2) Unit capacity of SC (supercritical) or USC (ultra-supercritical) coal fired plant

The unit capacity of an SC or USC coal fired plant is normally between 420MW and 1100MW as USC used to be regarded as applicable to middle to large scale power generation.

In ASEAN countries, there is a need for small-capacity coal-fired power plants. Until recently, there was no SC or USC small-scale coal fired power plants in the region. In Indonesia, a USC coal fired power plant of 315MW with Japanese technology[33] will be built for the Lontar Coal Fired Steam Power Plant. The project adds a new dimension to coal power development.

[33] The boiler will be supplied by IHI Corporation, while the steam turbine and power generator will be supplied by Toshiba Corporation.

<table>
<tr><td>type</td><td>Subcritical unit<br>(Drum type boiler)</td><td>Supercritical and Ultra-supercritical units<br>(Once-through type boiler)</td></tr>
<tr><td>Water circulation</td><td>
</td><td>
</td></tr>
<tr><td>Features</td><td>・Boiler-water is fed to drum through the economizer.<br>・Boiler-water is supplied to furnace wall through down-comer and heated up in the furnace. Heat addition generates a steam-water mixture and returns to drum. In the drum, the steam is separated from boiler water and supplied to super-heater. Superheated steam is supplied to turbine for power generation.<br>・In circulation, gravity acting on the density difference between the sub-cooled water in the down-comer and steam water mixture in the heating tube circuit produces the driving force for circulation.<br>・Maximum capacity of the plant is limited up to about 600MW due to the limitation of the drum sizing.</td><td>・Fluid (feed-water) at supercritical pressure experiences a continuous transition from water-like to steam-like characteristics. The fluid passed through the economizer in liquid phase flows to the furnace wall tubes and is heated-up in the furnace and changed to vapour (steam) phase and connected to super-heater. Superheated steam is supplied to turbine for power generation.<br>・No two phases state occurs in the furnace and drum is not required.</td></tr>
</table>

| Steam Conditions<br>Pressure MPa (Typical)<br>Temperature ℃ (Typical) | Subcritical<br>16.6<br>538 - 566 | Supercritical<br>24.1<br>538 - 566 | Ultra-supercritical<br>24.1<br>593 - 620 |
|---|---|---|---|
| Boiler type | Drum | Once-through | Once-through |

| | | | |
|---|---|---|---|
| Generating Efficiency | low | high | highest |
| Fuel/ Exhaust gas | more | less | Least *1 |
| Water quality control | easy | severe*2 | more severe *2 |
| Steam temperature control | easy | severe | |
| Load changing rate | low | high | |
| Start-stop time | long | quick | |
| Operation | relatively easy (base) | Quick responding action required *3 | |
| Maintenance | relatively easy (base) | Establishment of maintenance procedure is required *4 | |
| Main tube material | low alloy | Low/ high alloy | Ferritic stainless *5 |

Remarks
*1. Less exhaust gas contributes to less amount of NOx, SOx, Particulate matter, and $CO_2$ emission.
*2. Impurities are entrained to turbine or accumulated in boiler tubes.
*3. Rapid steam pressure and temperature control is required due to less holding amount of boiler water.
*4. Considering characteristics of new materials for high temperature use, maintenance procedure is required to republish.
*5. Austenitic stainless steel tubes are used for high temperature steam condition.
*6. Typical side view of Subcritical Boiler
*7. Typical side view of Supercritical Boiler

Figure 51. Comparison of New Designed Boiler with Previous Boiler[34]

[34] Japan Coal Energy Center

(3) Boiler Combustion Simulation Technology

Computer Simulation analysis has been utilized to reduce unburnt carbon or NOx emission and resolve the problems of ash deposition for pulverized coal fired boilers.

1) Outline of simulation technology

Simulation technology is established by incorporating pulverized coal combustion models into commercialized Computer Fluid Dynamics (CFD) software, 'FLUENT'

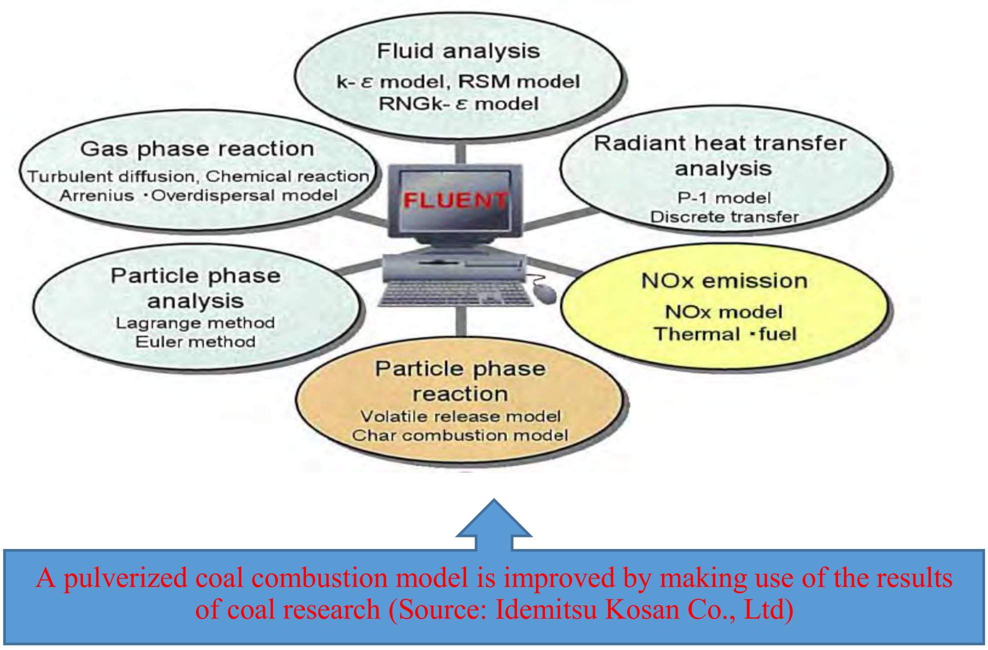



Figure 52. Outline of Simulation Technology[35]

[35] Idemitsu Kosan Co., Ltd

2) Analysis method

a. Input and output

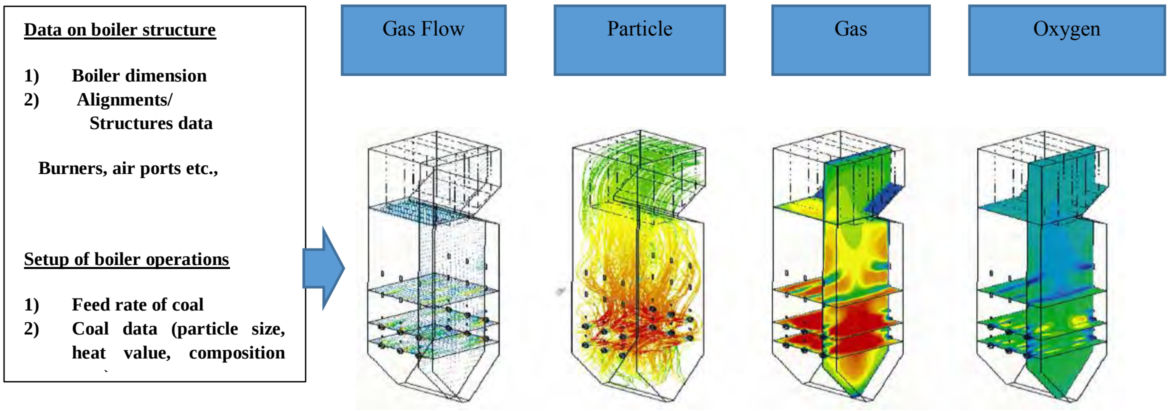



Figure 53. Input and Output (Example)[36]

b. How to use the output

(a) Search of optimum operating conditions (Combustion air distributions)

(b) Reduction of unburnt carbon to improve the efficiency

(c) Reduction of NOx

(d) Improvement of slagging troubles

(e) Effect prediction in case of coal changing.

3) Example

[36] Idemitsu Kosan Co., Ltd

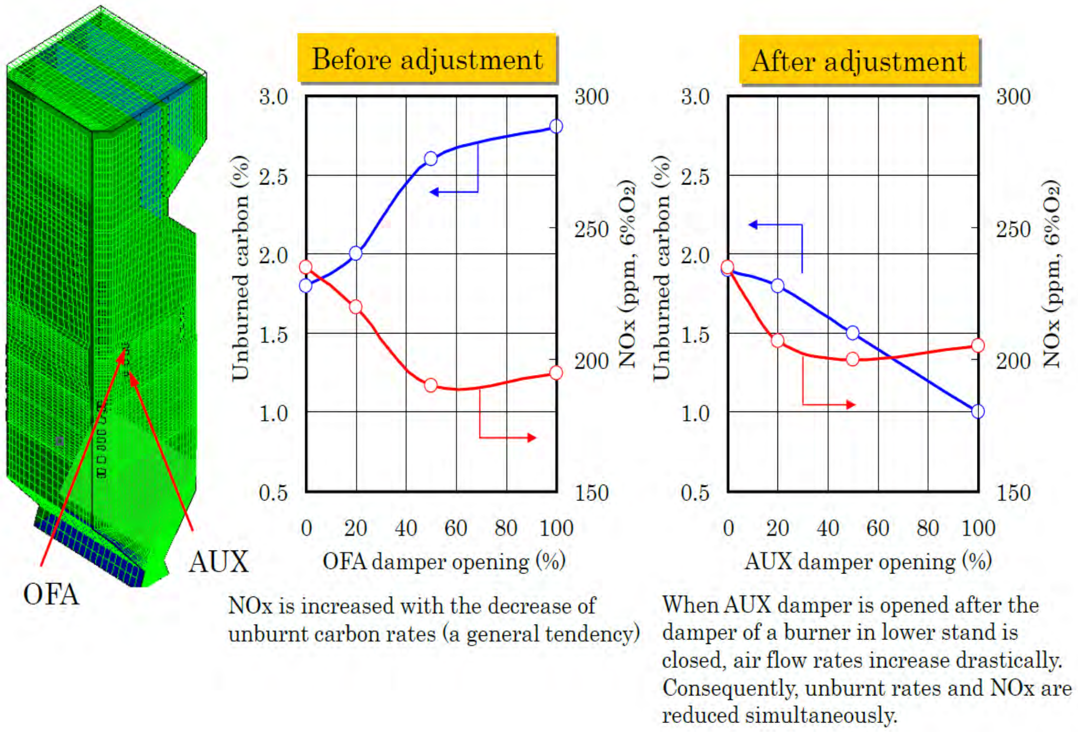



Figure 54. Example of Application[37]

Reduction of unburnt carbon and NOx was produced by altering the setup of damper openings.

[37] Idemitsu Kosan Co., Ltd

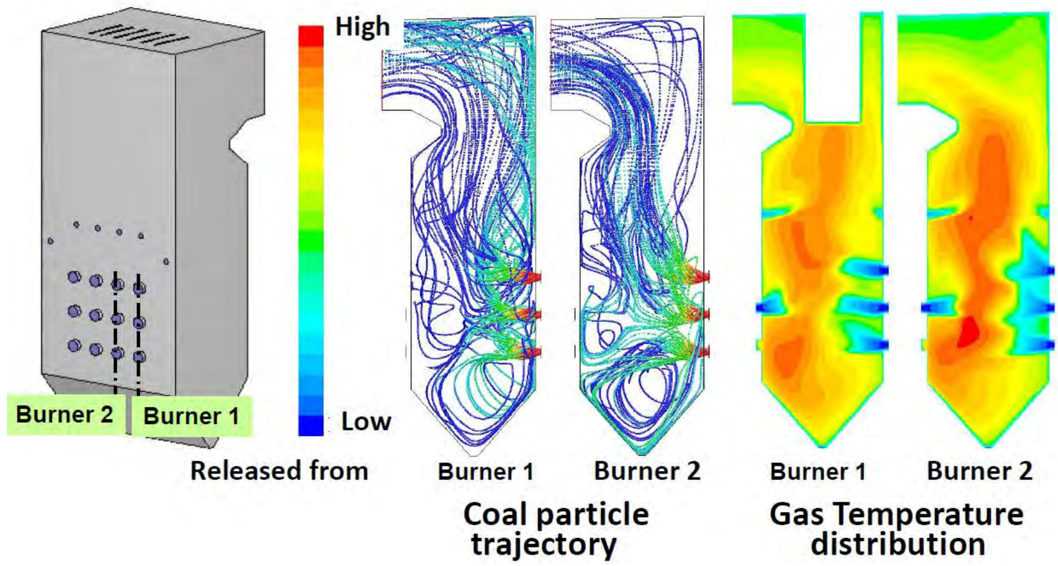



Figure 55. Example of Application[38]

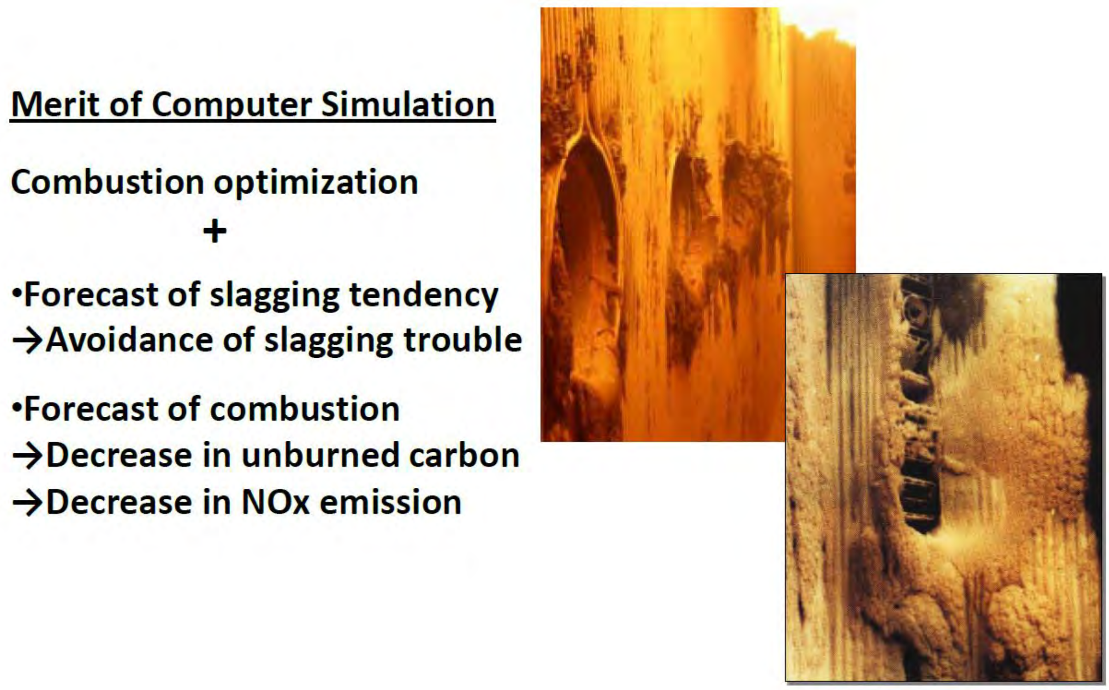



Figure 56. Example of Application[39]

38 IHI Corporation
39 IHI Corporation

4.2 CFB Boiler

While a one-through USC boiler is rather dominant, especially for large-scale coal-fired power development, for mid-or small-scale a CFB (circulating fluidized bed) Boiler may be one of the best possible options. CFB technology has emerged among the leading combustion technologies for utility-scale solid-fuel-fired power plants, especially in combustion of lignites. CFB provides irresistible benefits; such as immense flexibility of fuel, low emissions, high efficiency and availability.

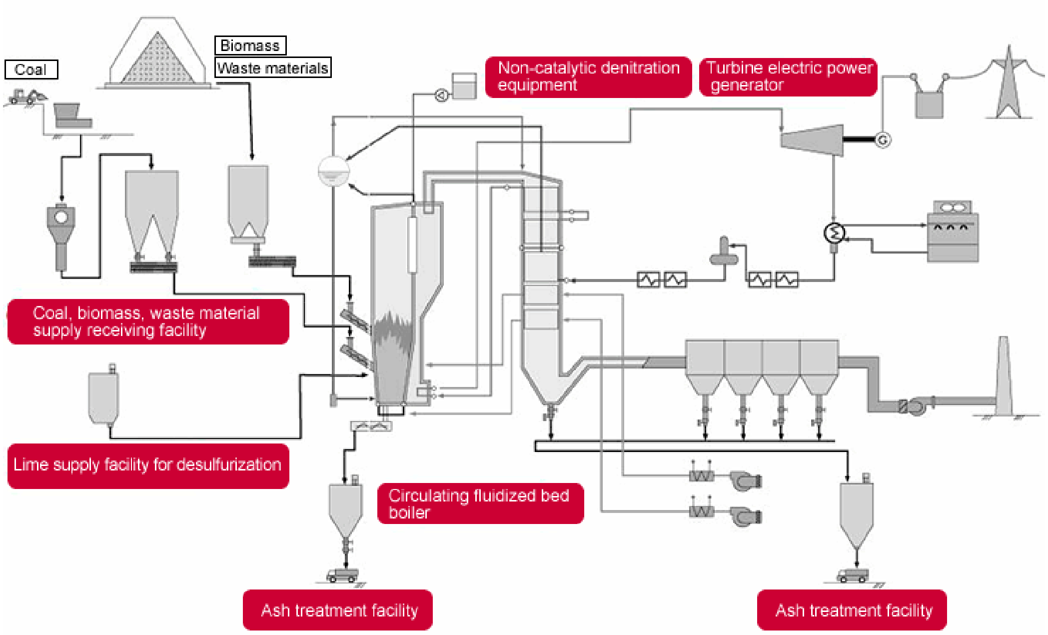



Figure 57. Schematic Diagram of CFB[40]

Biomass fuel (for $CO_2$ reduction), varieties of coal including high moisture low rank coal (for energy security), waste tire (TDF) and plastic refused fuels (for waste to energy) are even used in a boiler.

CFB can utilize a wide range of fuels due to the following features:

A) Long combustion time by the circulating ⇒ Easy to burn unreactive fuels like Anthracite.

B) Large heat capacity in furnace ⇒ Easy to burn high moisture fuels like Biomass.

C) Controlled combustion temperature ⇒ Low and Controlled Emission (SOx and NOx).

D) Strong Fluidization in Bed ⇒ large size fuels, various figure fuels.

[40] Sumitomo Heavy Industries

4.3 Consultancy on Maintenance (Risk Based Maintenance: RBM)

(1) General

Risk Based Maintenance (RBM) for boilers has been developed to provide the best optimization of maintenance for long-term operations. The RBM operated based on the American Petroleum Institute's API1581. RBM was utilized since the 90s for boiler plants to anticipate unexpected accidents. The programme successfully decreased the frequency of accidents drastically, while for some plants they could be reduced to less than half the amount of earlier years. Additionally, the financial gain could be as much as $10 million a year due to the implementation of the RBM program by Japan. The evaluation of the "Risks" can be envisioned from the "likelihood of damage" and "Possible consequence of failure" specified in Figure 59.

A long term maintenance plan is provided for the timings of replacement and inspection according to the evaluated risks with cost benefit analysis.

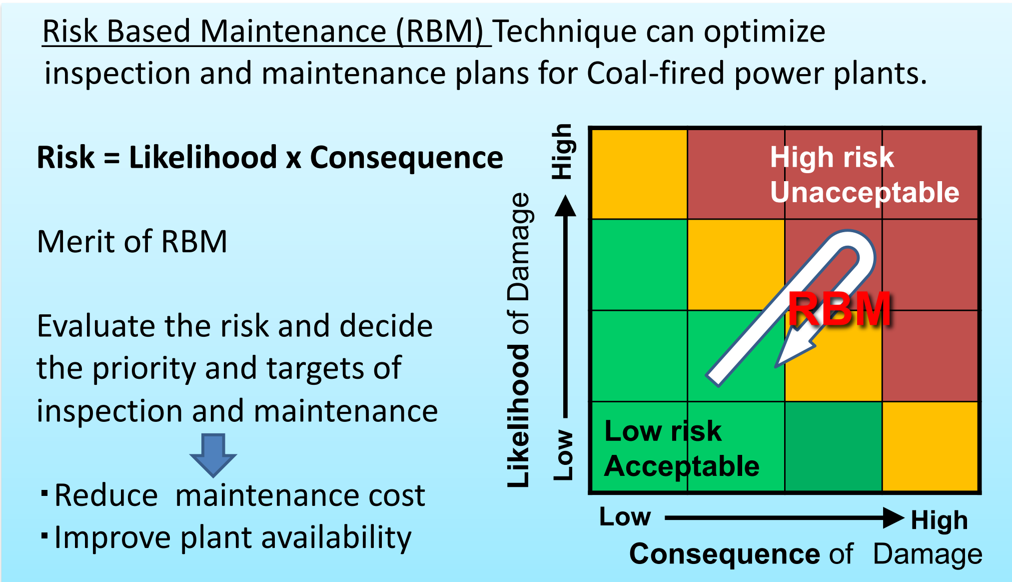



Figure 58. Risk Based Maintenance (RBM)[41]

(2) Procedure

[41] Mitsubishi Hitachi Power Systems, Ltd.,

RBM procedure is shown in Figure 60; Inspection data is referred to the previous data and verified by the accumulated data base and Inspection/Maintenance planning is then established.

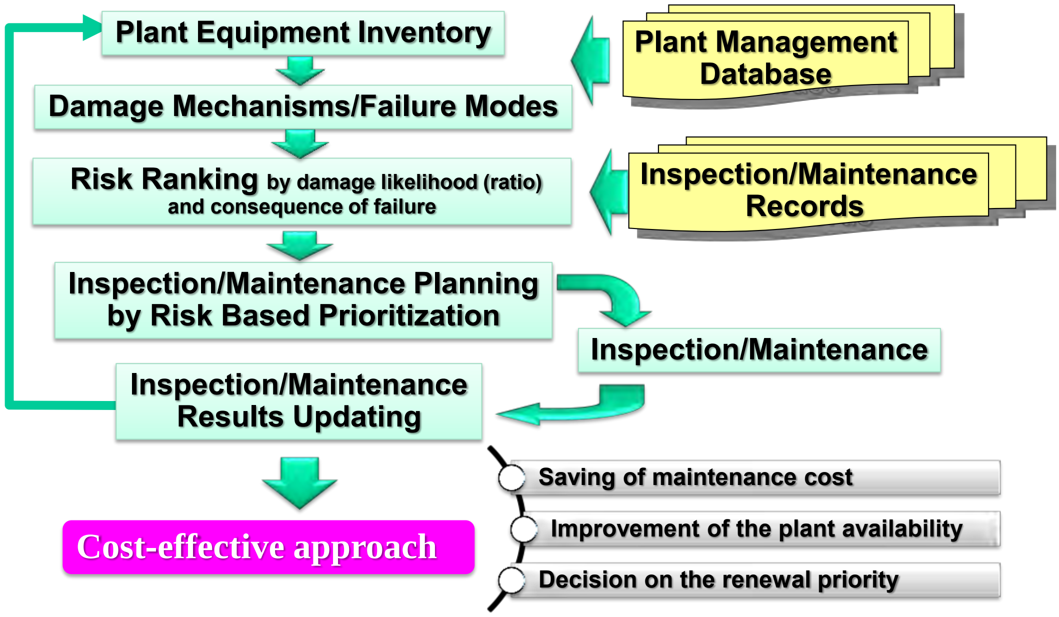
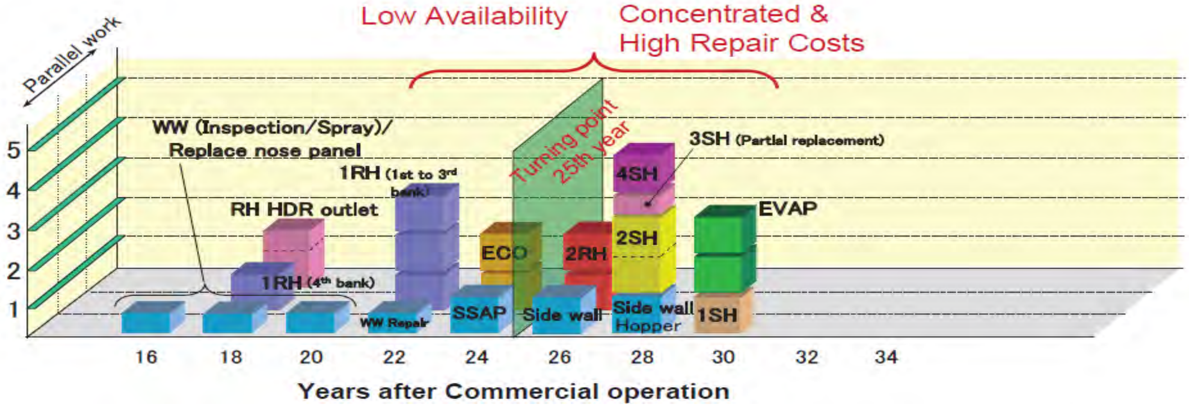



Figure 59. RBM Procedure[42]

(3) Typical Boiler major RBM categories and Asset Services




[42] Mitsubishi Hitachi Power Systems, Ltd.,

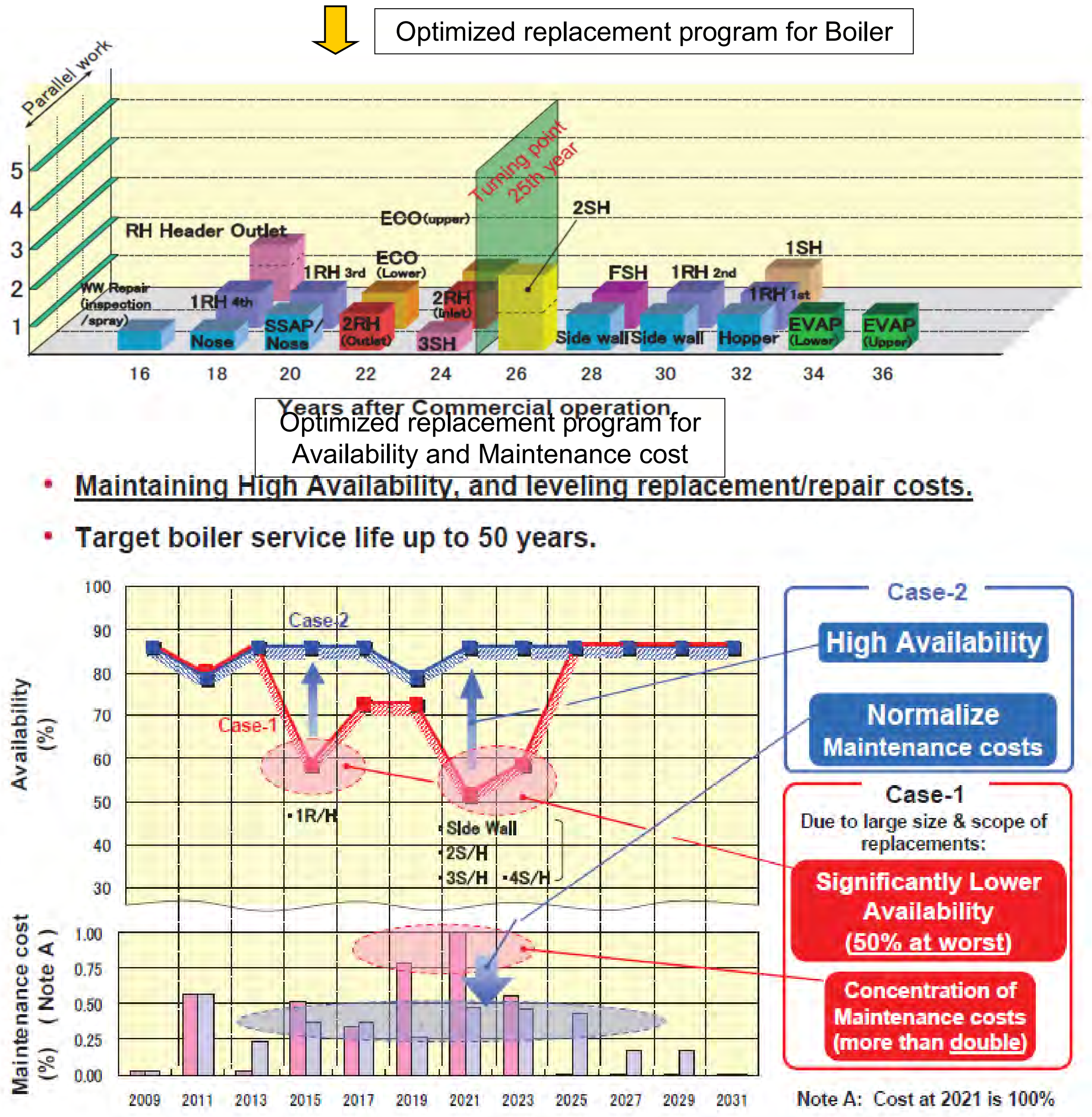



Figure 60. RBM Procedure[43]

(Boiler Operation Optimization/Tuning Services)

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[43] Mitsubishi Hitachi Power Systems, Ltd.,

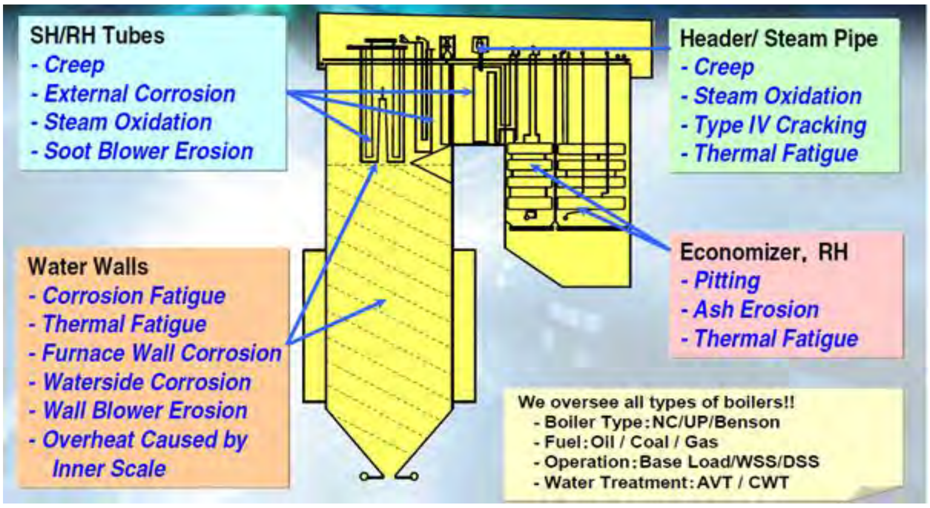



Figure 61. Typical Components to be Inspected[44]

(4) Summary

1) RBM is composed of precise inspection techniques and metallurgical assessment based on a 30 year database.

2) RBM could evaluate creep, corrosion fatigue, thermal fatigue, and so on.

3) An RBM program can advise an economical maintenance procedure with minimised un-anticipated accidents that contributes to a financial loss.

[44] Mitsubishi Hitachi Power Systems, Ltd.,

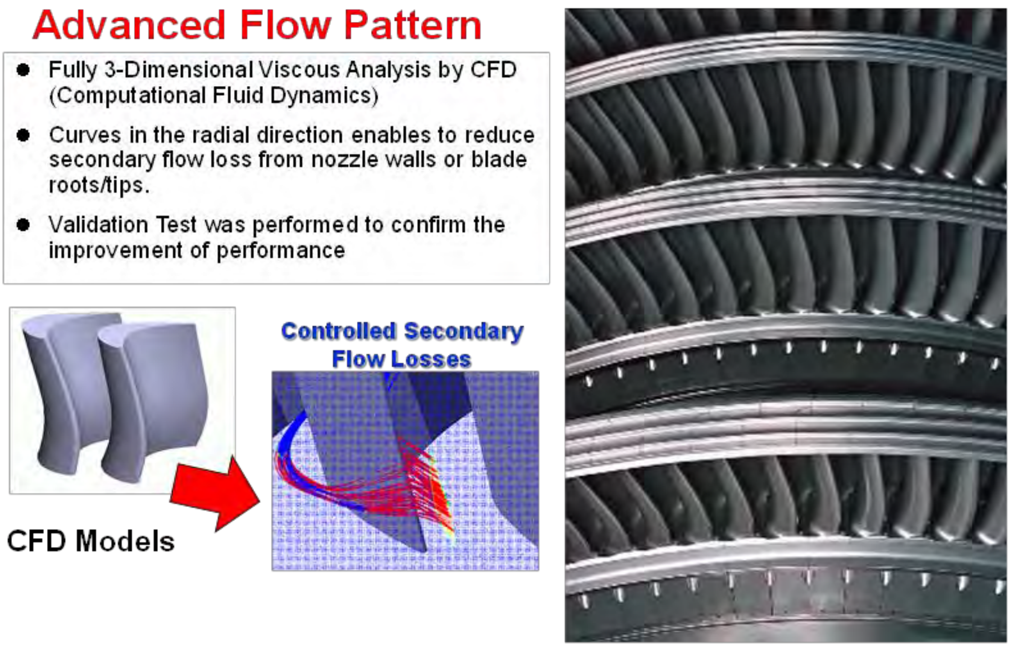
4.4 Steam Turbine Technology (Rehabilitation for Steam Turbine)

The refurbishments of turbines have been implemented using state-of-the-art technology for an improvement in efficiency and reliability, with some of them planned concurrently to increase the electric output.

(1) Efficiency improvement technology

The efficiency improvement can be achieved by reducing turbine internal loss. In the 90s the Computational Fluid Dynamics (CFD) methods and test facilities were developed quickly for the study of optimum turbine internal configuration to minimise the internal losses. The thermodynamic and aerodynamic performance of the steam turbine is primarily determined by steam path such as high-efficiency nozzle (stationary blade) and blades with a steam seal device.

1) Updated advanced flow pattern in the steam path
<u>For High & Intermediate Pressure Turbine</u>




<u>For Low Pressure Turbine</u>

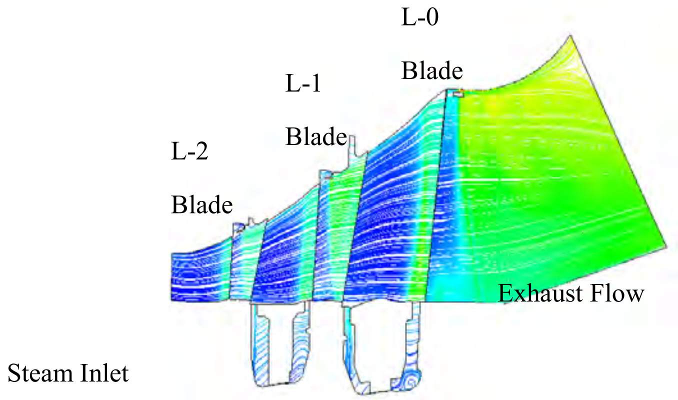
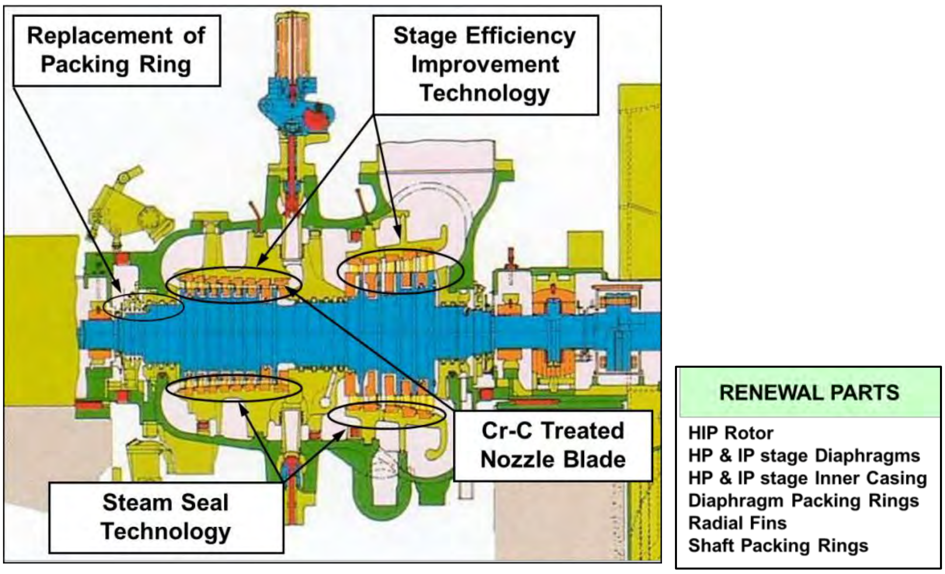



Figure 62. Outline of High Efficiency Technology[1]

2) Efficiency improvement technology (typical)

(a) High and intermediate pressure (HIP) turbine Typical efficiency improvement scopes for HIP turbines are referred to in Figure 64.




(b) Low pressure (LP) turbine

Typical efficiency improvement scopes for LP turbine are referred to in Figure 64.

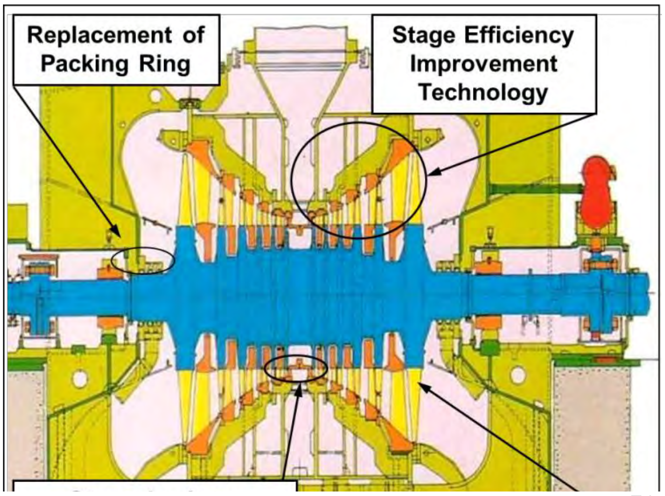



Figure 63. Efficiency Improvement for LP Turbine[74]

Typical measures for the achievement of high reliability are as follows:

[45] Mitsubishi Hitachi Power Systems

1) Treatment or coating; such as Cr-C (chromium-carbide-coating) on the material surface of the nozzle and blade with attachments.
2) Adoption of special materials for valve stems and bushes made of high corrosion resistant materials; such as Incoloy, Stellite etc.,

The Oxide scale on the Stem and Bush produced under high temperature steam reduces the narrow clearance and causes the stem-stick.

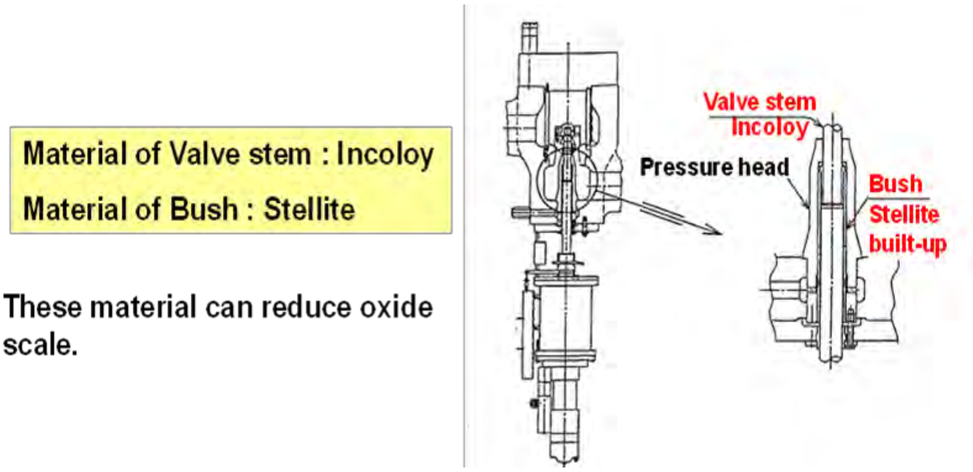



Figure 64. Example of Measures for High Reliability

3) Adoption of Snubber blades

In the low pressure (LP) turbine blades such as the last minus one (L-1), the last minus two (L-2) and so on, which are operated in moist conditions, corrosion damage like stress corrosion cracking and corrosion fatigue may sometimes appear. Snubber blades effectively contribute to solve these issues and to improve reliability.

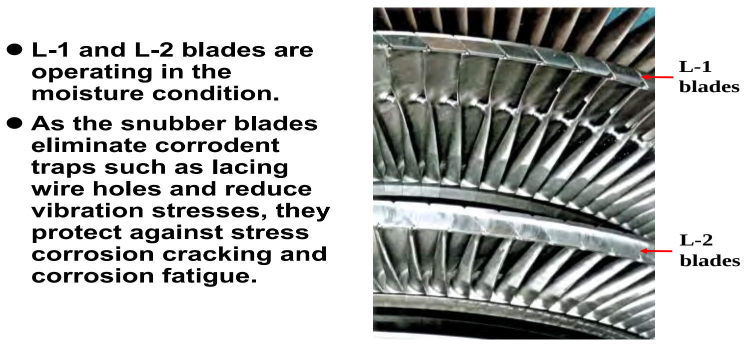



Figure 65. Example of Measures for High Reliability[46]

[46] Toshiba Corporation

(2) Typical example of turbine restoration with Japanese technology

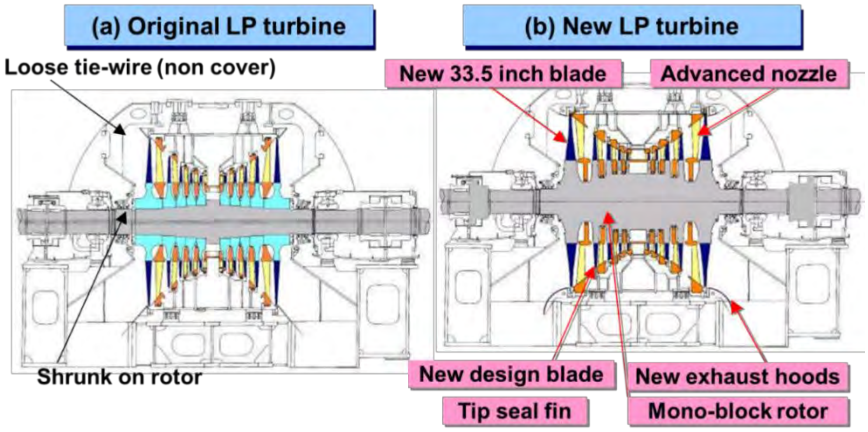



Figure 66. Turbine Restoration (Case 1)[1]


Figure 67. Turbine Restoration (Case 2)[47]

4.5 Advanced Process Control of Boiler, Turbine & BOP

(1) General

The coal fired power generation plant has been strongly recommended for improved efficiency through Advanced Process Control (APC) for contributing to energy conservation. The power plant uses a conventional DCS (Distributed Control System), the control parameters are changed by the operator manually in accordance with the situation based on the experience and available allowances. However, in general, the set point data variability in manual setting is quite broad and is required to consider some unexpected contingencies. Consequently,

[47] Toshiba Corporation Power Systems Company

some allowances in the operating limitations are taken, which results in performance deterioration.

APC can improve the controllability of the process and it ensures the ability to optimize the allowance of a variation in set-points within operating limitations. APC also improves the plant efficiency through stricter control band. The APC can provide not only high controllability, but also an operating optimization in the total power generation plant system. APC can predict possible future behaviour of the power plant and change the control variable based on the manipulated and disturbance conditions and achieve both high controllability and an optimization facility in the control algorithm.

Outline of APC is referred to in Figure 69.

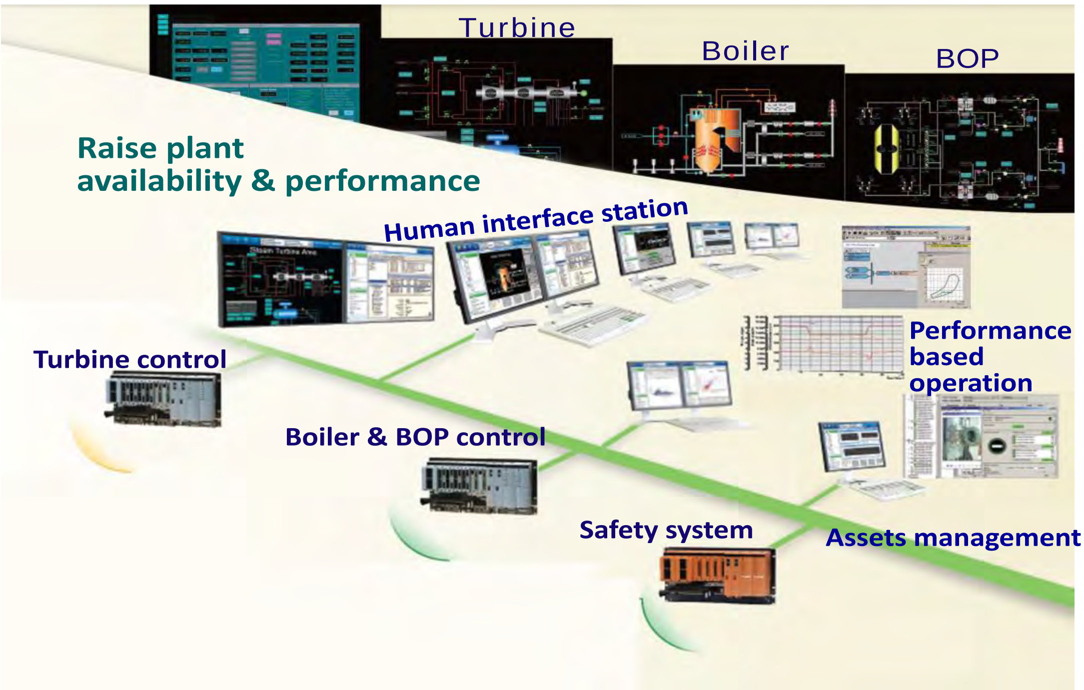



Figure 68. Outline of APC for Coal Fired Power Generation Plants[48]

(2) Envisaged benefits of APC adoption

1) Improvement of power plant efficiency
2) Improvement in plant availability
3) Minimizing of environmental emissions

(3) Example: Integrated Monitoring and Control System

[48] Yokogawa Electric Corporation

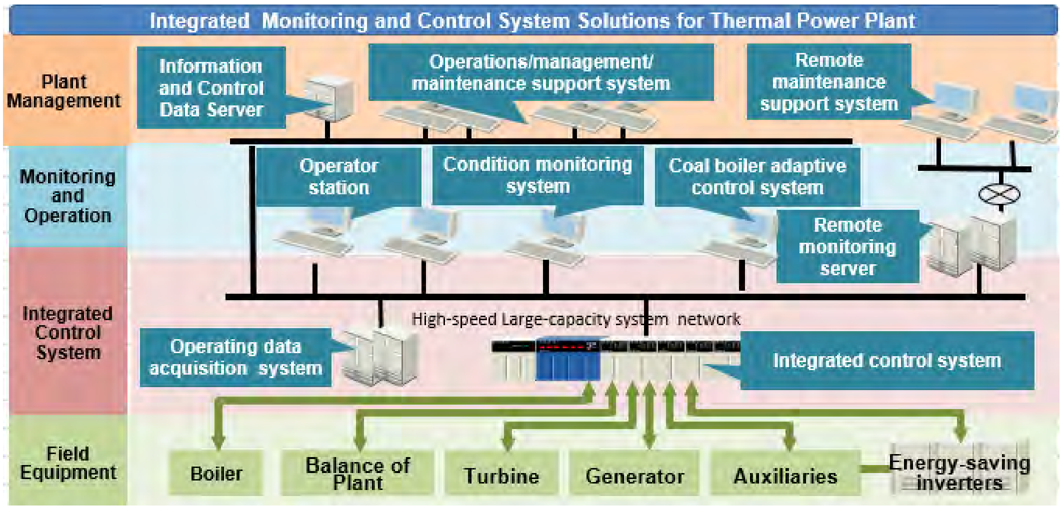



Figure 69. Outline of APC for Coal Fired Power Generation Plants[49]

Source: Mitsubishi Hitachi Power Systems, Ltd

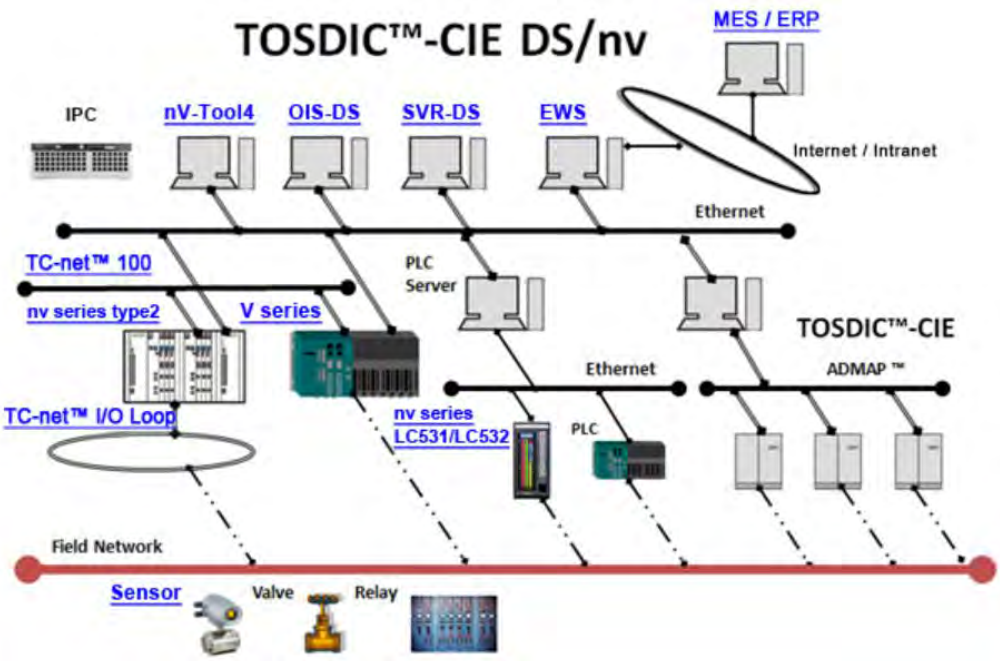



Figure 70. Outline of APC for Coal Fired Power Generation Plants[50]

(4) Introduction of new steam pressure controls

Steam Pressure controls in power plants are difficult to optimize, due to the characteristics of the fuel/combustion/steam generation processes, and also constraints imposed by material stresses, fuel delivery systems, and boiler firing limitations.

[49] Mitsubishi Hitachi Power Systems, Ltd
[50] Toshiba Corporation

The optimization by the advanced control strategy provides minimised over firing through a dynamic pressure set point formation and a continually adjustable reserve margin for frequency response.

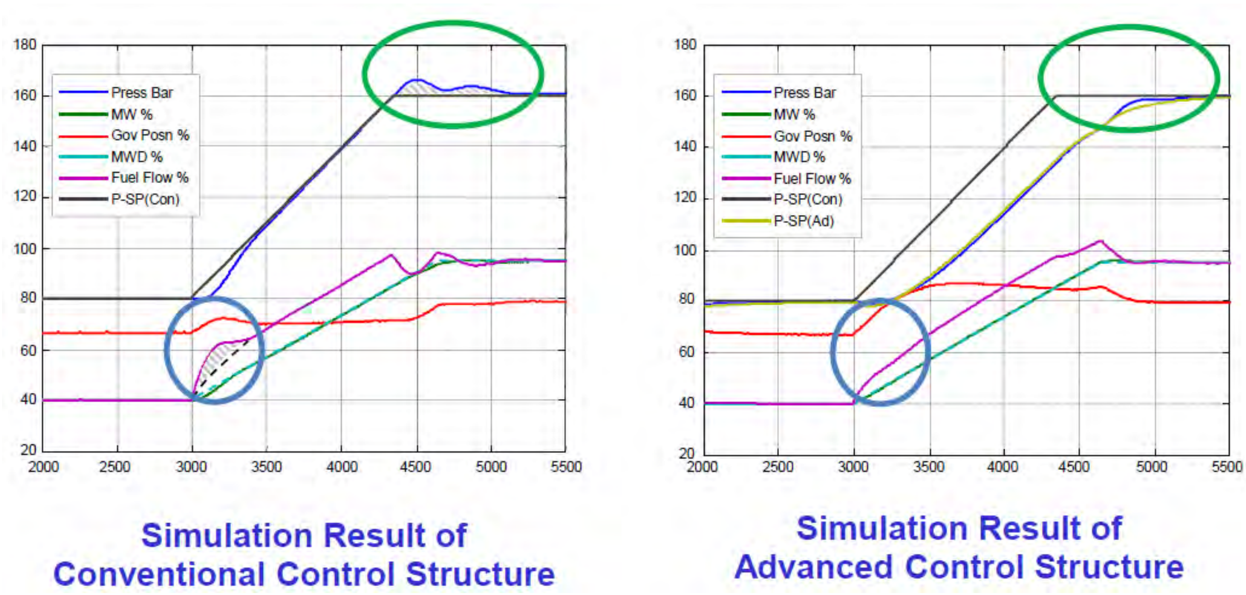



Figure 71. Advanced Feedback Control of Steam Pressure

using a Two-degree-of-freedom Model[51]

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[51] Toshiba Corporation

4.6 Environmental Flue Gas Treatment Technology

(1) General

Environmental flue gas treatment systems are very important for power plants. Rich experience in Japan on De-NOx, and FGD (Flue Gas De-sulfurization) and EP systems can comply with the extremely low emission requirements in Japan.

Recently, in Japan, a low-low temperature EP system (High-performance system) has been adopted to reduce PM emissions. A low-low temperature EP system improves the dust collection efficiency, when compared with the conventional system, thereby enabling low PM emissions. SO3 reduction and emissions, also leads to corrosion prevention of the GGH. In the case of no GGH of the system, make-up water is increased in the wet FGD system.

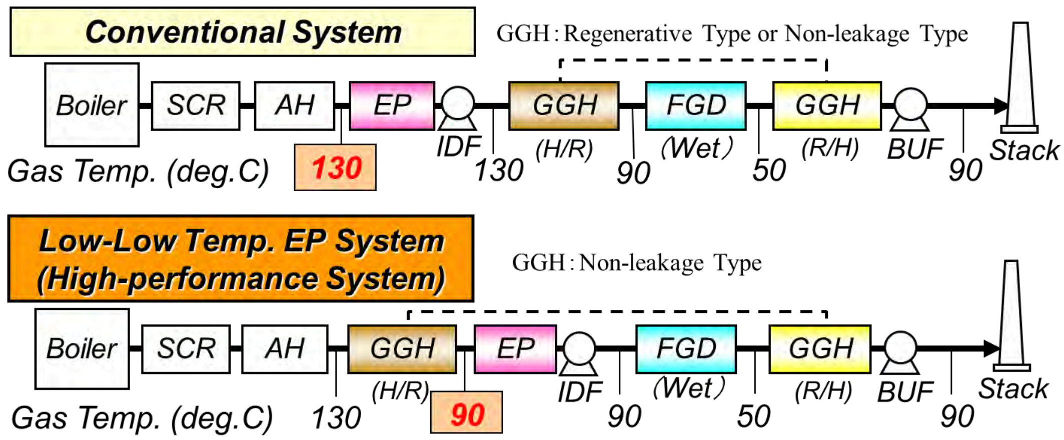



Figure 72. Difference between a Conventional System and a Low-low Temperature EP System[52]

(2) Environmental system

1) De-NOx system

To meet the severe and various requirements, the following Selective Catalytic Reduction (SCR) Process for De-NOx can be applied as proven technology.

A De-NOx System can achieve high De-NOx efficiency. Reliable and high performance Catalysts will be selected and a De-NOx system can be established in coordination with boiler and auxiliary facilities.

[52] Mitsubishi Hitachi Power Systems, Ltd.

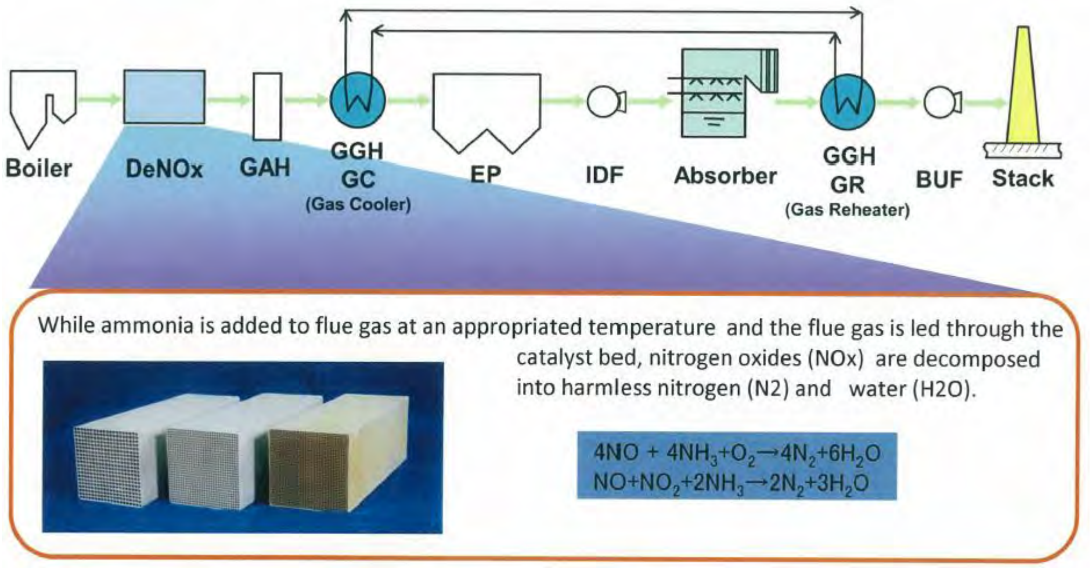



Figure 73. De-NOx System[53]

The catalyst type is selected based on the flue gas condition. The best selection of catalysts provides benefits for plant operation and maintenance costs. A honeycomb type catalyst and plate type catalyst is used for coal firing power stations.

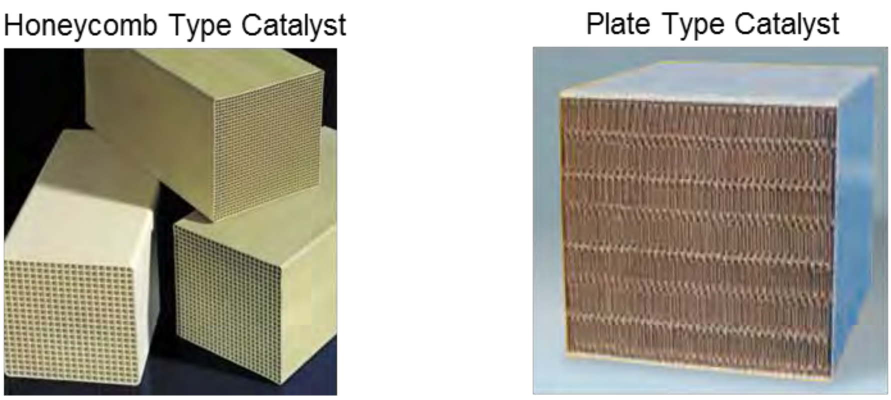



Figure 74. Honeycomb Type and Plate Type Catalyst for SCR[54]

2) De-SOx(FGD) system

[53] IHI Corporation
[54] Mitsubishi Hitachi Power Systems

A wet type FGD System (Limestone – Gypsum Process and other Alkaline Processes) is the most efficient De-SOx system for power plants. Japanese FGD Systems have high De-SOx efficiency, and a compact layout can also be accomplished. Figure 76 shows a typical FGD arrangement, one is a cylindrical type, and the other is a rectangular type.

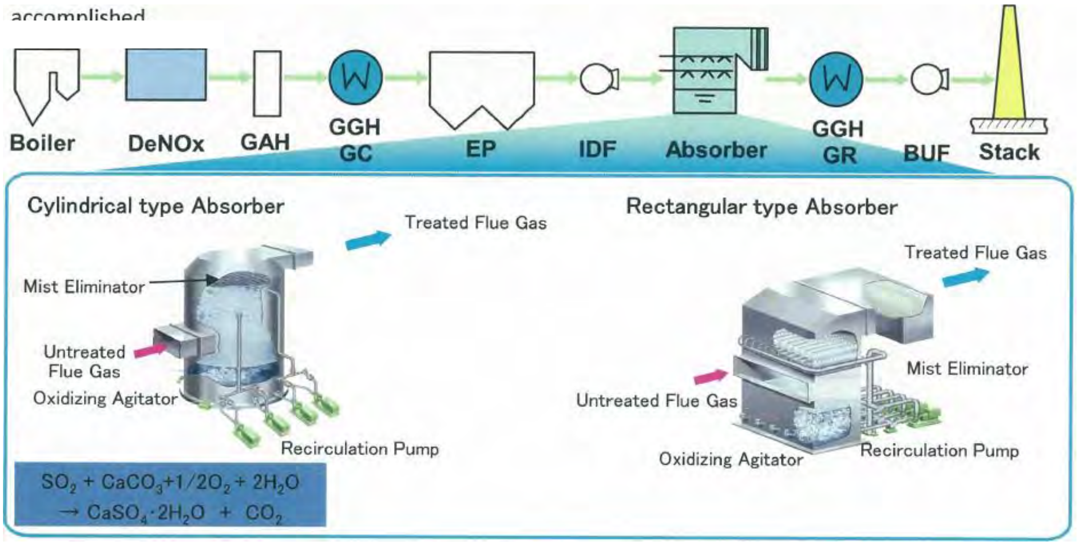



Figure 75. De-SOx System[55]

The Main features are:

- Simultaneous treatment of desulfurizing, dust-removing, and oxidizing in one absorber
- Large capacity treatment by single absorber up to the unit for a 1000 MW power plant
- Selection of absorber type (Cylinder or Rectangular) suitable for compact layout
- Easy maintenance due to simple configuration
- Low running costs due to lower pressure loss
- Faster load change due to slurry spray flow control

3) Non-Leakage type Gas-Gas Heater (GGH)

To prevent the particle leakage and utilize the Hot Flue Gas the most, a Non - Leakage GGH system can be applied, which allows EP to reduce the particle emission most effectively in the low-low temperature range.

[55] IHI Corporation

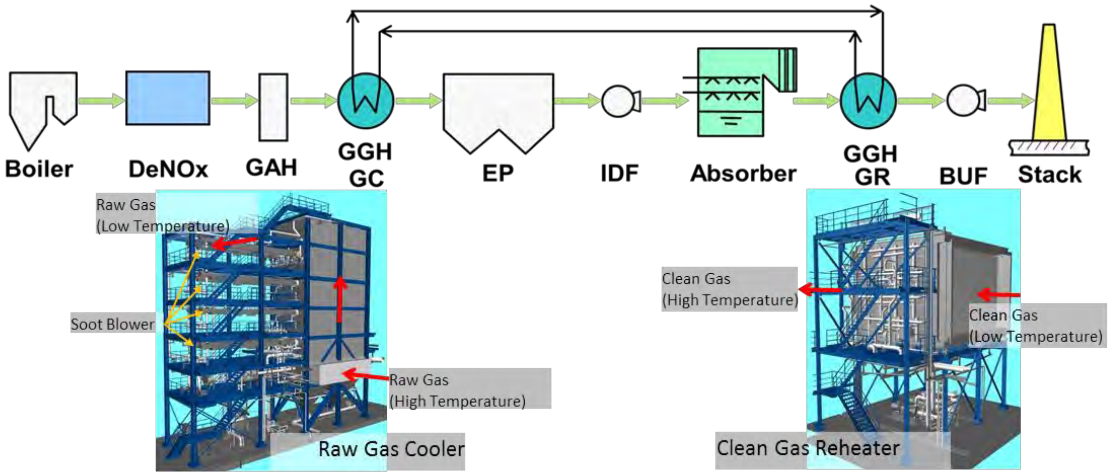



Figure 76. Non-leakage Type GGH[56]

4) Electrostatic Precipitator (EP)

Air pollution is spreading beyond borders in the world. In particular, a major player in particulate matter treatment, Electrostatic Precipitators (EP) is contributing to the preservation of the atmospheric environment in a wide range of fields such as thermal power generation plants, ironworks, and various industrial plants. There are two types available for dry type EP, one is the fixed-electrode type EP, and another is the moving-electrode type EP**.** The moving-electrode type has the following features:

- The surface of collecting plates keeps clean since the brushes at the bottom of collecting electrodes scrape off the collected dust.
- Therefore, the rapping entrainment and back corona will be reduced due to such a function; fine and high-resistivity dust can then be efficiently collected.

[56] IHI Corporation

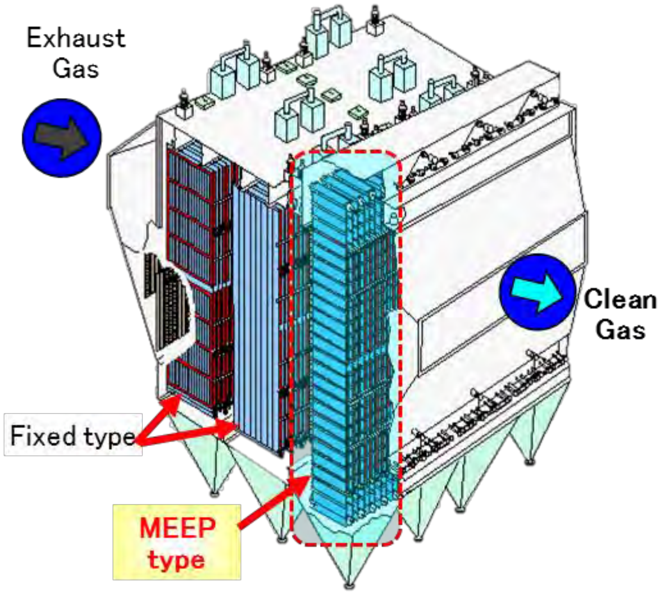



Figure 77. Moving-Electrode Type Electrostatic Precipitators (MEEP)[57]

[57] Mitsubishi Hitachi Power Systems Environmental Solutions, Ltd.

4.7 Coal Handling System

(1) General

When planning the coal handling system for the coal centre and power plants, there is a need for total engineering to optimally design the equipment, such as capacity and the type of each instrument, and its layout. Furthermore, it is important to plan in considerations of the local environment.

Examples are shown below.

(2) Continuous Ship Unloader

The benefits are as follows:

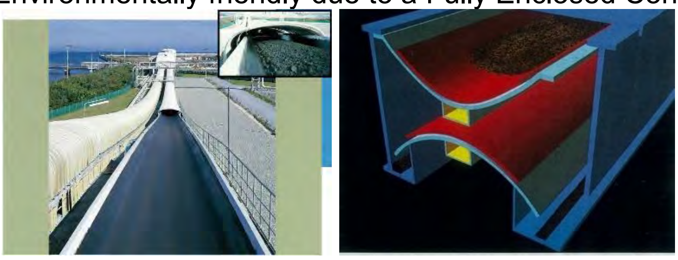
- High unloading efficiency
- Simple operation using high technology
- High clean-up efficiency greatly reduces assistance of bulldozer
- Energy saving by constant volume unloading
- Subsequent facility can be compact
- Environment-friendliness by fully enclosed conveying line inside the machine

Figure 78. Bucket Elevator Continuous Ship Unloader (CSU)[1]

Air Floated Conveyor

The benefits are as follows:

- Low acoustic noise brought by rollerless design
- Simple design
- High speed conveying
- Environmentally friendly due to a Fully Enclosed Conveying Line



Air Floated Conveyor

Source: IHI/IUK (IHI Transport Machinery Co., Ltd.)

(4) Environmental Consideration

a. Prevent coal dust scattering and Water Treatment System

To prevent coal dust scattering, a water treatment system is a significant tool in coal storage. The process consists of washing and watering by using reusable clean water that will prevent coal dust spreading to the environment.

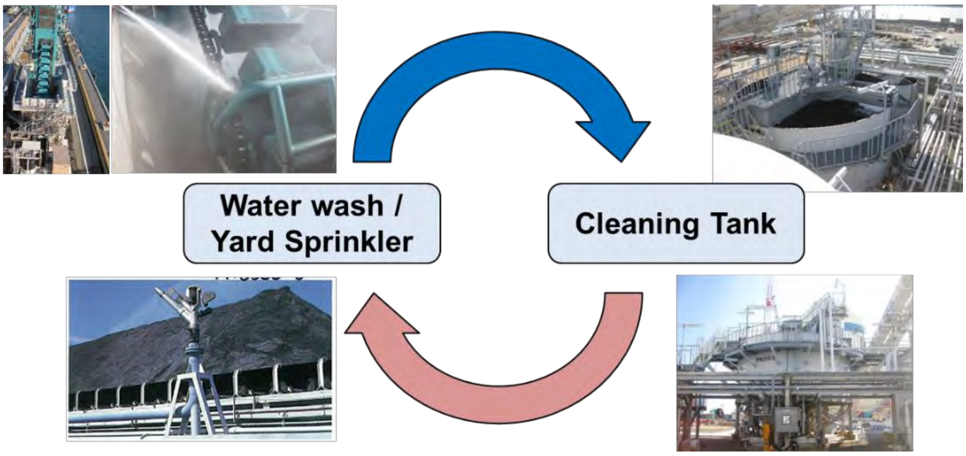



Figure 79. Water Treatment System[58]

b. Dust Collector and Wind Fence

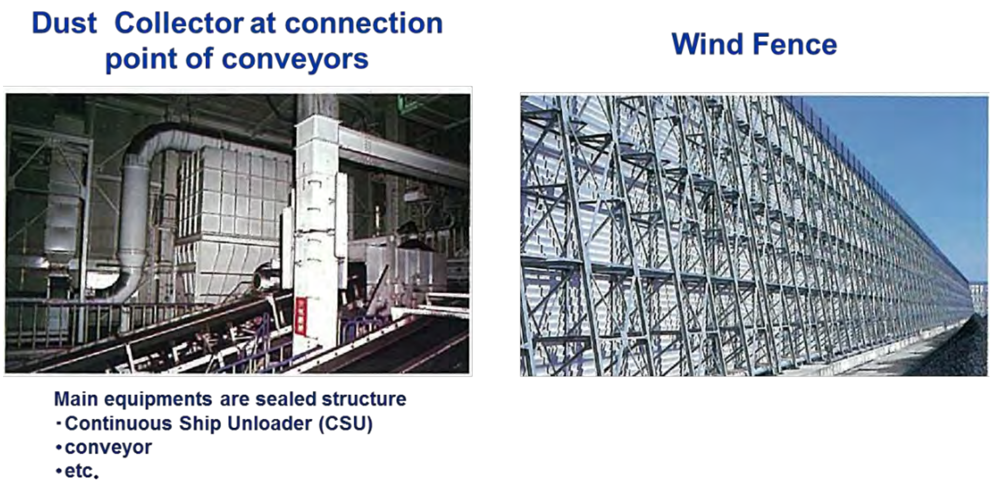



Figure 79. Dust Collector and Wind Fence[59]

[58] IHI/IUK(IHI Transport Machinery Co., Ltd.)
[59] IHI/IUK (IHI Transport Machinery Co., Ltd.)

## 4.8 Coal Upgrading Technology

### (1) Upgrading Brown Coal (UBC)

About half of the coal resources in the world, especially within ASEAN are low rank coal (LRC), such as sub-bituminous and lignite, or more commonly known as brown coal. LRC is a high water content coal with a low calorific value and high ignition susceptibility. Its characteristics have led to several disadvantages; including its limitation in long-distance transportation and producing low energy in high emissions.

UBC® (Upgraded Brown Coal) technology has been developed to dewater low rank coal and increase its calorific value. The UBC® process is similar to the principle of tempura (Japanese battered deep-fried food) that efficiently removes the water in heated light oil. There are two kinds of applications, namely; 1) UBC Briquette for transportation, 2) UBC Powder for UBC based power generation.

UBC reduces the moisture in LRC such as lignite, as the best practices provided by Kobe Steel's. The UBC Process increases the calorific value, thereby converting the lignite into high - grade energy resources.

As mentioned above, UBC Process uses light oil as a dewatering agent. The process includes crushing low rank coal, dispersing the crushed coal in light oil, and dewatering the dispersion at a temperature of 130℃ to 160℃ under a pressure of 400 to 450 kPa. Moisture content of lignite over 60% can be reduced to an 8% level with no reabsorption of water. Dewatered UBC has a heat value of 6,000kcal/kg (AR) level.

The briquettes of UBC can be shipped overseas without spontaneous combustion. UBC produced by the demonstration plant has been transported and test-used at three different commercially operated power stations, once at Kobe Steel’s steel works and twice at other third parties’ power stations. Alternatively, UBC right after being dewatered is a powder shape with a moisture content of 0%.

Feeding the UBC powder directly into a high efficiency boiler, such as a Ultra Super Critical (USC) boiler which is to be built adjacent to a UBC plant, enables the high efficiency power generation at a lignite mine site and a reduction in $CO_2$ emissions. Testing to collect data for the design of UBC-fired Ultra Super Critical boilers has been conducted successfully at testing facilities of boiler manufacturers.

3) Features, advantages and experience:

The UBC Process was developed by Kobe Steel, LTD. with the support of both the Government of Japan and the Government of Indonesia represented by tekMIRA, Ministry of Energy and Natural Resources of Indonesia. The 600t/day Demonstration Plant has been in operation for two years at Satui, South Kalimantan, Indonesia to maintain the process and operation cost. The demonstration plan is a cooperation between PT Bumi Resources Tbk and PT Arutmin of Indonesia. The UBC process gives heat value and monetary value to decrease the moisture content in lignite. The UBC process benefited both mine owners and coal users all over the world.

1) UBC process flow

Figure 81. shows a typical UBC process flow:

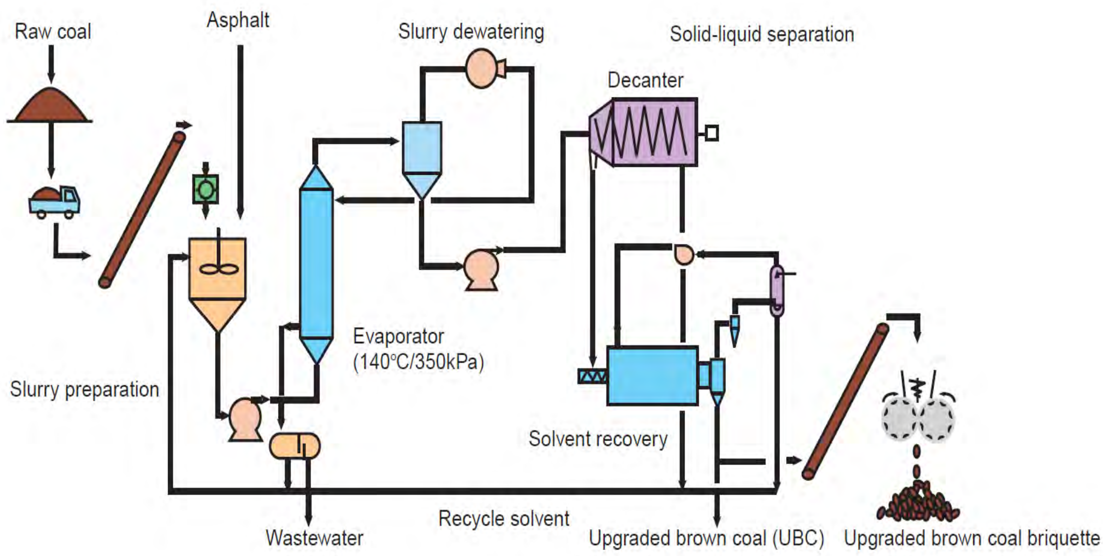



Figure 80. Typical UBC Process Flow[60]

2) Product

Fundamentals of LRC upgrading are dewatering and the adsorption of heavy oil/ asphalt into the surface of the pores and is referred to in Figure 82.

[60] Japan Coal Energy Center

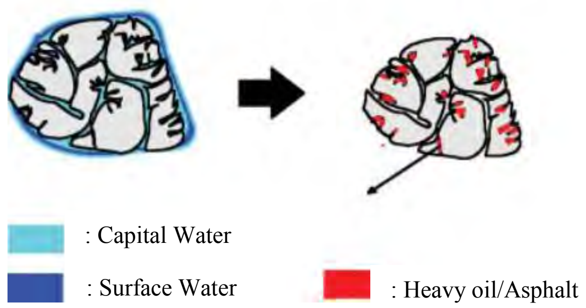



Figure 81. Fundamentals of Low-rank Coal Upgrading[61]

The upgrade coal in the UBC process is in a powdery state, so for transportation to non-local customers, it is formed into briquettes. Figure 83 shows the briquettes:

Figure 82. UBC Briquettes[62]

3) Features, advantages & experience:

The unique and innovative UBC Process was developed by Kobe Steel Ltd., with the support of METI of the Japanese government and tekMIRA of the Indonesian government. The 600t/day Demonstration Plant has been operating for two years in Satui, South Kalimantan, Indonesia in order to confirm the process and operation cost in corporation with PT Bumi Resources Tbk, and its coal subsidiary PT Arutmin Indonesia.

The UBC process gives both heat and monetary value to unutilized high moisture lignite. The UBC process upgrades the future for both mine owners and coal users all over the world.

(2) JCF®

[61] Japan Coal Energy Center
[62] Japan Coal Energy Center

JCF® (JGC Coal Fuel) is produced using JGC's proprietary low-rank coal slurrification technology-upgrading low-rank coal and increasing its calorific value by Hot Water Treating (HWT), and processing upgraded coal into a liquid type fuel. JCF® Process is a unique process that a produces a mixture of powdered coal and water with a small amount of additive. The produced fuel maintains a stable state over a long period and addresses accordingly coal's handling disadvantage as a solid fuel and provides better handling convenience in storing, transportation, and combustion. JCF® has been proved to have the same combustibility as marine fuel oil (MFO).

Coal is formed from plant biomass through hundreds of millions of years of exposure to heat and pressure, deep underground. The JCF process artificially accelerates the natural coalification process, using HWT (Hot Water Treating) Upgrading Technology.

1) JCF® Process

a. Upgrading (HWT)

When LRC (Low Rank Coal) is immersed in high-temperature, high-pressure water (15 MPa at 330 ℃), its properties change from hydrophilic to hydrophobic, and the water held in numerous pockets within LRC is expelled. At the same time, some of the LRC undergoes a reaction and breaks up to form tar which fills the pockets, preventing the water from seeping back in while simultaneously increasing the caloric value of the coal.

b. Slurrification

With the addition of special additives, the water expelled from LRC can be used to convert the newly upgraded LRC into slurry, which is composed of small solid particles suspended in a liquid and which has fluid-like properties.

With Upgrading and Slurrification, LRC is transformed into JCF – removing the disadvantages inherent in LRC. JCF coal slurry can be handled just as if it were heavy oil (Marine Fuel Oil, MFO), with storage tanks and pipeline transportation adopted.

Figure 84. shows a typical JCF process flow:

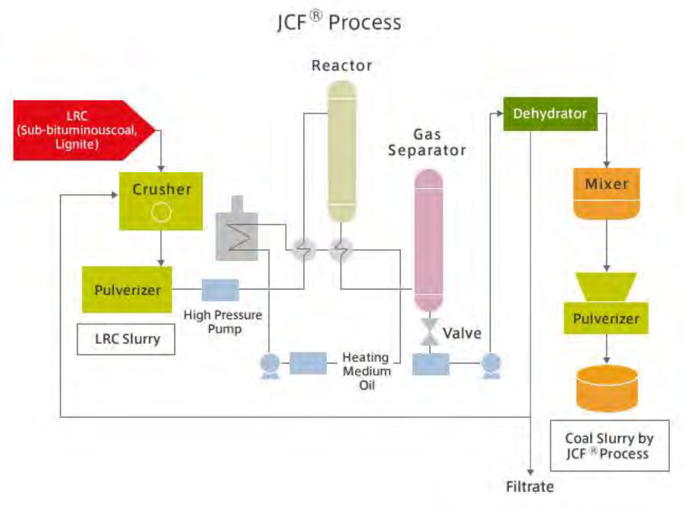



Figure 83. Typical JCF Process Flow[63]

2) Demonstration plant

JCF Production Plant (10,000 t-JCF/y) over 7,500 hrs

Plant site: Karawang, West Java, about 50 km east of Jakarta JCF Fired Power Plant (700 kw) over 3,000 hrs

[63] JGC CORPORATION

### 4.9 Water Treatment System

#### (1) General

Water treatment at a coal fired power plant is vital to increase the efficiency and contribute to better environmental sustainability, as it prevents issues such as carryover to the turbine components, as well as corrosion and scale formation/deposition in the boiler and turbine systems and equipment non-conformities. The required water quality for boilers and turbines of thermal power may be ensured through water treatment.

#### (2) Necessity of Water Treatment for Boilers

Water used as a boiler feedwater, such as tap water, industrial water, underground water and river water, usually contain various substances such as suspended solids, dissolved solids, and gases. The amounts of these substances vary largely depending on the sources of the raw water. The use of such raw water without pre-treatment may result in problems, such as scale, corrosion, and carryover, in boilers, and the auxiliary equipment.

Boilers are generally supplied deaerated and demineralized water as the feedwater. However, since they are operated at both a high temperature and high pressure, the presence of a small amount of impurities causes problems, such as metal oxide deposits on the heating surface of the boiler, the corrosion of the auxiliary equipment, and scale adhesion in the super heaters or on turbine blades.

In order to prevent these problems and to operate the boilers safely and efficiently, the application of suitable water treatment is required for each boiler. The water treatment for boilers is divided into the external (mechanical) and internal (chemical) treatment. The mechanical treatment is to remove the impurities in water by applying coagulation, sedimentation, filtration, ion exchange, de-aeration treatments, etc.

The chemical treatment is divided into the treatment for the feedwater and condensate lines, and for the boiler itself.

The chemical treatment for the feedwater and condensate lines aims to control corrosion by adding oxygen scavengers and corrosion inhibitors to the lines, and to supply water containing as little impurities as possible into the boiler. Boiler compounds, oxygen scavengers, sludge dispersants and so on are used for the chemical treatment of boilers. These chemicals prevent corrosion and make the scale forming components in the water insoluble and dispersed particles to discharge them from the boiler with the blowdown water. Those water treatments are indispensable for operating boilers safely and efficiently.

Figure 84. A Typical Water Treatment System[64][65]

(3) Internal boiler water treatment

Even if the external boiler water treatment is employed, it is difficult to perfectly prevent the boiler water contamination with substances which cause the corrosion and scale problems. Boiler water treatment chemicals are used for protecting whole boiler systems including the feedwater and the steam condensate line from those problems.

(4) Management of boiler water treatment

a. Determination of the control ranges of feedwater and boiler water qualities according to the structure, pressure etc., of an aimed boiler.

b. Selection of a suitable water treatment method, blowdown method, chemical injection method, etc., to maintain the target water qualities.

c. Monitoring of the water qualities and the treatment effects by the water analyses, etc., and an improvement of the operation control method if necessary.

[64] POWER

[65] An on-line magazine on business and technology for the power sector.

4.10 Ash Handling System

Ash processing technology, will be roughly divided into bottom ash and fly ash processing.

(1) Bottom Ash Processing

Previously, bottom ash processing only contained wet processing. Nowadays, the process also includes dry ash processing.

The bottom ash processing with dry clinker conveyor process is a mechanical treatment system which does not require cooling water, equipment and significant simplification of the configuration, can contribute significantly to the heat effective use.

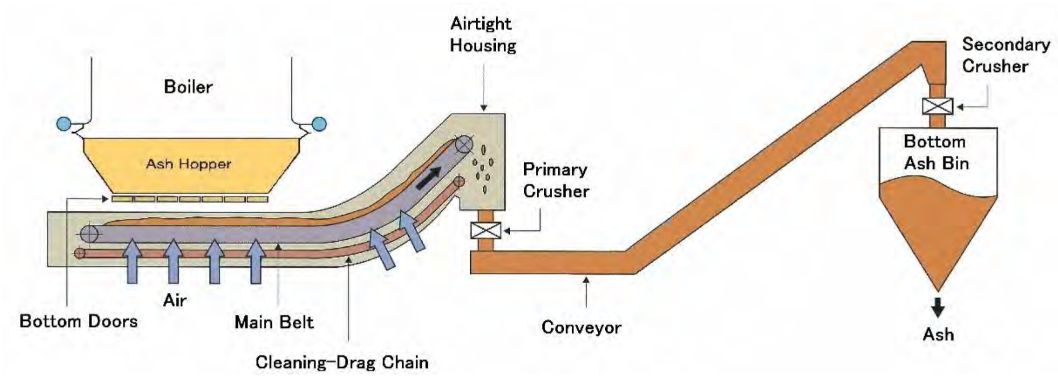



Figure 85. Dry Bottom Ash Handling System[66]

[66] Kawasaki Heavy Industries, Ltd.

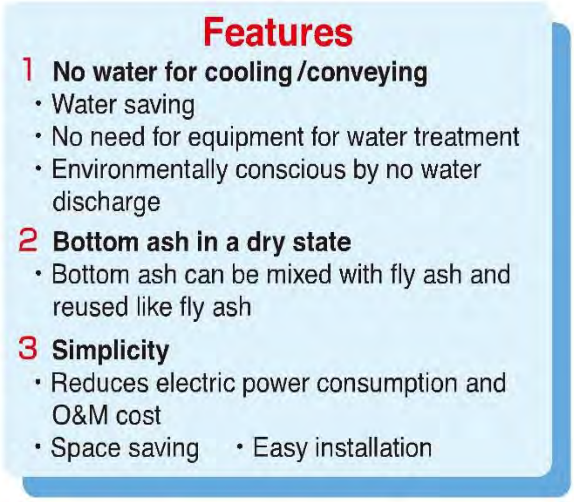



Figure 86. Features of Dry Bottom Ash Processing[67]

(2) Fly ash processing

Design conditions remain, that is, by the concentration of fly ash and by the transport distance, it is important to determine the transport capacity and the system of fly ash processing.

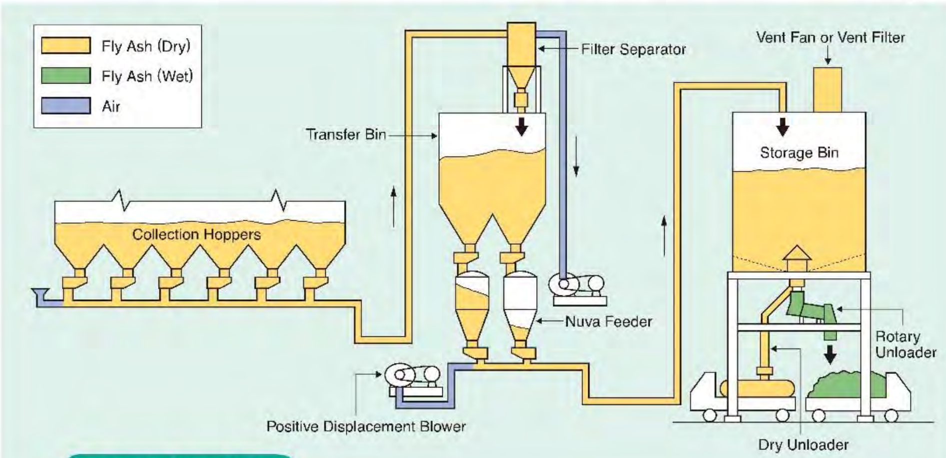
[67] Kawasaki Heavy Industries, Ltd.

This system is used when system economies can be realized by taking advantage of the simplicity and lower cost of the equipment of Negative Pressure System, while providing the benefits of Positive Pressure System— high capacity and long distance conveying. The system is effectively applied where a large number of ash hoppers are served and fly ash must be conveyed to remote storage bins.

**Features**

- Possesses the both merits of the two systems shown in the left


Strage Bin




**Process Description**

Fly ash is once conveyed to a transfer bin by applied negative pressure system and after that, it is transferred to the positive pressure system and then conveyed to a strage bin.

Figure 87. Dry Bottom Ash Processing System[68]

[68] Kawasaki Heavy Industries, Ltd.

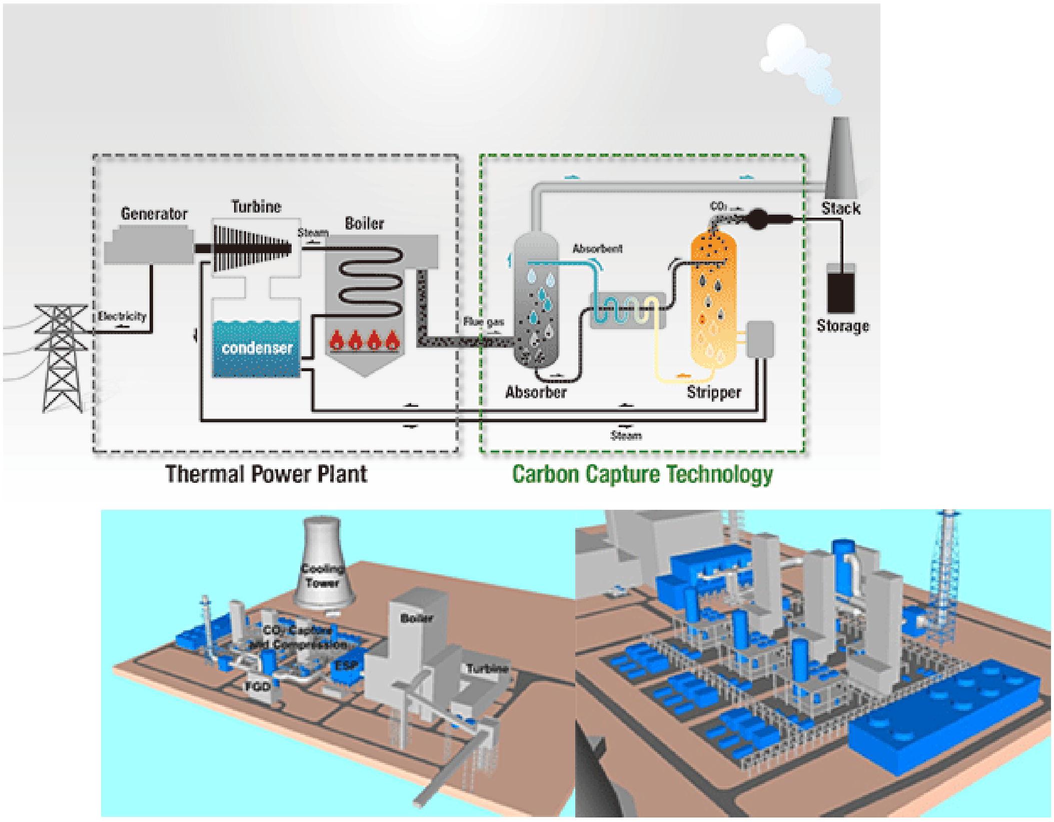
4.11 Carbon Dioxide Capture and Storage Technology (CCS)

(1) Post combustion capture technology

Post combustion capture technology is based on an amine based chemical absorption process. This technology can be applied not only to new build coal fired power plants, but can be retrofitted onto existing plants.

Technology also applies to other $CO_2$ emitting plants such as oil fired, gas fired, gas combined cycle, biomass fired plants. The portion of $CO_2$ emissions to be captured from the power plant is selectable, giving this technology the flexibility to answer to the various needs of the market and regulations.

Post combustion capture technology uses chemical absorbents which selectively capture $CO_2$ in the flue gas at a certain condition in the absorber tower, and release it under a different condition in the stripper tower, $CO_2$ is continuously separated from the flue gas of the thermal power plant.




CCS Ready USC Plant          Carbon Capture Plant

Figure 88. Schematic Diagram of a CCS System [69]

[69] Toshiba Corporation

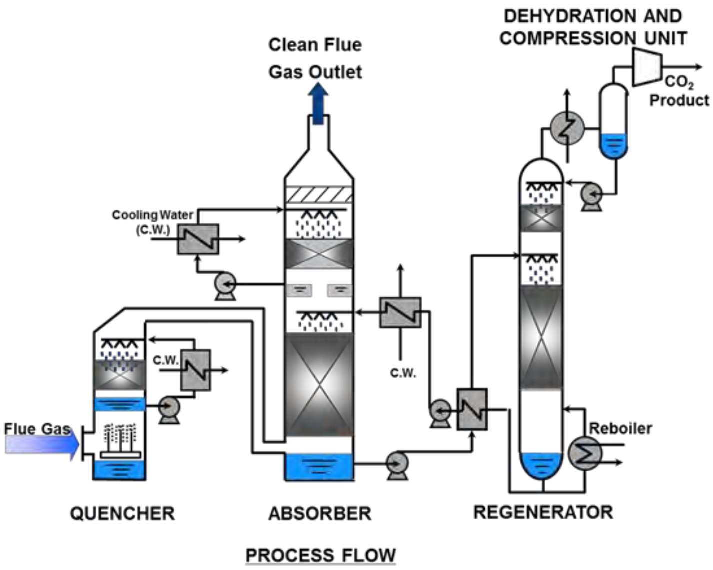



Figure 89. KM CDR Process® [69]

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Established on 1st January 1999, the ASEAN Centre for Energy (ACE) is an independent intergovernmental organisation within the Association of Southeast Asian Nations' (ASEAN) structure that represents the 10 ASEAN Member States' (AMS) interests in the energy sector. The Centre accelerates the integration of energy strategies within ASEAN by providing relevant information and expertise to ensure the necessary energy policies and programmes are in harmony with the economic growth and the environmental sustainability of the region. It is guided by a Governing Council composed of Senior Officials on Energy from each AMS and a representative from the ASEAN Secretariat as an *ex-officio* member. Hosted by the Ministry of Energy and Mineral Resources of Indonesia, ACE's office is located in Jakarta.

On 26th May 2015, the ACE Governing Council endorsed the business plan of an Enhanced ACE; a high-performing institution and a regional centre of excellence which builds a coherent, coordinated, focused, and robust energy policy agenda and strategy for ASEAN. The three critical roles of the Enhanced ACE:

1. As an ASEAN energy think tank to assist the AMS by identifying and producing innovative solutions for ASEAN's energy challenges on policies, legal and regulatory frameworks, and technologies.
2. As a catalyst to unify and strengthen ASEAN energy cooperation and integration by implementing relevant capacity building programmes and projects to assist the AMS develop their energy sector.
3. As the ASEAN energy data centre and knowledge hub to provide a knowledge repository for the AMS.

**www.aseanenergy.org**

Japan Coal Energy Center (JCOAL) is the one and only intermediary organization that covers from upstream to downstream of the coal chain with its origin back to 1945, when its predecessor Japan Coal Association was established. Later the association was merged with Coal Mining Research Center, Japan and Center for Coal Utilization, Japan and a few others in order to consolidate efforts for the further development of the coal sector. The current JCOAL was established in 2005. JCOAL is well versed in the global situation of coal resources and coal utilization as well as related technologies, and has been keenly engaging in knowledge and technology transfer/exchange about coal production and safety and cleaner coal utilization to different countries; especially those in the Asia Pacific region, which is in accordance with Japan's policy to support growing economies to establish energy security, steady economic growth and environmental sustainability.

JCOAL has built a rapport with ACE and AFOC through the AFOC Council Meeting and other activities during recent years. Japan Coal Energy Center (JCOAL), will further engage in relevant activities by means of technology development, studies and other supporting activities for optimal business plan formulation, technology transfer, and dissemination, human resources development, for the sake of sustainable energy supply, industrial economy development and global warming mitigation as well as environmental compliance.

**w**

**ww.jcoal.or.jp**

**ATTACHMENT**

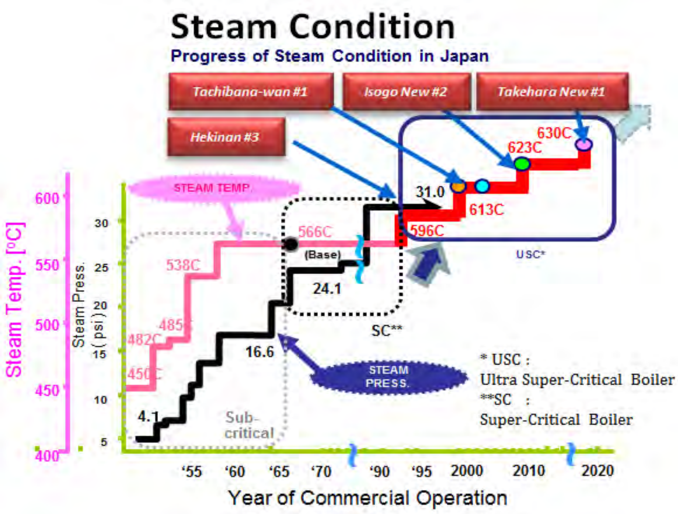
# IHI's Ultra Super Critical (USC) Boiler as Clean Coal Technology

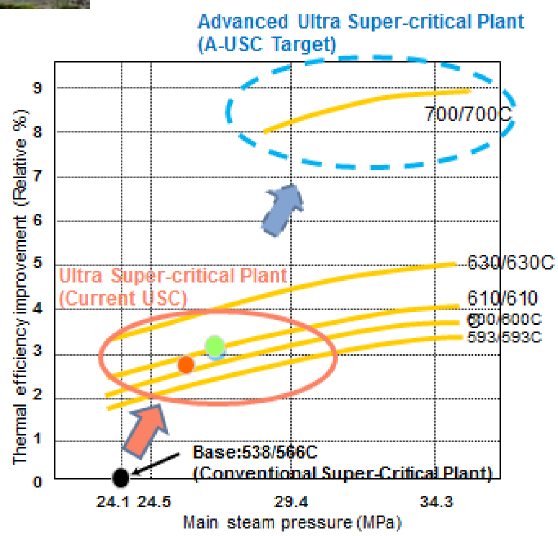
Since first delivery of boiler in 1955, IHI has been pushing boundaries of boiler technology.
IHI's state-of-the-art boiler offers broad capabilities in designing, manufacturing, and constructing from small packaged boiler to large scale ultra super-critical boilers with a steam generating temperature of over 620° C and a capacity of over 3,000t/h of steam generation or over 1,000MW thermal power plant.
By adopting high efficient USC boiler and utilizing Clean Coal Technology (CCT), IHI realizes lower $CO_2$ emissions and a better use of coals.

## IHI's High Efficient USC Technology

As a leading company and a pioneer in Ultra Supercritical (USC) coal-fired boilers, IHI delivered a 1st USC boiler in Japan at Hekinan #3, world's largest capacity USC boiler at Tachibana-wan #1, and USC boiler with world's highest reheat temperature at Isogo New #2.
We are currently participating in the joint development of the Advanced USC 700° C-class boiler in order to achieve a plant efficiency of 46% (net HHV) and further to reduce $CO_2$ emissions.


**Lünen**
Capacity : 813MW
Steam Flow:2,225 t/h
Steam Condition: 28.7MPa/600/610° C
COD: 2013




Improvement of Plant Efficiency by Higher Steam Condition

IHI JCOAL Japan Coal Energy Center

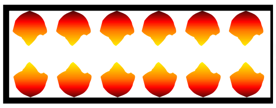
## Technical Features for IHI Boiler

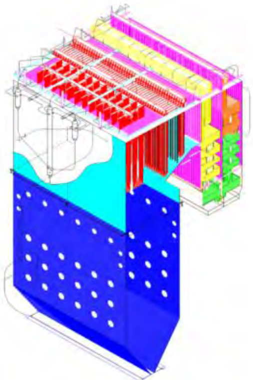
IHI boilers are designed based on proven technology and extensive research and development.
Our high performance boilers are available worldwide.

### Wall Firing (Opposed Firing)

- ✓ HIgh Combustion Efficiency
- ✓ Uniform Gas Flow and temperature
- ✓ High Flame Stability

*Flame View in Furnace from the top*





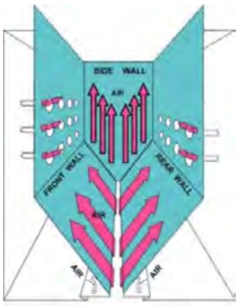
### Pararell Pass Design

Separate Gas Pass of Reheater & Superheater

- ✓ No gas recirculation fan required
- ✓ Effective RH temperature control
- ✓ Minimum maintenance required
- ✓ Flexible operation

### Boundary Air System

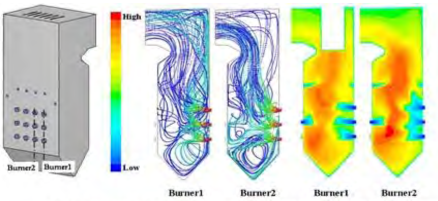
- ✓ Minimize slagging
- ✓ Reduce unburned carbon




OPEN FURNACE DESIGN
BOUNDARY AIR SYSTEM

### Effectual Heat

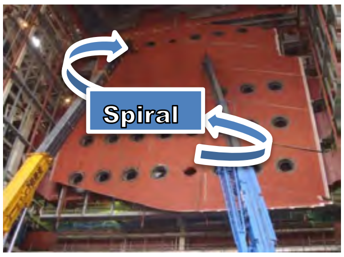
- ✓ High Combustion Efficiency
- ✓ Uniform Gas Flow & Temperature Distribution along Furnace Width
- ✓ Stable Flame




Combustion Simulation for Optimum Furnace Design

### Helical Tube Furnace Wall (for USC / Supercritical boilers)

- ✓ Enhancing stability & reliability




## High Availability

IHI's first USC coal fired boiler in Japan (Unit3, Hekinan Thermal Power Station) has been operating for more than 22 years with a high plant availability rate of over 95%.

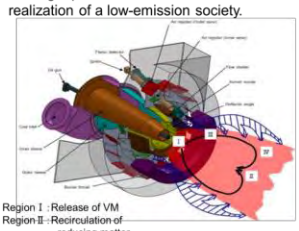
| Plant | Electricity Output | Steam Capacity | Steam Condition | COD | Country | USC |
|---|---|---|---|---|---|---|
| Hekinan No.3 | 700MW | 2,250 t/h | 25.0MPa/543/596C | 1993 | Japan | x |
| Noshiro No.2 | 600MW | 1,860 t/h | 25.0Mpa/570/596C | 1994 | Japan | x |
| Reihoku No.1 | 700MW | 2,260 t/h | 25.0Mpa/570/568C | 1995 | Japan | - |
| Nanao Ohta No.2 | 700MW | 2,120 t/h | 25.0Mpa/597/595C | 1998 | Japan | x |
| Tachibana-wan No.1 | 1,050MW | 3,000 t/h | 25.9Mpa/605/613C | 2000 | Japan | x |
| Hekinan No.4 | 1,000MW | 3,050 t/h | 25.0Mpa/571/596C | 2001 | Japan | x |
| Callide No.3/No.4 | 420MW | 1,281 t/h | 25.9Mpa/569/568C | 2001 | Australia | - |
| Hekinan No.5 | 1,000MW | 3,050 t/h | 25.0Mpa/571/596C | 2002 | Japan | x |
| Tomato Atsuma No.4 | 700MW | 2,040 t/h | 25.9Mpa/603/602C | 2002 | Japan | x |
| Isogo New No.1 | 600MW | 1,710 t/h | 27.5Mpa/605/613C | 2002 | Japan | x |
| Tarong North No.1 | 450MW | 1,370 t/h | 25.9Mpa/569/568C | 2003 | Australia | - |
| Shinko Kobe No.2 | 700MW | 2,340 t/h | 25.0Mpa/541/568C | 2004 | Japan | - |
| Sumitomo Kashima | 507MW | 1,590 t/h | 25.0Mpa/542/568C | 2007 | Japan | - |
| Isogo New No.2 | 600MW | 1,670 t/h | 27.2Mpa/605/623C | 2009 | Japan | x |
| Maizuru No.2 | 900MW | 2,570 t/h | 25.4Mpa/600/598C | 2010 | Japan | x |
| Sandy Creek No.1 | 998.5MW | 2,852 t/h | 26.9Mpa/585/583C | 2013 | U.S.A | - |
| TKL Lünen | 813MW | 2,225 t/h | 28.8Mpa/600/610C | 2013 | Germany | x |

Sectional side view of Hekinan No.3 Unit

## Emission Reduction Technology

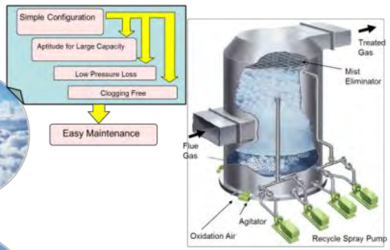
### *Low NOx Combustion System*

IHI's burners, whether used with solid, liquid, or gas fuels, have high combustion efficiency, low NOx emissions and high reliability. IHI is making a positive contribution to the realization of a low-emission society.



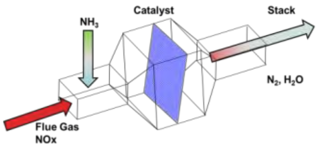
Region I : Release of VM
Region II : Recirculation of reducing matter
Region III : Combustion of VM
Region IV : Reduction of NOx


### *IHI De-SOx System (Spray Tower)*




### *IHI De-NOx System (SCR System)*

Ammonia ($NH_3$) is added to the flue gas at the appropriate temperature and the flue gas is led through the catalyst bed, nitrogen oxides (NOx) are decomposed into harmless nitrogen ($N_2$) and water ($H_2O$)




Concentrated $CO_2$ can be directly obtained by burning fuels with pure $O_2$ instead of air. It realizes easier $CO_2$ capture.

### *Callide Oxyfuel Project*

## Application of Low Rank Coal

IHI has large test facilities " Coal Combustion Test Facility (CCTF) " at our own factory to promote Clean Coal Technology.
CCTF enables us to carry out basic combustion tests, develop burner technology for various fuels such as low-rank coal and biomass, and demonstrate both of the oxy-fuel combustion and chemical absorption systems of CO2 capture technology, at actual plant scale.


### Purpose

- ✓ New Burner Development
- ✓ Low Rank Coal & New Fuel Firing
- ✓ Enhance CO2 Capture Technology

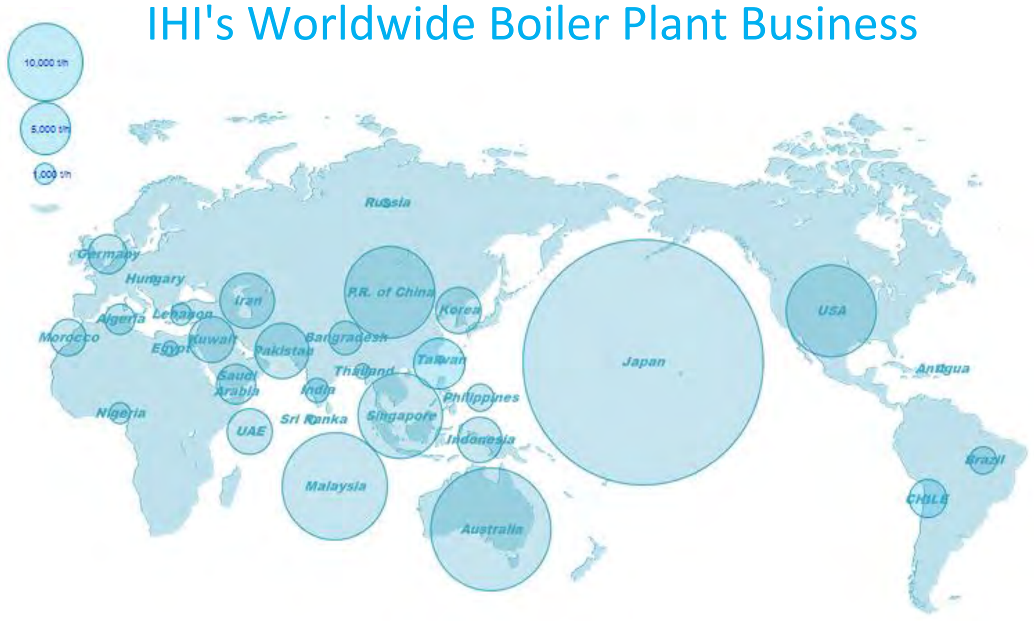
### CCTF Specification

| | |
|---|---|
| Thermal input | 20MWth (3,000kg/h-coal) |
| Furnace | Vertical hopper-bottom type with water jacket cooling |
| Burner | IHI DF Burner (Coal, Oil) |
| Pulverizer | IHI VS-16 (8,120kg/h) |
| DeNOx | Selective catalytic reduction process |
| DeSOx | Limestone-gypsum process |
| CO2 capture | Oxy-fuel Post-Combustion |

Oil Fired Flame

Pulverizer

# IHI's Worldwide Boiler Plant Business

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MITSUBISHI HITACHI POWER SYSTEMS

JCOAL Japan Coal Energy Center

# Coal-Fired Steam Generator

Abstract of Product / Technology

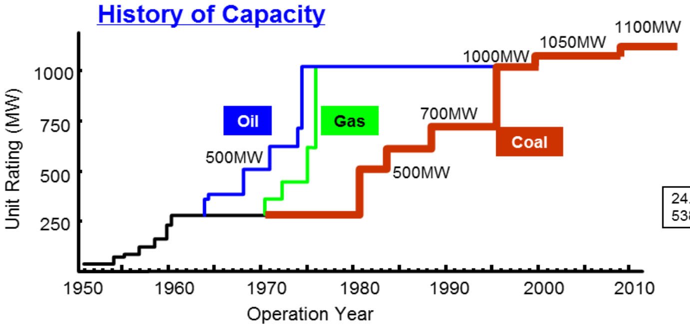
*MITSUBISHI HITACHI POWER SYSTEMS, LTD. (MHPS) is a leading company to furnish a state-of-the-art, highly efficient and reliable steam generator system based on its proven technologies and designs for large 500 to 1,050 MW supercritical pressure operation boilers. MHPS's experience includes 121,100 MW of large fossil fuel fired supercritical pressure, once-through type, reheat steam boilers with substantial experience in wide range coal firing.*

Detail Introduction of Product/Technology

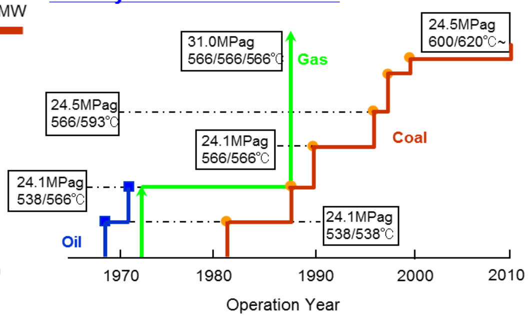
## Steam Parameter Improvement

*Ultra-supercritical steam condition contributes to the high-efficiency coal utilization, reduced $CO_2$ (Carbon-Dioxide) and pollutant emissions. MHPS has enhanced the steam temperature step by step up to 620 ℃ at turbine inlet and achieved practical use with high reliability and operability.*

History of Capacity

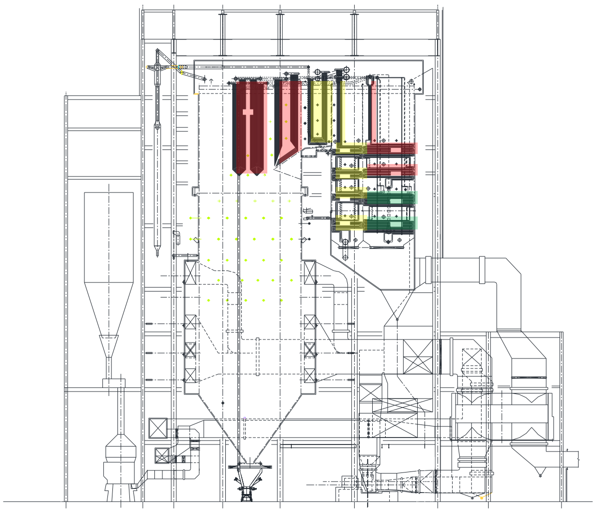



History of Steam Condition




## USC Coal-Fired Boiler

*MHPS's USC coal-fired boilers have advantages of high efficiency, high availability, flexible operation and easy maintenance.*

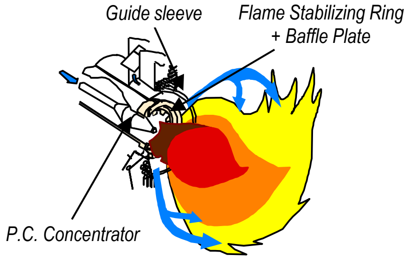


### Design Feature

- *Advanced, Simplified Furnace Wall Construction*
- *High performance combustion system*
  - *- Low NOx Burner*
  - *- In Furnace DeNOx System*
  - *- High Performance Coal Mill*
- *Optimized Heating Surface Design*
  - *- Proven high strength material for high temperature*
  - *- Adequate arrangemet to prevent ash deposit & erosion*
- *Based on Extensive Coal Characteristics Research*

## Key Combustion System

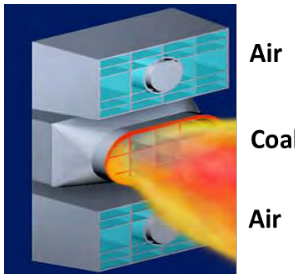
*MHPS has developed the low NOx Burners both for wall firing system & coner firing system.*




**HT-NR Burner (Wall)**

*Feature*

1. Extremely low NOx emission
2. High combustion efficiency
3. Stable ignition




**PM Burner (Corner)**

## Reference with Low Rank Coal

*MHPS is capable of providing Low Rank Coal fired boiler for lignite and sub-bituminous coal.*
*The followings are example of MHPS's world-class Low Rank Coal supercritical boiler technology.*

| Coal Type | Moisture in Coal (%) | Heating Value (kcal/kg) | Reference Plant |
|---|---|---|---|
| *Lignite* | 65 | 1,500 |  *Germany Neurath #F&G 1100MW x 2* |
| | 35 | 4,500 | |
| *Sub-Bit. Coal* | 20 | 5,500 |  *Indonesia Paiton III 865MW x 1* |

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**DUNTM heating element /Advanced Heating Surface for Air preheater**

**Abstract of Product /Technology**

DUN$^{TM}$ element has become the current standard element for Ljungstrom® air preheaters replacing with the traditional DU element which was developed in 1950's.

Special features of DUN$^{TM}$ element over the traditional DU element are 1) improved uniform flow distribution, 2) improved thermal efficiency, and 3) improved mechanical strength.

These special features of DUN$^{TM}$ element have been recognized by the major Japanese customers through their operating experience since its first installation in Japan in 1999.

**Detail introduction of Product/Technology**

In the mid 1990's it was recognized that the widely used DU heating element profile produced undesirable outlet velocity gradients that contributed to increased fouling rate.

This led Alstom to develop the DUN$^{TM}$ heating element in 1997 as a direct replacement for DU profile. The DUN$^{TM}$ now has proven installation records with improved performance and superior cleanability.

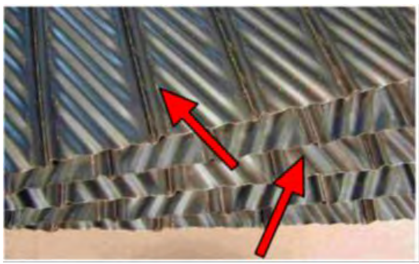
**1. Improvement for uniform flow distribution**

Traditional heat transfer surfaces like the DU profile shown below left, employed geometry where every other sheet had continuous undulations that were oriented at an angle to the fluid flow. Measurements have revealed that this continuous undulation geometry creates outlet velocity gradients also known as SkewFlow$^{TM.}$

SkewFlow$^{TM}$ is non-uniform mass flow distributions that lead to reduced heat transfer, increased pressure drop, and higher fouling tendencies.

As long as the undulations on the sheets without the notches are all pointed in the same direction SkewFlow$^{TM}$ will result in a velocity gradient at the exit plane of the basket.

DU profile



DUN$^{TM}$profile

The DUN$^{TM}$ profile as shown above right is an optimized heat transfer surface that provides a uniform flow velocity, does not cause diversion of gas flow in a sideways direction, and provides superior cleanability compared to traditional DU profile. The undulations on each adjacent sheet are crossed, which guides the flow directly through the element pack . In addition, each element sheet has notches to create channels to minimize the loss of cleaning media energy.

DUN™ heating element /Advanced Heating Surface for Air preheater

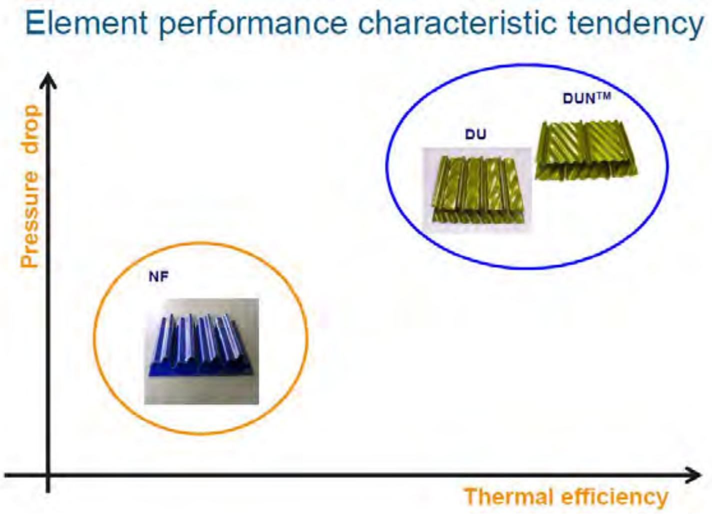
**2. Improved thermal efficiency**

Thanks to CFD analysis during development stage aiming the optimized element profile, DUN™ element has gained greater improvement in thermal efficiency with comparatively smaller increase in pressure loss.

For example, DUN™ element can achieve the same thermal performance as DU element with approximately 10%*) smaller element depth than that of DU for the typical air preheater application, thus allowing to design more compact heat exchanger for the new installation.

For the retrofit plant where fan capacity allows, replacement of the existing DU element with DUN™ of the same element depth will benefit higher energy recovery.

Note *) This value is dependent on the design condition.




**3. Improved mechanical strength**

Beside advantage related to less fouling tendency, DUN™ profile has higher mechanical strength than DU, which is an advantage in durability to effective sootblowing.

It is often the case that U (undulation) sheets of the traditional DU profile are prone to be damaged by excessive sootblowing impact.

DUN™ profile, consisting of pair of NU(Notch Undulation) sheets, has section modulus of approx. three times greater than that of DU profile having U (undulation) sheets. This will give more flexibility to cleaning operation than the case for DU profile.

## DUN™ heating element /Advanced Heating Surface for Air preheater

**Advantage & Experience:**

Special features of DUN™ element over traditional DU element as described above have been recognized by major Japanese customers.
Following table shows some of installation records of DUN™ element to new plants in Japan, covering plants equipped with SCR with various kind of fuel fired.
There are also lots of retrofit plants where the existing DU elements were replaced with DUN™ element.

| Application | Capacity | SCR installed | Fuel | Air preheater size x number | Layer by DUN element | Del. time |
|---|---|---|---|---|---|---|
| Utility Boiler | 700MW | YES | Coal | 32x2 | Hot/Int | 2001/06 |
| Utility Boiler | 1000MW | YES | Coal | 33.5x2 | Hot/Int | 2000/10 |
| IPP | 185MW | YES | VR&Gas | 26.5x2 | Hot/Cold | 2001/12 |
| IPP | 700MW | YES | Coal | 35x1 | Hot/Int | 2002/02 |
| Utility Boiler | 500MW | YES | Coal | 30.5x2 | Hot/Int | 2001/11 |
| IPP | --- | YES | VR | 28x2 | Hot/Cold | 2003/04 |
| Industry | --- | YES | Coal | 25x1 | Hot/Cold | 2003/05 |
| Utility Boiler | 500MW | YES | Coal | 30.5x2 | Hot/Int | 2002/11 |
| IPP | 507 MW | YES | Coal | 33x1 | Hot/Int | 2005/09 |
| Industry | 225T/H | YES | Coal | 22x1 | Hot/Cold | 2005/09 |
| Industry | 150MW | YES | Coal | 28.5x1 | Hot/Cold | 2006/11 |
| Industry | 220MW | YES | Coal | 30.5x1 | Hot/Cold | 2007/04 |
| Industry | 250t/h | YES | Oil & Gas | 23x1 | Hot/Cold | 2006/08 |
| Industry | --- | YES | Coal, Coal+FGB | 23.5x1 | Hot/Cold | 2008/05 |
| Industry | 450T/H | YES | Residue Oil | 23.5x2 | Hot | 2008/10 |
| Utility Boiler | 900MW | YES | Coal | 33x2 | Hot/Int | 2009/02 |
| Utility Boiler | 1000MW | YES | Coal | 33.5x2 | Hot/Int | 2011/06 |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2) Contact in Asian area
(a) : Division ditto
(b) : Person
(c) : Tel No Fax. No :
(e) : Mail Address :

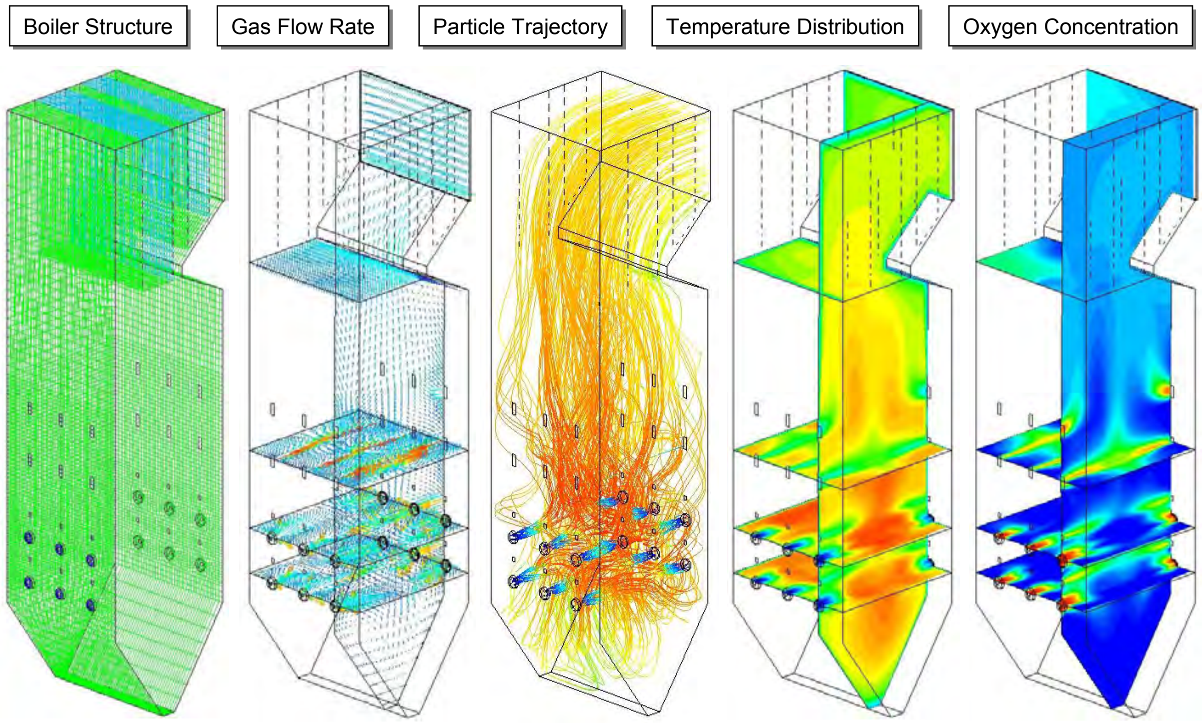

Remarks

# Coal Combustion Simulator

## Abstract of Technology

Numerical analysis on pulverized coal fired boiler using the computer fluid dynamics technology can simulate the gas velocity, particle trajectory, temperature distribution, oxygen concentration and so forth by constructing the boiler geometry and operating conditions in the computer.

This technology enables us to propose the optimum operating condition which leads to the improvement of boiler efficiency, the decrease of environmental impact including NOx, and the avoidance of various troubles such as slagging.

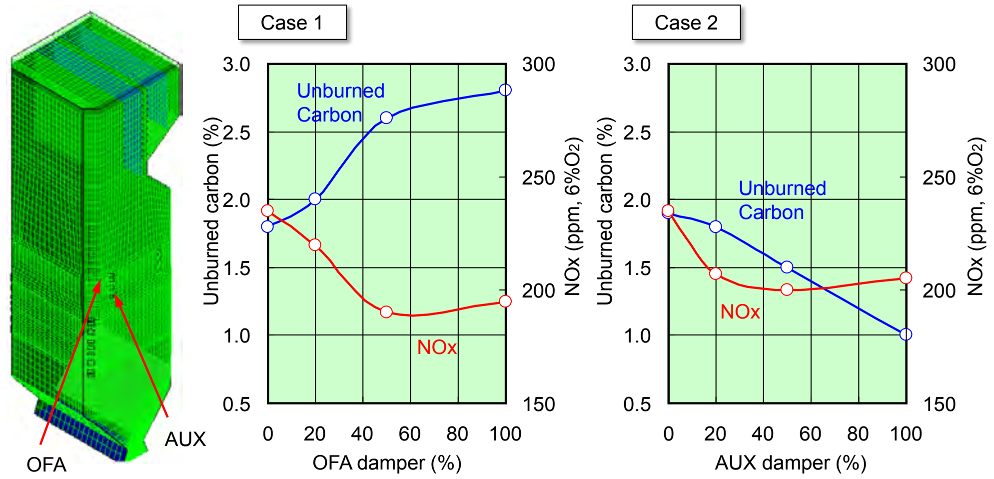



## Details of Technology

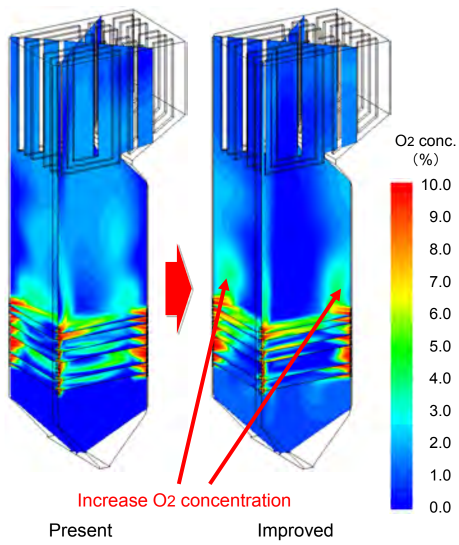
Based on the long term research on coal combustion, Idemitsu developed the original coal combustion and NOx formation model and integrated them into the commercialized computer fluid dynamics software named “FLUENT”. Many analyses of various scales and combustion systems are carried out. Combustion simulator enables to achieve higher boiler efficiency without any hardware modifications. Reduction of NOx emission and avoidance of slagging troubles are also expected.

Improvement of boiler efficiency and decrease of coal consumption can be attained by combustion optimization using numerical computer simulation. It is important to review operating conditions under which unburned carbon in fly ash are decreased without raising the flue gas temperature. In addition, it is necessary to consider that environmental properties including NOx should not be damaged.

Normally, unburned carbon increases with the decrease of NOx by opening the OFA damper. On the other hand, in case the AUX damper is opened after the burner dampers in lower leveler are closed, unburned carbon and NOx decreased simultaneously because the air flow rate at additional air zone increase drastically.




Improvement of combustion efficiency was conducted at Chinese power plant. Right figure shows the changes in the oxygen concentration under the present and improved conditions. The increase of air flow from OFA port expands high-oxygen area. Coal particles from middle level burner come to pass through high-oxygen area. This leads to reduce unburned carbon. As a result, the unburned carbon reduced from 5.2% to 2.5% by adjusting the damper openings. NOx emission did not increase by this damper adjustment. Consequently, the boiler efficiency was improved at 0.92%, and coal consumption rate reduced at 3.8g/kWh.



**Features, Advantages & Experience**

Compared to the renovation of facilities requiring a great deal of costs and time, numerical computer simulation can be expected to bring quick-impact results to improvements in combustion because it can achieve energy savings due to improvements in combustion efficiency and improvements in availability due to the reduction of slagging by just changing the operating conditions with simulation software. In particular, the software into which a unique combustion model that we have constructed based on many years of findings in coal combustion is incorporated is characterized by being practicable, having high analytical accuracy, and being applicable to a wide range of fields.

The performances include the analyses of various scales and fuels, extending from large-scale boilers for power generation to small-medium-scale ones for industry. Our customers make good use of this simulation for predicting effects in case of changing commercial grades of coal, setting optimum operating conditions in case of using new coals and so forth, including the improvements of combustion efficiency and environmental capabilities (NOx) and the troubleshooting of in-furnace ash adherence.

Please make use of this simulation for optimizing the combustion of your boilers.

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Remarks

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## Boiler Asset Services (BAS)

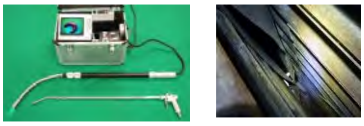
*Boiler Asset Services are Technology to provide effective long term plans in order to achieve improvements in overall Boiler availability and efficiency.*
*The major categories of Boiler Asset Services available include:*

* *Mitsubishi Hitachi Power Systems's (MHPS's) Risk Based Maintenance (RBM) & Life Cycle Planning*
* *Boiler Operation Optimization/Tuning services*

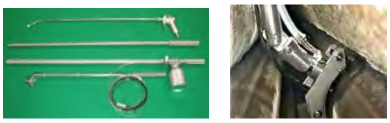
### 1) Key Points of MHPS's RBM & Life Cycle Planning

* *Diagnosis plans from basic operation and structure data, and from previous inspection data and past failure/damage records.*
* *Knowledge and optimal selection of inspection locations (higher risk points based on known phenomena).*
* *Highly experienced boiler inspection staff and Special equipment developed by MHPS.*
* *Established techniques for evaluation of inspection results, using vast historical boiler evaluation databases.*

Visual Inspection Device



Thickness Measuring



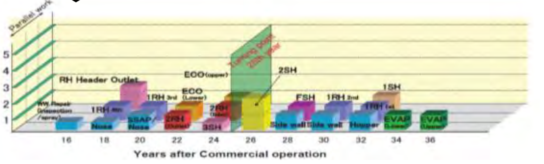
Planning for Inspection and replacements

| Component | | Damage | 2007 | 2010 | 2013 | 2016 | 2019 | 2022 | 2025 | 2028 | 2031 | 2034 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Economizer | Inlet HDR, Link | FAC, CF | D | D | R | | | | I | | D | |
| | Tube | Erosion, FAC | D | I | D | D | I | I | D | I | D | I |
| | Outlet HDR, Link | CF | | I | D | | I | | D | | I | |
| Drum | Main body Inner component | FAC, CF | | I | D | I | D | I | D | I | D | I |
| Water-wall | Hopper | TF, CF | D | I | D | I | I | D | I | I | D | I |
| | BNR WB | TF, CF | D | I | D | I | I | D | I | I | D | I |
| | High heat flux | OH, HA | D | I | D | I | D | I | D | I | D | I |
| | Arch panel | OH, HA | D | I | D | I | D | I | D | I | D | I |
| | Corner panel | AC, CF, TF | D | I | D | I | D | R | | | I | I |
| Super heater | Horizontal | Erosion | D | I | D | I | D | I | D | I | D | I |
| | Platen | Thinning, Creep | D | I | D | I | D | I | D | I | D | I |
| | Finish | Thinning, Creep | D | D | R | | | I | I | D | I | I |
| | Outlet HDR | Creep, TF | D | D | R | | | I | I | D | I | I |
| Reheater | Horizontal | Pitting, Thinning | D | R | | I | I | D | I | D | I | D |
| | Finish | Thinning, Creep | D | I | D | I | D | I | D | I | D | I |
| | Outlet HDR | Creep, TF | D | I | D | I | D | R | | | I | I |
| Main pipe | Main steam pipe | Creep, Scale | D | I | D | I | D | I | D | I | D | I |
| | Cold reheat pipe | TF | | I | | D | | I | | D | | I |
| | Hot reheat pipe | Creep, Scale | D | I | D | I | D | I | D | I | D | I |
| Spray pipe | SH spray | FAC, Thinning | D | I | D | I | D | R | | | I | I |
| | RH spray | FAC, Thinning | D | I | D | I | D | R | | | I | I |

### 2) Boiler Operation Optimization/Tuning Services

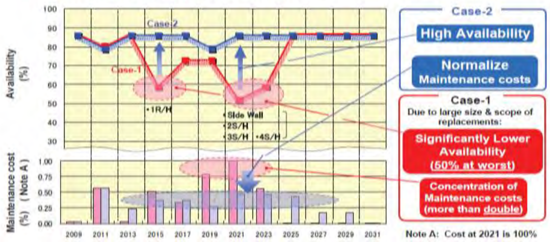
*Based on the results of inspections and assessments, MHPS can provide detailed proposals for* ***economical maintenance planning*** *and* ***boiler improvements*** *.*


Optimized replacement program for




Optimized replacement program for Availability and Maintenance

* Maintaining High Availability, and leveling replacement/repair costs.
* Target boiler service life up to 50 years.




### 3) Design Improvement / Upgrades

*Based on the result of inspection and assessment, MHPS can provide Boiler design improvement and upgrades to improve boiler operation conditions suitable for our customers future operation plans and conditions in addition to operation optimization/tuning services.*
*MHPS's boiler services and technologies have achieved industry recognitions and have provided* ***measurable improvements*** *resulting in* ***real economic benefits*** *for clients.*

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*Most of our international experience for Boiler Asset Service were provided to power stations even made by other boiler makers. The services extended to power stations resulted to the improvement of their boiler availability. Following list shows the BAS services extended to power stations outside of Japan.*

## Result of RBM Diagnosis out of Japan

| No. | Country | Plant | OEM | Period |
|---|---|---|---|---|
| 1 | Korea | S plant #1 | Doosan(Hanjung) | Nov. 2007 |
| 2 | Australia | M plant #1 | B&W | Sept. 2008 |
| 3 | Korea | S plant #4 | Doosan(Hanjung) | Jan. 2009 |
| 4 | Philippiness | P plant #2 | MHPS (Nagasaki) | Feb. 2009 |
| 5 | Philippiness | SL plant #1 (HRSG) | MHPS (Kure) | Nov. 2009 |
| 6 | Korea | Y plant #1 | MHPS (Kure) | Nov. 2009 |
| 7 | Philippines | SR plant #1,3 (HRSG) | Doosan(Hanjung) | Feb. 2010 |
| 8 | Philippines | P plant #1 | MHPS (Nagasaki) | Mar. 2010 |
| 9 | Philippines | SR plant #2,4 (HRSG) | Doosan(Hanjung) | Apr. 2010 |
| 10 | Philippines | SL plant #2 (HRSG) | MHPS (Kure) | Oct. 2010 |
| 11 | Philippines | M plant #1 | MHPS (Nagasaki) | Dec. 2010 |
| 12 | Philippines | M plant #2 | MHPS (Nagasaki) | Jan. 2011 |
| 13 | Korea | H plant #1 | Doosan(Hanjung) | Jun. 2010 |
| 14 | Philippines | S plant #2 | Alstom | Sep. 2010 |
| 15 | Brazil | J plant #7 | TImace | Jan. 2011 |
| 16 | Korea | H plant #1 | Doosan(Hanjung) | Mar. 2011 |
| 17 | India | W Plant #1 | BHEL | Jul. 2011 |
| 18 | Philippines | S plant #1 | Alstom | Sep. 2011 |
| 19 | Indonesia | S Plant | B&W Canada | Oct. 2011 |
| 20 | Philippines | M plant | Kawasaki | Oct. 2011 |
| 21 | India | V Plant | BHEL | Dec. 2011 |
| 22 | Singapore | S plant #30 | CMI | Jun. 2012 |
| 23 | Singapore | S plant #40 | CMI | Oct. 2012 |
| 24 | Philippines | S plant #2 | Alstom | Aug. 2012 |
| 25 | Philippines | S plant #1 | Alstom | Sep. 2012 |
| 26 | Australia | L plant #3 | ICA | Mar. 2012 |
| 27 | Australia | C plant #2 | MHPS (Kure) | Jun. 2012 |
| 28 | Italy | T plant #4 | MHPS (Kure) | Jun. 2012 |
| 29 | Italy | T plant #3 | MHPS (Kure) | Oct. 2012 |
| 30 | Malaysia | K plant #4 | IHI | Oct. 2012 |
| 31 | UAE | F plant | MHPS (Kure) | Oct. 2012 |
| 32 | Canada | G plant #3 | MHPS (Kure) | Oct. 2012 |
| 33 | Korea | H plant #1 | Doosan(Hanjung) | Nov. 2012 |
| 34 | Thailand | K plant #1 | MHPS (Kure) | Nov. 2012 |
| 35 | India | D Plant #4 | BHEL | Dec. 2012 |
| 36 | India | B Plant #4,5 | BHEL | Dec. 2012 |
| 37 | Philippines | M plant #1 | MHPS (Nagasaki) | Jan. 2013 |
| 38 | Korea | H plant #2 | Doosan(Hanjung) | Apr. 2013 |
| 39 | Singapore | S plant #50 | CMI | May 2013 |
| 40 | Malaysia | T plant #30 | IHI | May 2013 |

| No. | Country | Plant | OEM | Period |
|---|---|---|---|---|
| 41 | Malaysia | T plant #20 | IHI | May 2013 |
| 42 | Malaysia | T plant #10 | IHI | July 2013 |
| 43 | Malaysia | T plant #30 | IHI | Aug 2013 |
| 44 | Philippines | P plant #2 | MHPS (Nagasaki) | Sep.2013 |
| 45 | Malaysia | T plant #20 | IHI | Oct 2013 |
| 46 | Malaysia | T plant #10 | IHI | Jan 2014 |
| 47 | Philippines | M plant #2 | MHPS (Nagasaki) | Jan.2014 |
| 48 | Malaysia | T plant #30 | IHI | Feb 2014 |
| 49 | Philippines | M plant #1 | MHPS (Nagasaki) | Mar. 2014 |
| 50 | Philippines | M plant #2 | MHPS (Nagasaki) | Apr. 2014 |
| 51 | Philippines | P plant #1 | MHPS (Nagasaki) | Jun. 2014 |
| 52 | Philippines | M plant #2 | MHPS (Nagasaki) | Jul. 2014 |
| 53 | Philippines | P plant #2 | MHPS (Nagasaki) | Aug. 2014 |
| 54 | Malaysia | K plant #2 | Mitsui Riley | Aug. 2014 |
| 55 | Malaysia | K plant #6 | IHI | Sep. 2014 |
| 56 | Korea | H plant #1 | Doosan(Hanjung) | Oct. 2014 |
| 57 | Ukraine | T plant #3 | Taganrog(Russia) | Oct. 2014 |
| 58 | Malaysia | J plant #2 | IHI | Nov. 2014 |
| 59 | Malaysia | K plant #1 | Mitsui Riley | Dec. 2014 |
| 60 | Philippines | M plant #2 | MHPS (Nagasaki) | Jan. 2015 |
| 61 | Malaysia | K plant #4 | IHI | Feb. 2015 |
| 62 | Philippines | G plant #2 | HARBIN | Feb. 2015 |
| 63 | Philippines | S plant #1 | KHI | Mar. 2015 |
| 64 | Philippines | PSC (HRSG) | JFE | Mar. 2015 |
| 65 | Korea | H plant #2 | Doosan(Hanjung) | Apr. 2015 |
| 66 | Malaysia | K plant #3 | IHI | Apr. 2015 |
| 67 | Singapore | S plant #10 | MHPS(Kure) | May. 2015 |
| 68 | Malaysia | T plant #10 | IHI | Jun. 2015 |
| 69 | Philippines | P plant #1 | MHPS (Nagasaki) | Jun. 2015 |
| 70 | Philippines | S plant #2 | KHI | Jul. 2015 |
| 71 | Malaysia | K plant #5 | IHI | Aug. 2015 |
| 72 | Malaysia | P plant #1 | Doosan(HRSG) | Aug. 2015 |
| 73 | Malaysia | T plant #30 | IHI | Sep. 2015 |
| 74 | Korea | H plant #3 | Doosan(Hanjung) | Oct. 2015 |
| 75 | Malaysia | M plant #3 | Alstom | Nov. 2015 |
| 76 | Malaysia | T plant #20 | IHI | Dec. 2015 |
| 77 | Philippines | M plant #1 | MHPS (Nagasaki) | Jan. 2016 |
| 78 | Malaysia | M plant #4 | Alstom | Feb. 2016 |
| 79 | Indonesia | S plant #4 | B&W Canada | Apr. 2016 |
| | | | | |


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JCOAL Japan Coal Energy Center

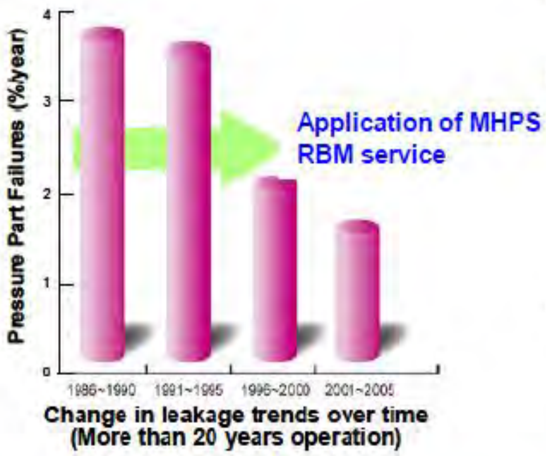
# Boiler Asset Services

## Effective Preventive Boiler Maintenance for Long Term Economic Operation

The technologies and systems for preventive maintenance of power plant boilers have significantly improved over the past 20 years. Although most power plants have inspection and maintenance plans in place, an advanced preventive boiler maintenance program can lead to improvements in overall unit availability and efficiency, and provide significant benefits to the power plant operator by:

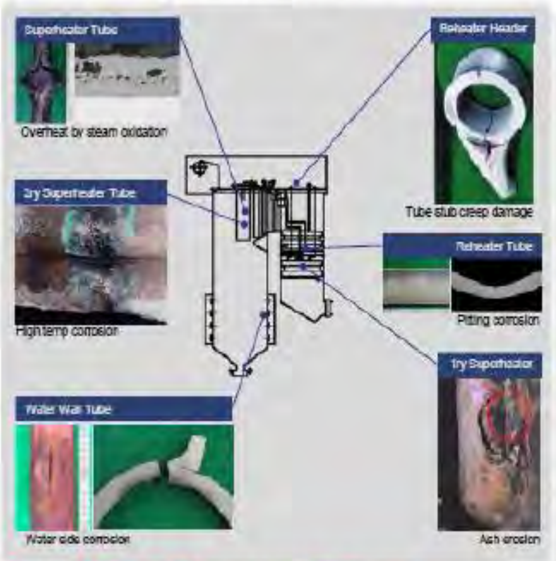
- Increased power generation
- Reduced fuel costs
- Reduced exhaust emissions

Mitsubishi Hitachi Power Systems ,Ltd. (MHPS) boiler asset services have been proven to reduce unplanned failures and improve availability of numerous boiler plants worldwide.




**Reduction of Unplanned Failures by MHPS RBM (55 Boilers, % occurring failures)**

A single unplanned unit outage due to a boiler component failure can cost tens of millions of dollars in lost power generation and repairs.




**Typical Boiler Component Failures**

MHPS provides a range of services and solutions including:

Risk based maintenance

- Optimized inspection planning
- Advanced assessment
- Long term economic-based maintenance scheduling

Boiler operation optimization

- Plant tuning
- Control improvements
- Combustion optimization

Design improvements and upgrades

- Surveying and assessment
- Implementation of improvement projects

Boiler Asset Services

## Benefit of MHPS Boiler Asset Services

- MHPS's advanced detailed inspection plans and assessment technologies are based on 30 years of boiler inspection and maintenance experiences, including the use of MHPS's large metallurgical and failure/phenomenon assessment database with historical information from a wide range of boiler designs and operating conditions.

- Boiler site inspection planning includes selection of optimal and specific inspection locations, based on MHPS's engineering knowledge of the critical inspection locations where specific failure phenomenon are likely to occur.

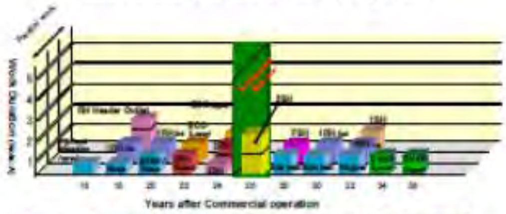
- MHPS has developed advanced specialized inspection tools and techniques for boiler assessment.

MHPS Deep Space Inspection Tool

- MHPS's senior inspection staff have over 15 years of boiler inspection and assessment experience.

- The reports, recommendations and long term plans are developed utilizing MHPS's boiler engineering resources with know-how from the design and supply of hundreds of boilers of various configurations and fuel firing conditions.

- By utilizing MHPS's vast historical database and boiler engineering technologies, MHPS can analyze the total boiler system and equipment and provide practical economical proposals to help the client's decision making according to the following goals…
  - ☐ Improve availability, resulting in reduced unplanned outages and reduced production losses.
  - ☐ Sustain high availability for extended boiler life, while maintaining an economical maintenance program.




| Component | 2010 | 2013 | 2016 | 2019 | 2022 | 2025 | 2028 | 2031 | 2034 |
|---|---|---|---|---|---|---|---|---|---|
| Inlet HDR | D | D | R | | | | | | D |
| Tube | | | D | D | | | D | | D |
| Outlet HDR | | | D | | | | D | | |
| Main body component | | | D | | D | | D | | D |
| Hopper | D | | D | | | D | | | D |
| BNR WB | D | | D | | D | | D | | D |
| Corner panel | D | | D | | D | R | | | |
| S/H Horizontal | D | | D | | D | | D | | D |
| S/H Finish | D | | R | | | | | D | |
| S/H Outlet HDR | D | | R | | | | | D | |
| R/H Horizontal | D | R | | | | D | | | D |
| R/H Finish | D | | D | | D | | D | | D |
| R/H Outlet HDR | D | | D | | D | | D | | D |
| Main steam pipe | D | | D | | D | | D | | D |
| Cold reheat pipe | | | | D | | | | D | |
| Hot reheat pipe | D | | D | | D | | D | | D |
| SH spray | D | | D | | D | R | | | |
| RH spray | D | | D | | D | R | | | |

Long Term Maintenance Planning

IHI

JCOAL
Japan Coal Energy Center

# IHI's After Market Services

IHI's refurbishment & renovation program would optimize and extend lifespan of power plants.
By analyzing your current troubles, remaining life of pressure parts of existing plant, and investigating auxiliary equipment performance, IHI can propose a best solution as a boiler producer.
Our solutions are various such as maintenance, replacement of existing parts, upgrades of combustion system, modification of control system, or application of new materials for pressure parts.

## Refurbishment & Renovation

### Pressure Parts Rehabilitation

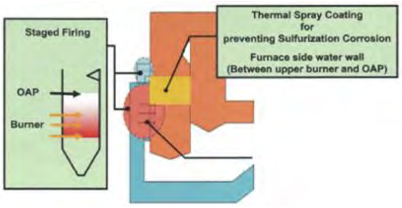
IHI offer total pressure parts replacement works .

- ✓ Furnace / HRA Wall
- ✓ SH/ RH/ECO elements
- ✓ Header and Manifold
- ✓ Large Diameter Piping

SH & RH Coils with T91 — SH & RH Header — SH Block Assembly — Furnace Wall Panels — Bank Tube Rehabilitation

### Boiler Renovation

- ✓ Performance / Efficiency Improvement
- ✓ Life time extension with upgrading material/ equipment
- ✓ Fuel Conversion, Dual Fuel Firing Modification
- ✓ Environmental friendly solution (Low NOx Burner, SCR System, FGD System)




### OEM Spare & Replacement Parts

- ✓ Pressure Parts
- ✓ Burner System
- ✓ Pulverize Wearing Parts
- ✓ Auxiliary Equipment Parts
- ✓ Control & Instrument Parts

Oil Burner Guns

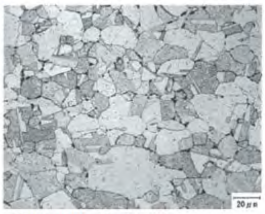
Pulverizer Roller Tire

## Engineering Support & Planning

As OEM, IHI provide both on-site and off-site technical support service.
Our support is based on long term experiences of large scale Refurbishment and Renovation Projects.

Creep Rupture Test Facility

Test Specimen



Microstructure of Sample Tube

- ✓ Technical advice & assistance for Operation & Maintenance (O&M)
- ✓ Re-tuning & optimization of boiler operation
- ✓ Planning support of repair work for major un-expected troubles
- ✓ Field Inspection, Performance Testing
- ✓ Material Testing
- ✓ Failure Analysis
- ✓ Life time evaluation of boiler pressure parts

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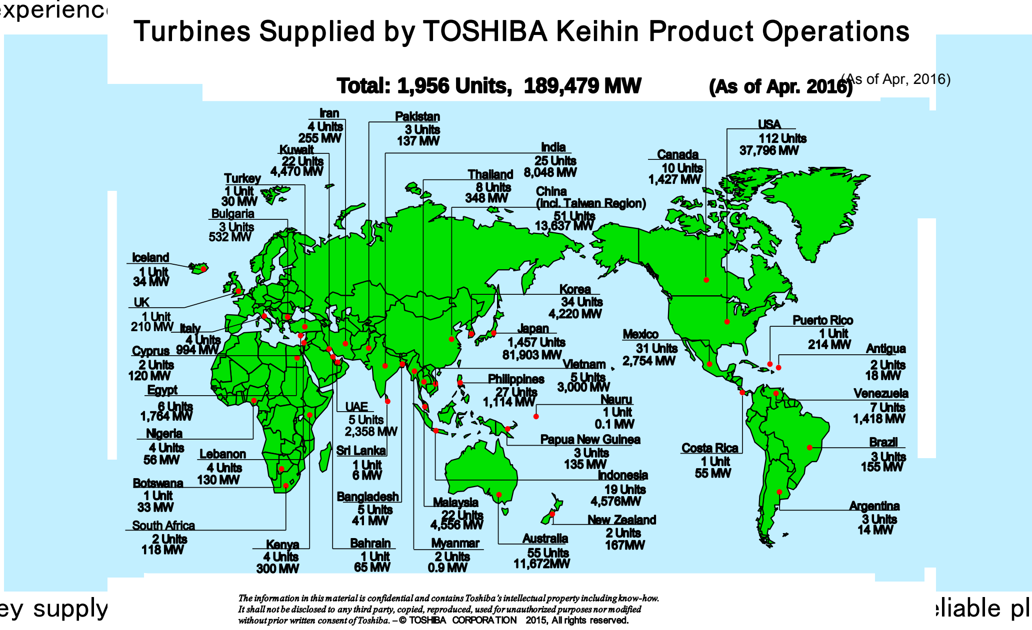
Toshiba Steam Turbine & Generator

Abstract of Product / Technology

Toshiba has the magnificent supply record of steam turbines & generators (STGs) as 1,956 units and 189GW capacity. Then, we are not a mere STG supplier but the turnkey project company based on EPC scheme (i.e. Engineering, Procurement & Construction). Our excellent EPC capability contributes to customer's benefit to realize the optimal plant on diverse specifications. Besides, our state of the art design on steam turbine and generator enables the highest efficiency as 42% coal-fired plant.

Detail Introduction of Product/Technology

◆Rich experienc

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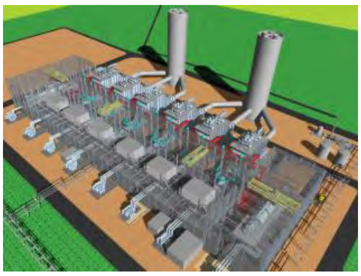
◆Turnkey supply ... liable plant.

**Engineering and Design** | **Procurement and Manufacturing** | **Construction and Commissioning**

**Intelligent Modeling** | **Utilize global supply chain** | **Optimization of construction term**




◆Recent reference in ASEAN

The sophisticated power plants have been installed and are under the substantial operation in ASEAN countries.

**Malaysia - Tanjung Bin 3x700MW Coal Fired**

**2x660MW Coal Fired**

TOSHIBA
Leading Innovation

JCOAL
Japan Coal Energy Center

Advantage & Experience:

◆Advantage

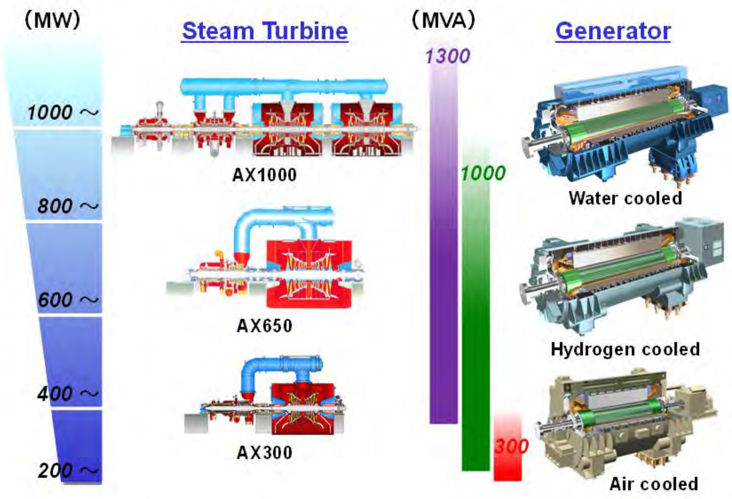
・Various products line-up are prepared to meet diverse specifications

Wide range of capacity and various type for every coal conditions which satisfies customer's requirements.

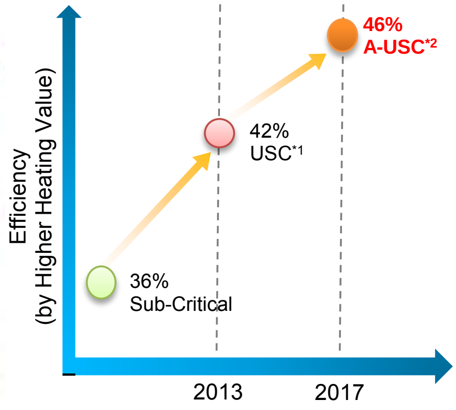
・Provide high efficiency steam turbine & generator

Cutting edge technologies of Toshiba steam turbine and generator enables the highest efficiency of 42% among coal-fired thermal power. Besides, A-USC (Advanced Ultra Super Critical) technology is under development considering the next generation system.

**Product line-up of steam turbines &**




**Trend of plant efficiency**




(*1) USC:Ultra-Supercritical
(*2) A-USC:Advanced Ultra Supercritical

◆Experience

**Toshiba to supply large capacity steam turbines & generators in ASEAN**

| Delivery Country | Rated Output | Commercial Operation |
|---|---|---|
| Indonesia | 2x660MW | 2006 |
| Malaysia | 3x700MW | 2006-2007 |
| Malaysia | 2x700MW | 2009 |
| Indonesia | 2x660MW | 2011-2012 |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TOSHIBA
Leading Innovation

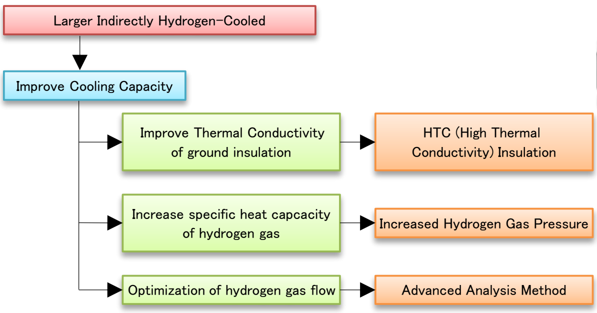
JCOAL
Japan Coal Energy Center

# Toshiba Indirectly Hydrogen-Cooled Turbo-generator for Extreme High Efficiency Operation

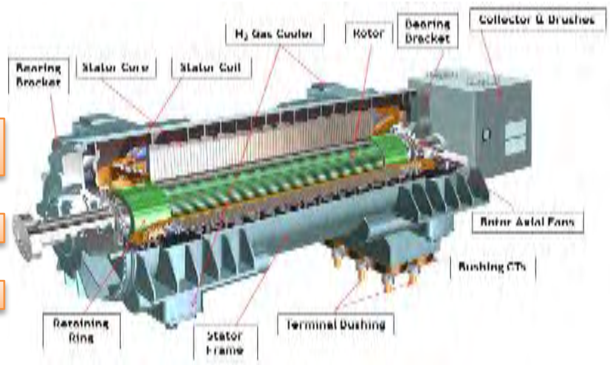
## Abstract of Product /Technology

High efficiency is a significant benefit of indirectly hydrogen-cooled generator. Hydrogen gas has excellent characteristics for cooling the generator as it is a medium of low density and thereby reduces losses while at the same time enhancing high thermal conductivity which yield cooling performance.
In addition, simple auxiliary unit system of indirectly hydrogen-cooled generator provides easy operation and considerable lower maintenance as compared to water cooling systems.
Toshiba's product line of indirectly hydrogen-cooled generator has been developped and extends up to 1,000MVA class by many advanced technologies.
This high capacity range have been expanded by technology developments of High Thermal Conductivity (HTC) insulation, increasing the hydrogen pressure, and optimizing hydrogen gas flow distribution as illustrated below.

**Applied Technologies for Large Capacity Generator**



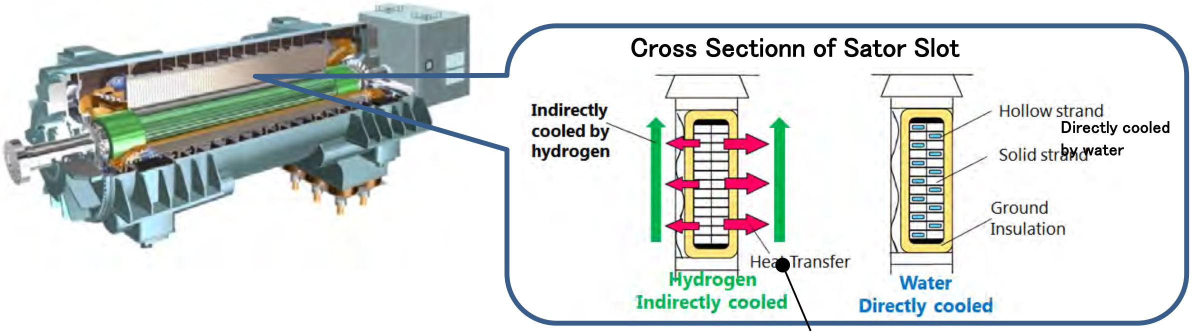

**Construction of Indirectly Hydrogen-Cooled Generator**




## Detail Introduction of Product/Technology

Toshiba's cutting-edge High Thermal Conductivity (HTC) stator insulation technology enhances stator coil thermal conduction and cooling performance. The HTC insulation has twice as high thermal conductivity compared with the conventional insulation, due to high thermal conductive material applied to the mica insulation layers.
The HTC stator insulation technology make possible to expand maximum capacity of indirectly hydrogen-cooled generator and provide high efficiency machine.

■ Difference of Stator cooling method between hydrogen indirectly cooled and water directly cooled




Increased heat transfer by HTC insulation
(HTC : High Thermal Conductivity)

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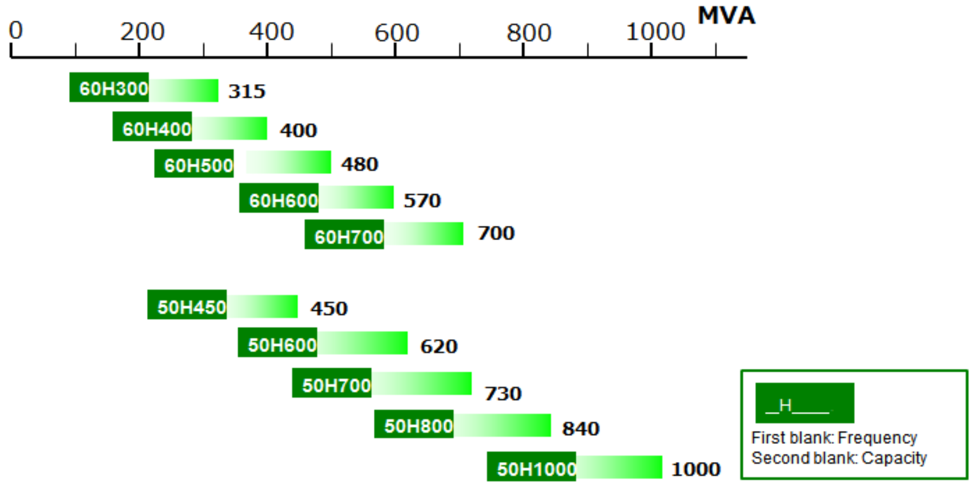
Experience and Product Line

◆Advantage

HTC (High Thermal Conductivity) insulation is the key technology for large capacity indirectly hydrogen-cooled generator. HTC has been applied to indirectly hydrogen-cooled generators over 50 units since 2000, and its the longest stable experience is over 15 years.
2p-60Hz-670MVA indirectly hydrogen-cooled generator was taken over to Japanese domestic utility in 2010 and have been operated over 5 years with excellent condition.

1,000MVA class indirectly hydrogen-cooled generator is developped and made up by HTC inslation technology, the most advanced computation analysis and existing well proven technology.

**Product Line Frame Size of TOSHIBA Indirectly Hydrogen-Cooled Generators**




◆Experien

**Delivery Record and Plan of Large Capacity Indirectly Hydrogen-Cooled Generators**

| Delivery Country | Capacity (MVA) | Frequency (Hz) | Commercial Operation |
|---|---|---|---|
| Japan | 563 | 50 | 2007 |
| Japan | 670 | 60 | 2010 |
| USA | 561 | 60 | 2017 |
| USA | 561 | 60 | 2018 |
| Japan | 670 | 50 | 2019 |
| Japan | 715 | 50 | 2020 |

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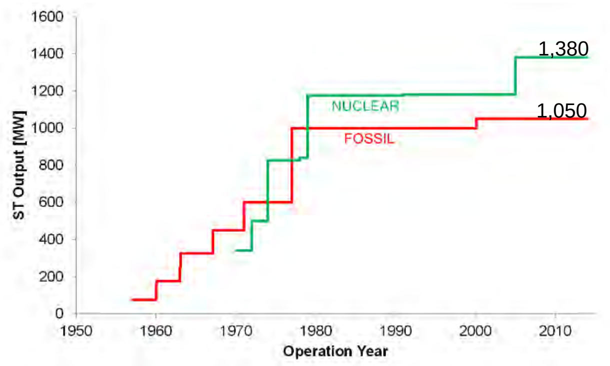
Steam Turbine

Abstract of Product /Technology
MITSUBISHI HITACHI POWER SYSTEMS, LTD. (MHPS) has supplied numerous steam turbines with high efficiency and reliability to various countries and regions since 1908.
MHPS steam turbines feature high-performance long blades and technical improvements to endure ultra-high temperature conditions of up to 600/620 deg.C.
Technical Improvements have been implemented over the years which are proven and reliable technologies.
Design features include:
- High efficiency based on High Pressure and High Temperature steam condition
- Reliable Last Stage Blades with various

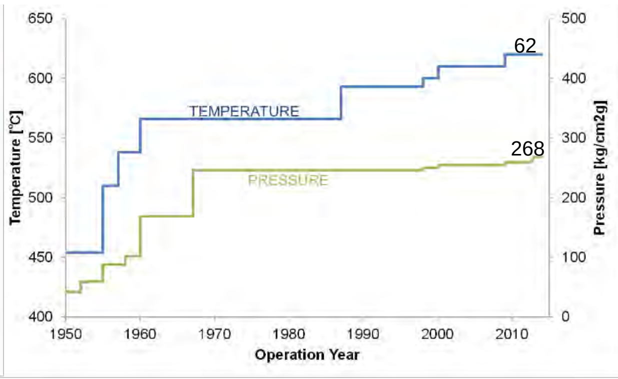
Detail introduction of Product/Technology

## History of MHPS Steam Turbine

Development of Turbine Capacity

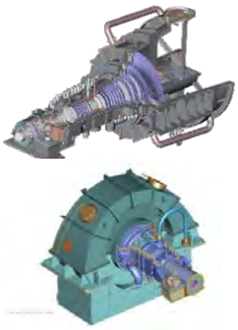



History of Inlet Steam Conditions

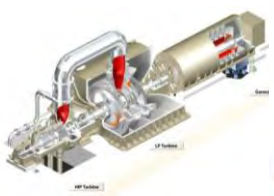



## Output and Application

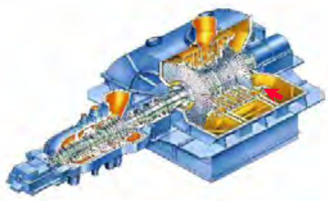
The following bird eye views are typical applications for MHPS steam turbines.



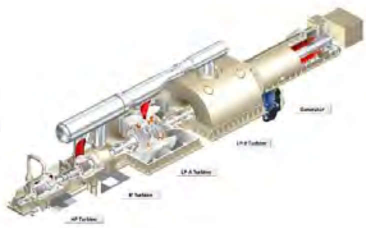
200MW class
(for GTCC plant)



300MW class
(for GTCC plant)



600MW class
(for Conventional plant)



1,000MW class
(for Conventional plant)

MITSUBISHI HITACHI POWER SYSTEMS

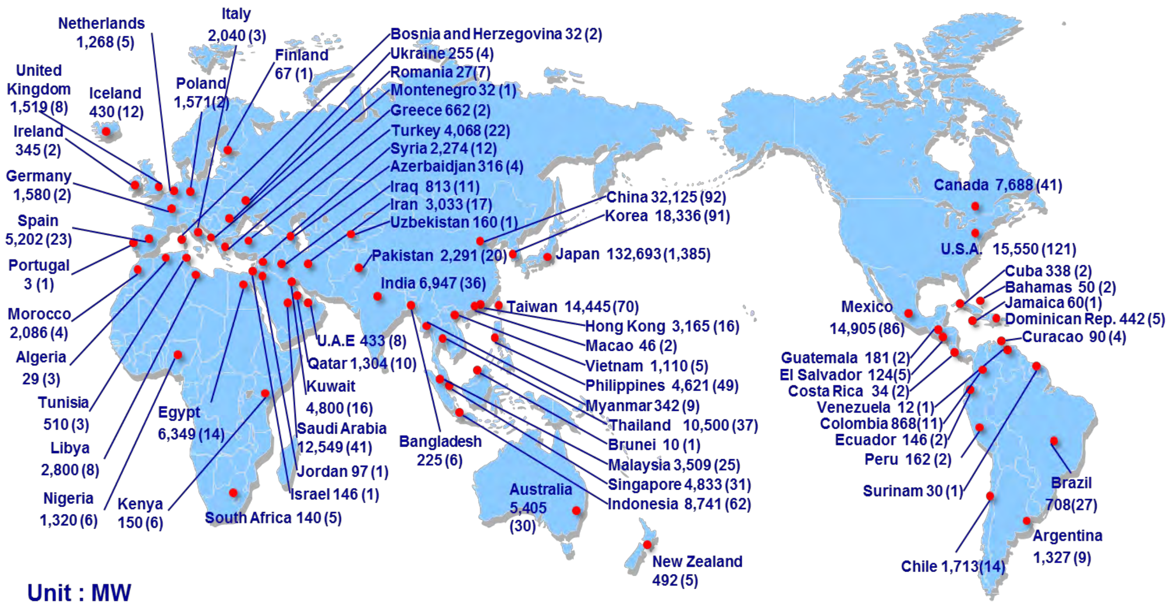
JCOAL Japan Coal Energy Center

Advantage & Experience:

MHPS is capable of designing and manufacturing Super Critical Type Steam Turbines for a wide range of generating capacity, and we have numerous turbines in successful and continued operation in the worldwide.

## Steam Turbines in the World

**Total Installed Capacity: 352.7GW (including 132.7GW in Japan)**




**Unit : MW**

**( ) : Number of Units**

As of April, 2015

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MITSUBISHI HITACHI POWER SYSTEMS

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# Generator

## Abstract of Product /Technology

Generators are coupled to steam and/or gas turbines to convert mechanical power into electrical power. High efficiency performance of MHPS turbine generators contributes to improve plant performance and reduce environmental impacts at power stations.
The generators are a three-phase synchronous machine type with compact design achieved by choosing a suitable cooling system.
- Air Cooled Generators to 350 MVA
- Hydrogen Cooled generators to 900 MVA
- Hydrogen/Water Generators to 1,400 MVA

## Detail introduction of Product/Technology

The most characteristic difference between generators is the cooling media use for heat removal from the generator windings and core. Air-cooled generators use fans to force air across the rotor and stator for cooling, widely applied on small capacity. While hydrogen cooled generators take advantage of the low density and high thermal conductivity hydrogen gas and use it in lieu of air as a cooling medium for large capacity. As a result, hydrogen cooled generators are generally more compact with higher efficiency. Hydrogen/Water cooled generators are used for larger capacity applications where air cooling or hydrogen cooling is not a suitable solution.
In coal fired thermal power plants, hydrogen or hydrogen/water cooled generators are normally used due to a large capacity range. A typical configuration is shown below.

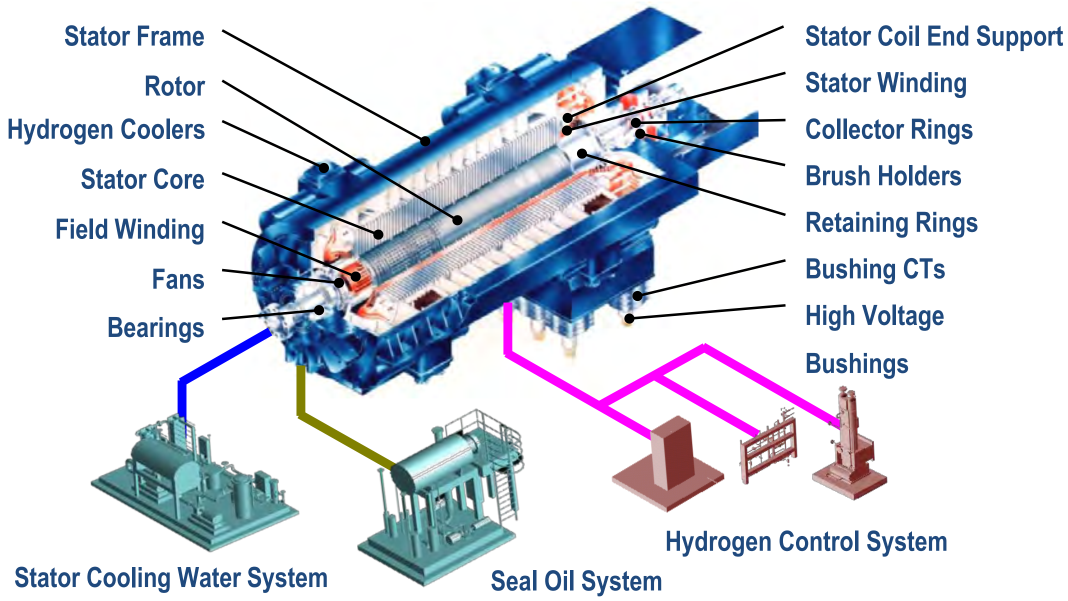


Figure : Typical Configuration of Large Generators

Advantage & Experience:

MHPS offers a suitable and optimized generators for each application with high efficiency and high reliability based on our worldwide experience.

- More than 1,000 generator sucessfully running around the world
- Experiences of wide range capacity & cooling system
- Proven design for high reliability
- High efficiency
- High reliability in manufacturing stage by well-trained workers and QA program
- Top of the World engineering technologies
- Factory running test to confirm the generator performance
- Packaged auxiliary systems

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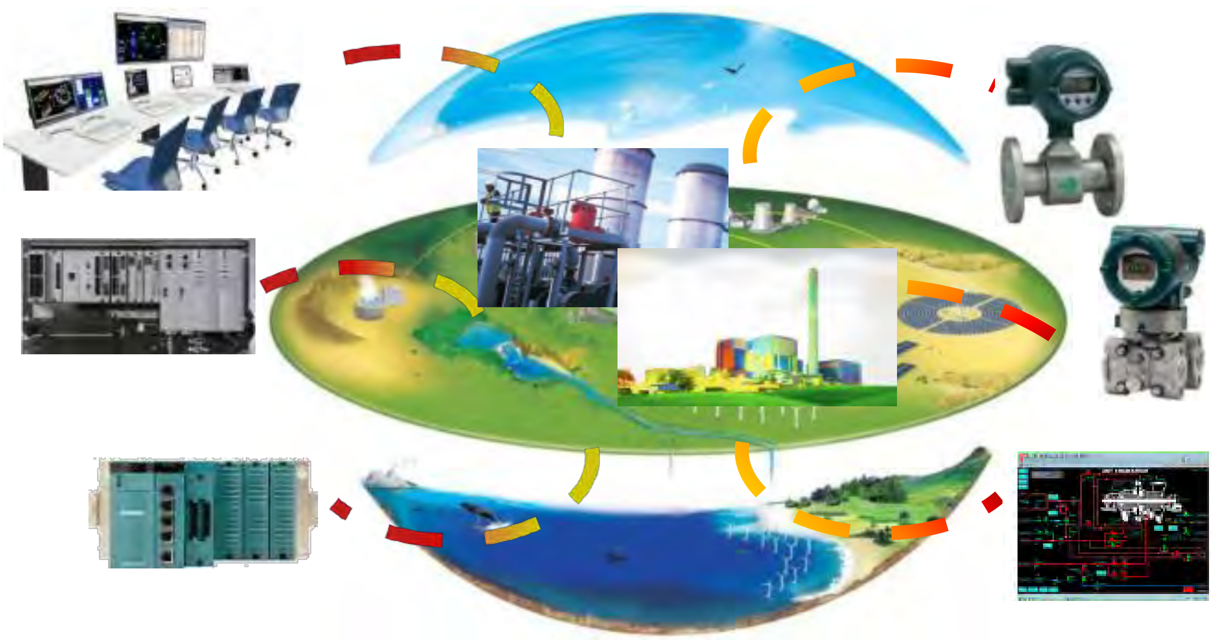
| | |
|---|---|
| DCS CENTUM series | Process Analyzers |
| STARDOM | CEMS |
| Field Instruments | Advanced Solutions |
| Power Plant Simulator | |

Abstract of Product /Technology

Yokogawa offers a wide range of products and solutions for operating various power plants, from fossil-fired to renewable energy-based plants. For operation and monitoring, our CENTUM Series DCS and STARDOM PLC/RTU and FAST/TOOLS SCADA systems have long led the industry. For field instrumentation, our pressure and differential pressure transmitters, flowmeters and process analyzers deliver premium performance. Yokogawa's solutions are engineered to cater the needs of total automation integration with the control systems and field instrumentation. Eventually Yokogawa builds and installs a smart system for power plants to achieve operational excellence. In addition, our model-based dynamic power plant simulator allows optimizing

Detail introduction of Product/Technology

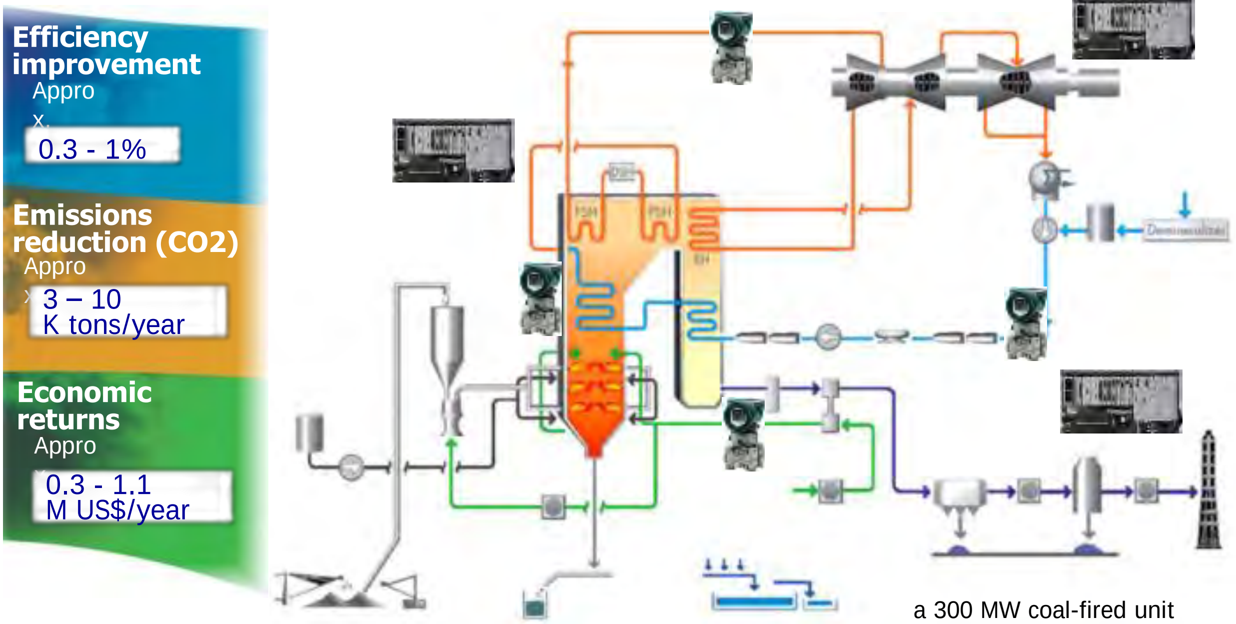
## Smart System for Smart Technological Solutions.



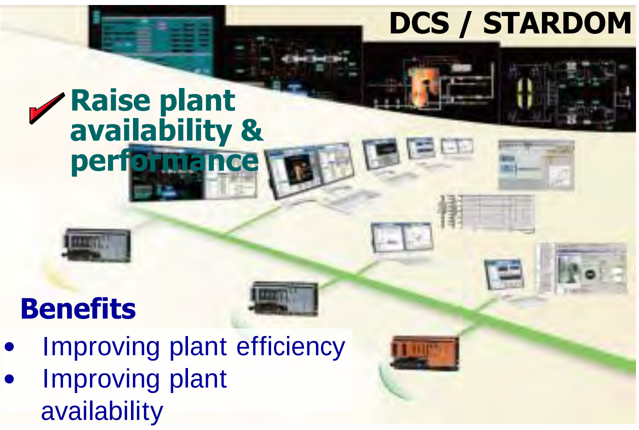
While building the smart system for power plant, Yokogawa's engineering effort always provide the control strategy which shall improve efficiency, reduce emissions, and achieve better economic returns. Further our unparalleled control schemes for coal-fired power plants help reduce CO2 emissions and generate clean power.

Estimated benefits are indicated in the table. Such benefits can be realized by modernization of control system, instrumentation and its integrated solution with effectively engineered control strategies.

Profits are also realized by adequate plant efficiency. For achieving better result, it is not always necessary to revamp boilers or turbines but one can implement effective control




Benefit estimation of CO2 emissions reduction and cost saving by systems and instruments modernization

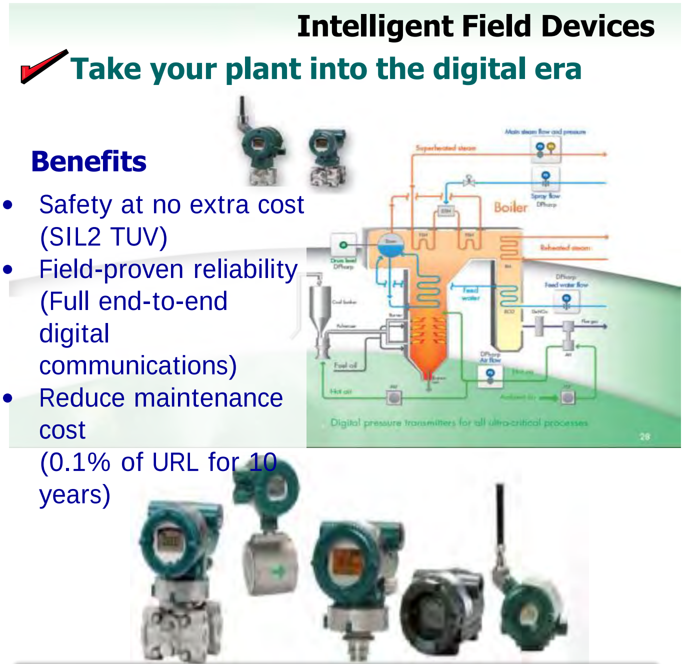



**Benefits**

- Improving plant efficiency
- Improving plant availability
- Reducing CO2 emissions

We are very proud that our CENTUM Series DCSs lead the world in the high level reliability in the industrial automation market realizing the non-stop operations with 99.99999% (seven-9s) of high availability. Our products contribute to long

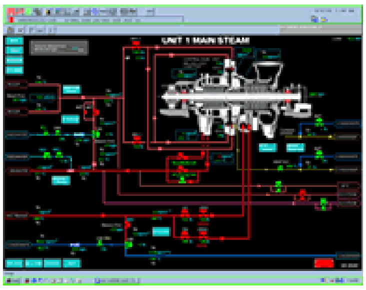
FAST/TOOLS with STARDOM: Yokogawa's STARDOM autonomous controllers are ideal for small- to medium-scale fossil-fired or renewable energy power plants, uniquely featuring remote management and stand-alone capabilities. When combined with Yokogawa's FAST/TOOLS SCADA, these controllers reduce running costs




In the Industry, Yokogawa's field devices (instruments) command respect for their reliability, high accuracy and stability, thanks to the Yokogawa's silicon resonant sensor technology for its differential pressure transmitters. They contributes to stable plant operation for a large number of customers all over the world.

Features:


Yokogawa's decades of power plant experience are embedded in this dynamic power plant simulator with a high-fidelity plant model. The simulator is ideal not only for operator training and up-skilling, but also enables you to keep upgrading your control system flexibly and safely with minimal time for outages and commissioning.



Features:

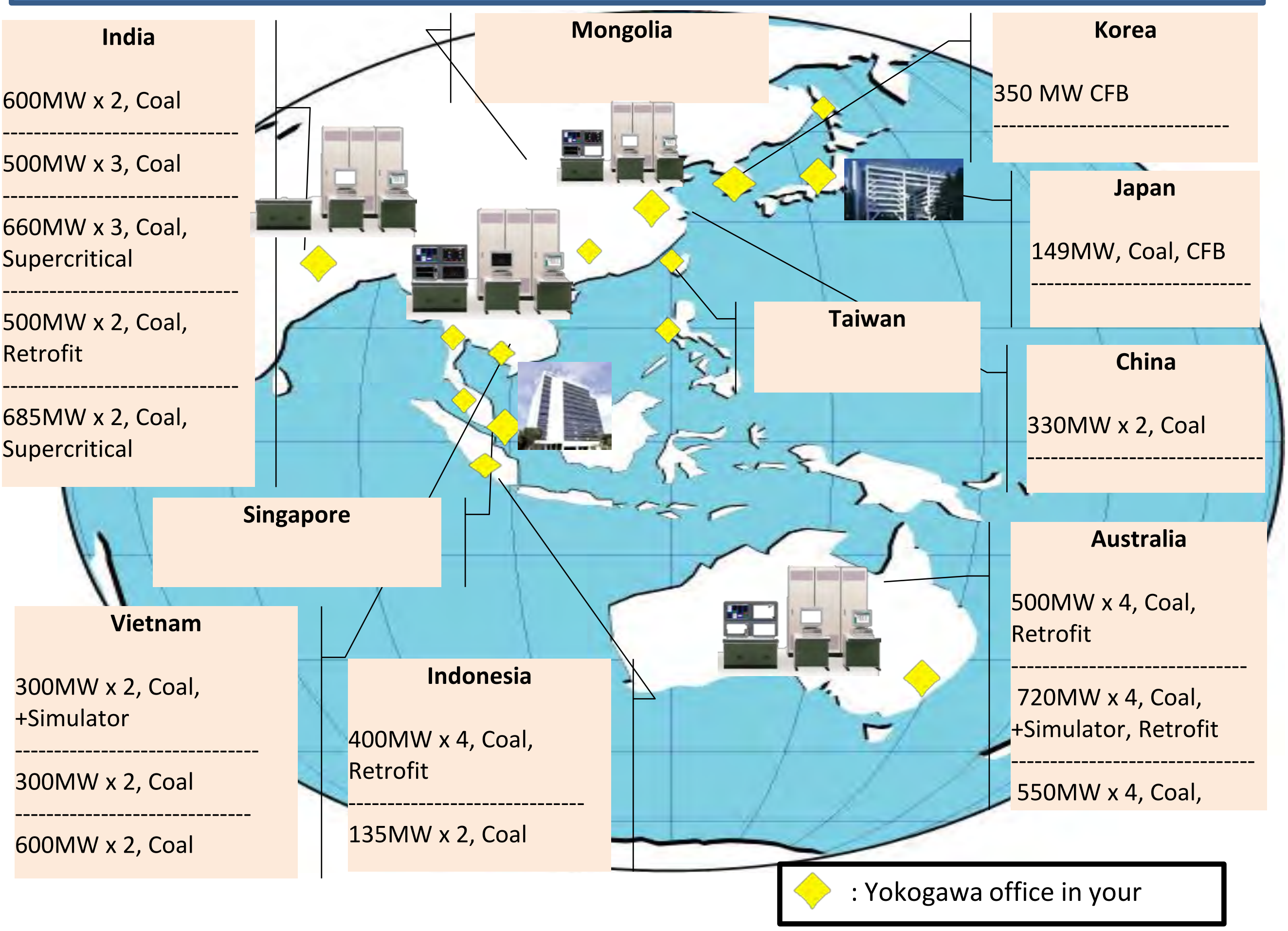
- High fidelity (>99% steady state; >95% dynamic state)
- Flexible training and evaluation
  - Executing routine operational procedures
  - Responding to plant malfunctions
  - Creating different kinds of malfunctions
  - Having any number of initial conditions such as cold,

warm and hot start-ups.

Advantage & Experience:

Yokogawa has more than 1600 systems installed in power market, not only in fossil-fired but also in renewable energy-based power plants, and over 150 local offices support your power projects all

## Yokogawa Major System Reference Map in Coal Fired Power Market in



YOKOGAWA

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Remarks

Integrated Monitoring and Control System Solutions
to Maximizing Performance of Coal-fired Thermal Power Plant

## Abstract of Product /Technology

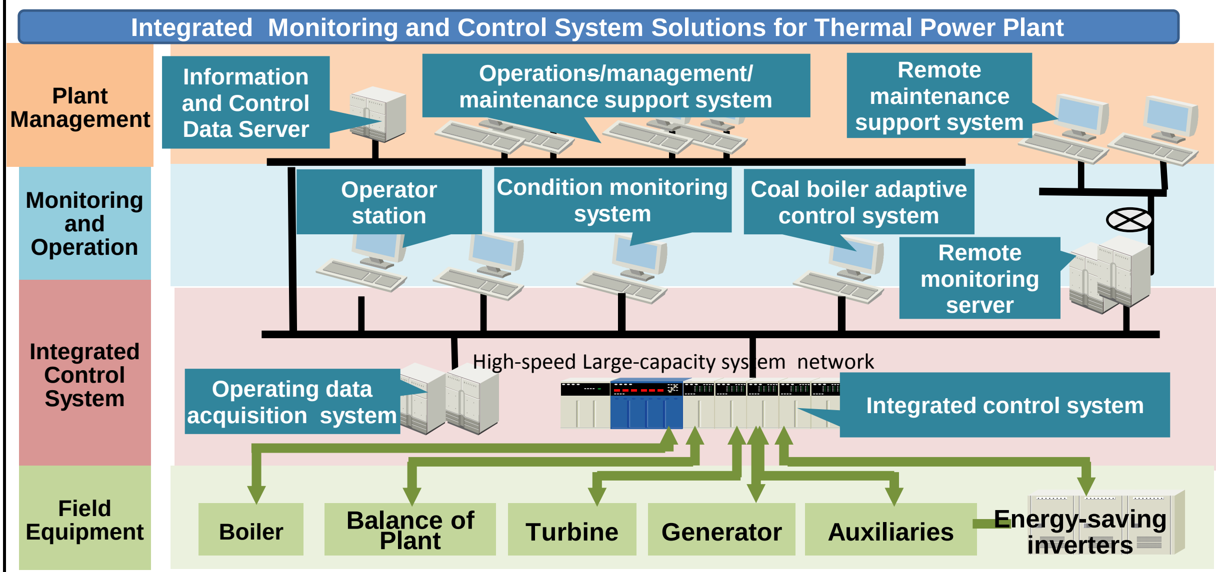

Thermal power plants are expected to enhance capacity utilization and to improve efficiency for reducing operational costs with environment-friendly technology in addition to ensuring the safety and security.These needs are attributed to a result of changes in the business environment surrounding energy.

MHPS is committed to ensuring that our customers receive the best solution based on our state-of-the-art monitoring and control system which is eco-friendly and able to keep providing energy even at emergency situation. Because we can realize optimum and robust control to attend to every need for the whole coal-fired thermal power plant by integrating highly skilled technology and know-how of information and control.


## Detailed introduction of Product/Technology

The feature of these solutions is the high-efficiency operation support and the effective plant management by utilizing plant data more effectively. The plant data mining allows the operators to keep track of equipment condition quickly and accurately and to keep plant more stable in optimum condition.

The highlight of the solutions based on the integrated monitoring and control system are given as follows.




**1) Integrated control solution**

- Adoption of common system architecture for the integrated control of all range of plant equipment
- Power plant information is integrated through a large-capacity and high-speed real-time network

**2) Reliable operation solution**

- Condition monitoring system allows early detection of equipment failure signs by advanced technologies
- High reliability system based on redundancy configuration and self-diagnosis function
- User-friendly human-machine interface

**3) Plant management solution and optimum control**

- Operation/Management/Maintenance support system based on the latest ICT(Information and Communication Technology)

MITSUBISHI HITACHI POWER SYSTEMS

JCOAL Japan Coal Energy Center

Advantage & Experience:

■**Advantages**

**1) Integrated control system**

The integrated control system are made up of highly-reliable and high-performance controllers and I/O modules. The introduction of this system contributes to improve cost performance.

**2) Reliable operation**

The early detection of equipment failure signs is able to minimize the losses in unscheduled outage or equipment breakdown. Also,advanced redundancy technologies keep continuous plant operatipn even if single failure of control system occurs.

3)Operation cost improvement

Various optimum controls make it possible to reduce operation cost for power plant.

4) Plant management improvement

Operation/management/maintenance support system provides optimum solutions for operators, maitenance engineers and management personnel.

■**Experiences**

- Sub-critical/Super-critical/Ultra-super-critical thermal power plant control system (including multiple coal fired boiler)
- Integrated coal Gasification Combined Cycle (IGCC) control system

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Toshiba BTG Control System

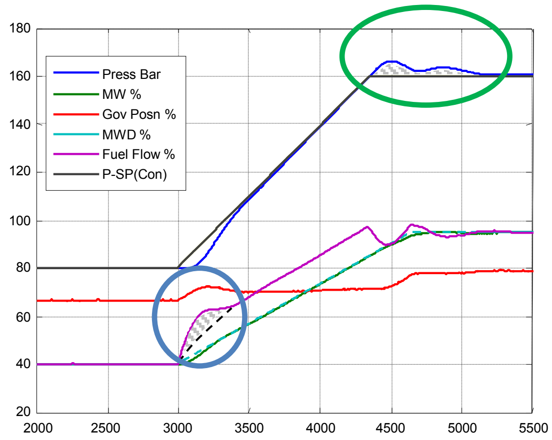
## Abstract of Product /Technology


Steam Pressure control in power plant is difficult to optimize due both to the characteristics of the fuel/combustion/steam generation processes and constraints imposed by material stresses, fuel delivery systems and boiler firing limitations.
Optimization through Toshiba's advanced control strategy provides minimized overfiring through dynamic pressure setpoint formation and continually adjustable reserve margin for frequency response. This technique makes full use of steam storage to reduce metal component stresses, maximizing unit efficiency with the widest possible throttle valve opening for the fast response MW reserve that is offered to the market. This results in higher ancillary services capability, lower fuel costs and longer

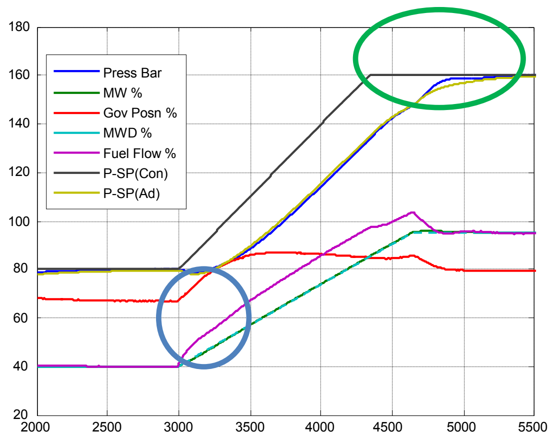

## Detail Introduction of Product/Technology

Advanced feedback control of steam pressure using Toshiba's two-degree-of-freedom model based controller provides stability during load ramps and disturbances such as frequency excursions, mill changes and sootblowing, enhancing unit security and range of operation.

The followings are simulation results of load ramps with conventional (left) and advanced (right) control structures.




**Simulation Result of Conventional Control Structure**




**Simulation Result of Advanced Control Structure**

The governor continues to provide adequate margin for frequency control, while overfiring has been reduced (see shaded region) and overshoot in pressure eliminated. The design makes significant improvements to steam temperature response, particularly at low load.

Advantage & Experience:

◆Improved unit efficiency (reduced throttling at low load; reduced carbon losses during load increases)
Direct fuel cost savings from throttling loss efficiency improvement without loss of frequency reserve margin. Reserve settable by operator according to market offer.

◆Improved frequency response
Maximum utilization of available pressure during frequency excursions. Improvement to ancillary services offered.

◆Reduced thermal stresses
Lower overfiring change rates reduce steam and metal temperature variations during load ramps. Up to 5 Deg C reduction in peaks.

◆Improved ramp rates
Increase in ramp rates by up to 1.5%/min (eg 2.0 to 3.5%/min)

◆Improved boiler stability
Wider load range, reduced operator intervention, reduced alarms, reduced trip rate. Improvement in operating staff efficiencies.

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Remarks

# Circulating Fluidized Bed Boiler (CFB) Co-combustion Technology

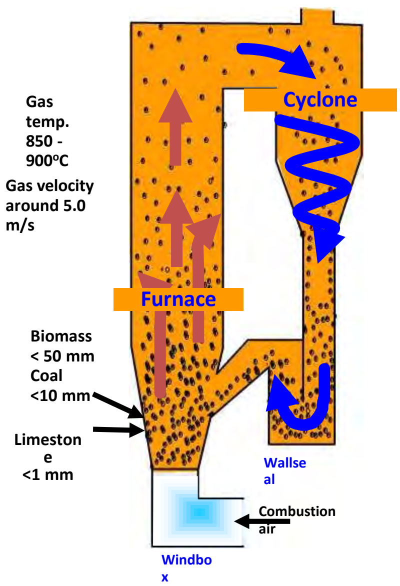
Abstract of Product / Technology

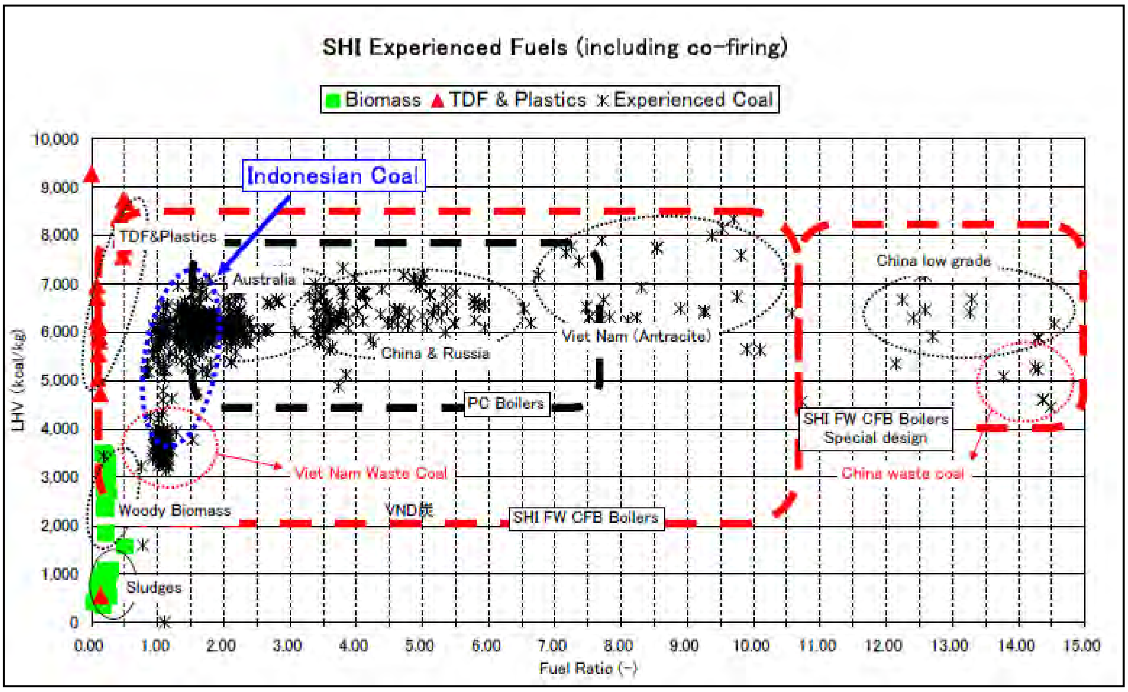
SUMITOMO HEAVY INDUSTRIES, LTD（SHI）delivers CFB boilers for utilizing low rank coals with co-combustion technology. Biomass fuel (for CO2 reduction), varieties of coal including high moisture low rank coal (for energy security), waste tire (TDF) and plastic refused fuels (for waste to energy) are used even in a boiler. SHI has already delivered over 50 units of CFB boiler utilizing those kind of fuels since 2002 and has completed high reliable operation records in Japan and Asian countries for the industrial facility and IPP use.

Details of Technology :

SHI has developed CFB co-combustion technology based on Foster Wheeler CFB Technology.
CFB can utilize wide range of fuels by following features :

A) Long combustion time by the circulating => Easy to burn unreactive fuels like Anthracite.
B) Large heat Capacity in Furnace => Easy to burn high moisture fuels like biomass
C) Controlled combustion temperature => Low and Controlled Emission (SOx and NOx)
D) Strong Fluidization in Bed => Large size fuels, various figure fuels,

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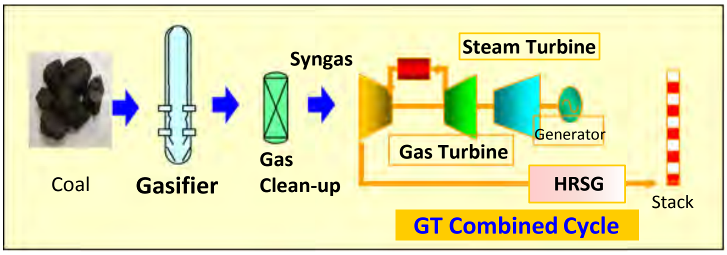
# Integrated Coal Gasifi cation Combined Cycle (IGCC)

## Abstract of product / technology:

The Integrated Coal Gasification Combined Cycle (IGCC) system is a system which generates electricity by highly efficient combined cycle technology.
The IGCC system has attracted attention as a major next-generation environmentally-friendly thermal power generation system due to its superior power generating efficiency to conventional coal-fired thermal power generation and ability to reduce CO2 emissions. MHPS designed, manufactured, transported and constructed a total IGCC plant including the coal gasifier, gas clean-up, gas turbine, steam turbine and heat recovery steam generator at a 250MW IGCC demonstration power plant, Clean Coal Power R&D Co., LTD. Based on this successful result, MHPS has started implementing IGCC commercial projects represented by Fukushima revitalization power 540MW×2.

## Details of product / technology:

IGCC is a system designed to achieve the utmost efficiency through coal gasification process coupled with a combined cycle (CC) system.
Coal is changed to combustible gas (syngas) in the Gasifier. The syngas is supplied to drive the Gas Turbine by burning.
High-temperature exhaust gas goes to a boiler, the Heat Recovery Steam Generator (HRSG) to generate steam and to drive the Steam Turbine.



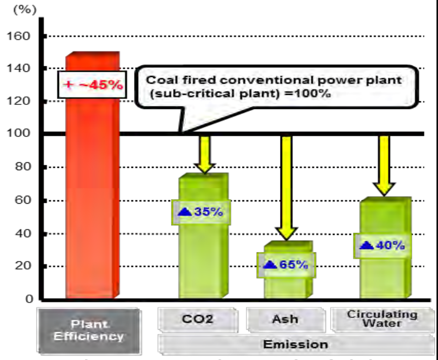

IGCC System Configuration

## Features & advantages:

<u>The highest efficiency and the minimum environmental impact</u>

- IGCC plant efficiency is 40-45 % higher than the coal fired conventional power plant. (Base line = 33 abs.% : the world average of sub-critical plant) Accordingly, CO2 emission decreases by 30-35%.
- IGCC discharges coal ash in an environmentally-friendly form of glassy slag, cutting volumes by more than half.
- IGCC reduces circulating water for cooling by 40% because it uses the gas turbine combined cycle system.

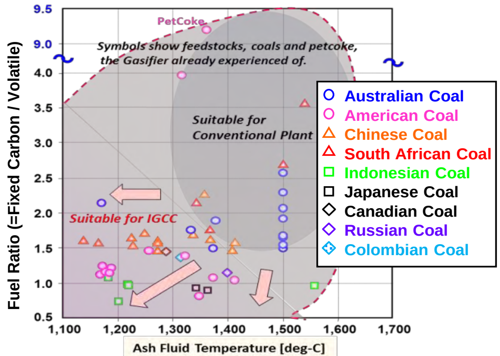
Flyash (Conventional Plant) Grassy Molten Slag (IGCC)




Performance of MHPS IGCC

<u>Flexibility to "variety of coal"</u>

- LRC (Low-rank coals), that have low ash melting temperatures, are not suitable for conventional plants due to causing ash slagging problem and limiting operation of the plants, but IGCC can use wider range of coals including LRC.
- The Air-blown IGCC System already verified its flexibility and capability to many brands of coal sourced in the world.




Applicable Coal Range
-All Plotted can be used in MHPS IGCC-

MITSUBISHI HITACHI POWER SYSTEMS

JCOAL Japan Coal Energy Center

## Experience:

Nakoso 250MW IGCC Plant

・ Nakoso 250MW IGCC Demonstration Plant achieved all the targets set forth in Japan.

✓Excellent Performance
(The Highest Efficiency,The Least Environmental Impact)

✓Higher Reliability
(The World Record of continuous operation)

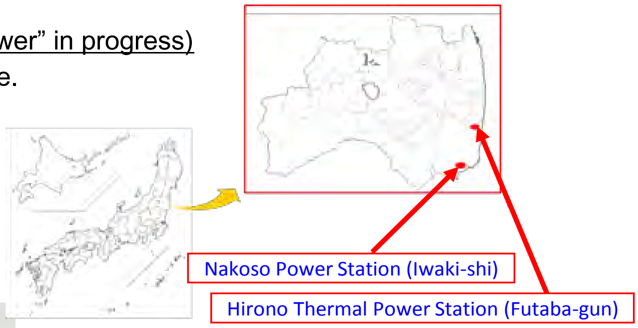
✓Fine Operability
(Load ramping rate @ 3%/min)
(Minimum stable load @ 36%)

✓Fuel Flexibility
(Verified applicability to LRC)


・ The plant, quickly recovered from the Great East Japan Earthquake in about 4 months, was converted to the First Commercial IGCC Plant in Japan as Nakoso #10 owned by Joban Joint Power Co., having started operation in the summer of 2013. Its total operating hours exceeded 32,000 hrs.

IGCC Commercial Plants (“Fukushima Revitalization Power” in progress)

・ High efficiency by using the state of the art Gas Turbine.
・ Lower CO2 emission intensity than the latest USC (Ultra Super-critical) coal fired power plant.
・ Fuel flexibility for high moisture LRC.
・ Highly reliable system verified in the 250MW IGCC plant.





***Principal Specification***

| | | |
|---|---|---|
| *Output* | *540 MW (gross) ×2*<br>*480 MW (net) ×2* | |
| *Gasifier* | *Air-blown Dry Feed* | |
| *Gas Clean-Up* | *Wet MDEA* | |
| *Gas Turbine* | *M701F GT (1 on 1)* | |
| *Plant Efficiency* | *48% (LHV)* | |
| *Project Schedule* | | |
| *EIA (Started)* | | *2014. 5* |
| *Site Mobilization* | *(Scheduled)* | *2016.10* |
| *COD (Scheduled)* | *Nakoso :* | *2020. 9* |
| | *Hirono :* | *2021. 9* |

MITSUBISHI HITACHI POWER SYSTEMS

JCOAL Japan Coal Energy Center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IHI

JCOAL Japan Coal Energy Center

# Flue Gas Treatment System

## Abstract of Product /Technology

IHI Integrated Flue Gas Treatment System based on Rich Experience on DeNOx and FGD (Flue Gas Desulfurization) System can comply extremely low emission requirements in Japan.
IHI has plentiful knowledge of all properties on any flue gas as the leading boiler manufacturers, and the state-of-the-art technology, especially Low-Low Temp. ESP System / Non-leakage type GGH can respond to severe environmental regulation.

■ Gas Flow Diagram

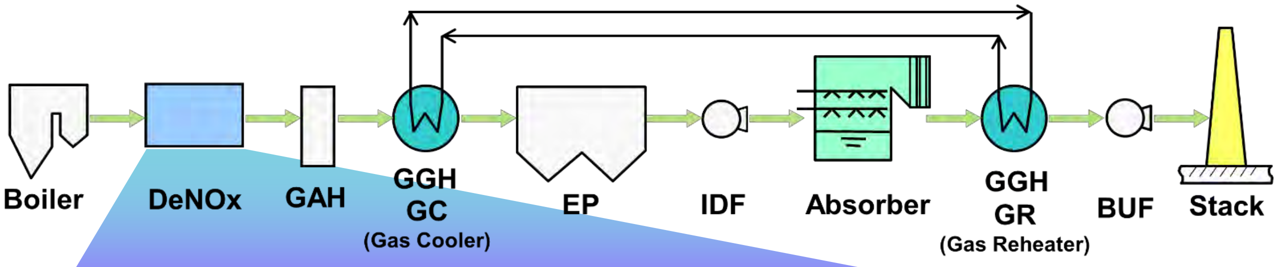
To meet the severe and various requirements, the following Selective Catalytic Reduction (SCR) Process for DeNOx and Low-Low Temp. ESP system can be proposed as proven technology.

■ Low-Low ESP system of the Largest Class in the world

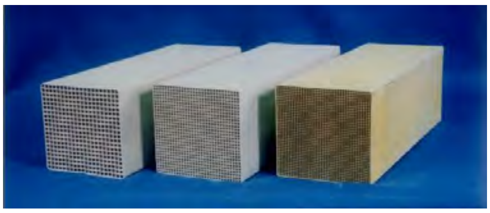
The largest Flue Gas Treatment System using Low-Low temp. ESP System for Tokyo Electric Power Company Hitachinaka Power Plant No.1 Unit (1,000MW) has been taken over on December 2003.

■ DeNOx System (Selective Catalytic Reduction Process)

To achieve the high de-nox efficiency, reliable and high performance Catalyst will be selected and DeNOx system can be established in coordinated with boiler and auxiliary facilities.



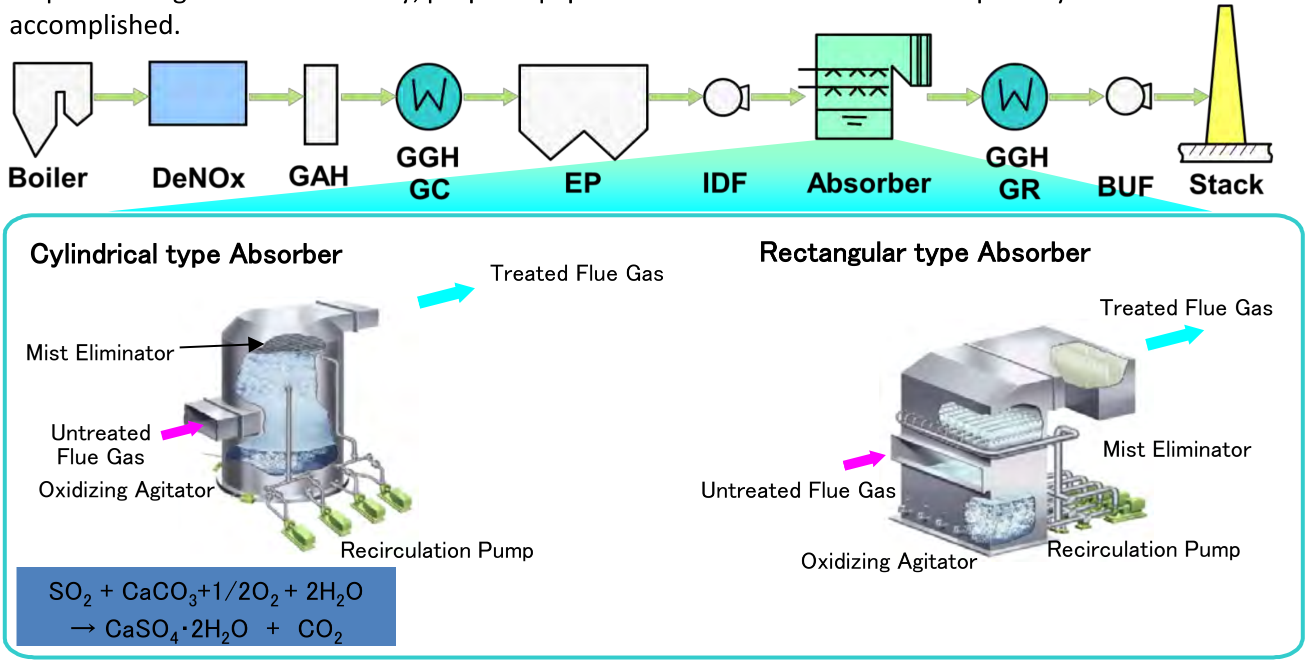

While ammonia is added to flue gas at an appropriated temperature and the flue gas is led through the catalyst bed, nitrogen oxides (NOx) are decomposed into harmless nitrogen (N2) and water (H2O).



$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$
$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$

■ Wet type FGD System (Limestone – Gypsum Process and other Alkaline Processes)

To perform high De-Sox efficiency, proper equipment has been selected and compact layout can be accomplished.



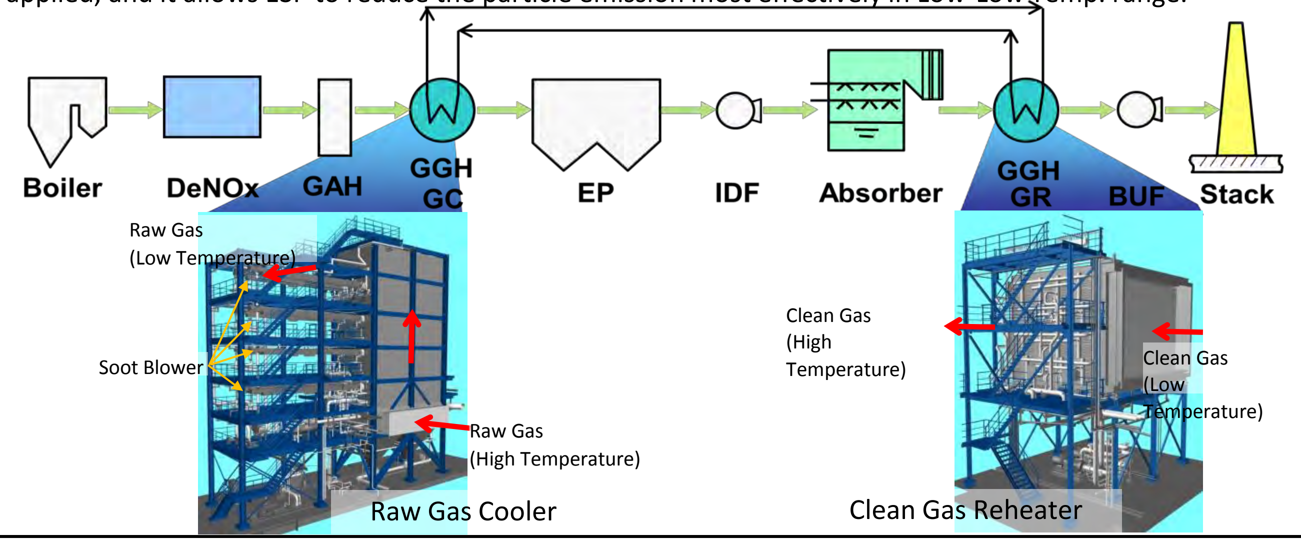

$$SO_2 + CaCO_3 + 1/2O_2 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O + CO_2$$

<Features>

- ●Simultaneous treatment of desulfurizing, dedusting and oxidizing in one absorber
- ●Large capacity treatment by single absorber up to equivalent of 1000MW unit
- ●Selection of absorber type (Cylindrical or Rectangular) suitable for compact layout.
- ●Easy maintenance due to simple configuration
- ●Low running cost due to lower pressure loss
- ●Speedy follow-up for load change due to changeable spraying slurry flow rate

■ Non-Leakage type Gas-Gas Heater (GGH)

To prevent the particle leakage and utilize the Hot Flue Gas at the most, Non-Leakage GGH system can be applied, and it allows ESP to reduce the particle emission most effectively in Low-Low Temp. range.



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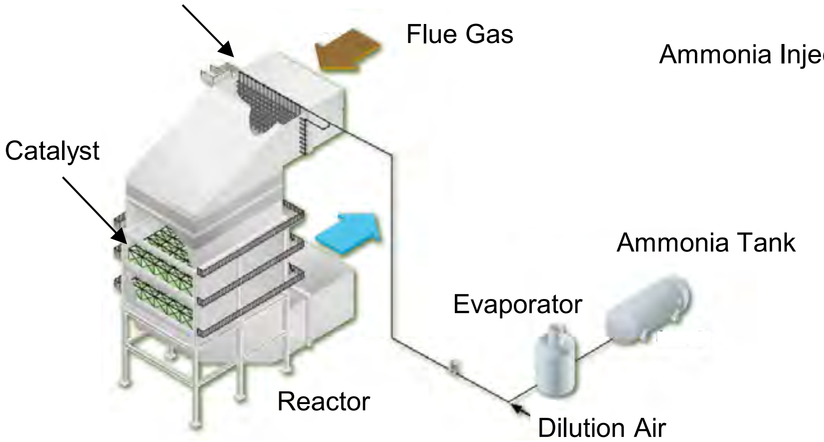
# SCR System

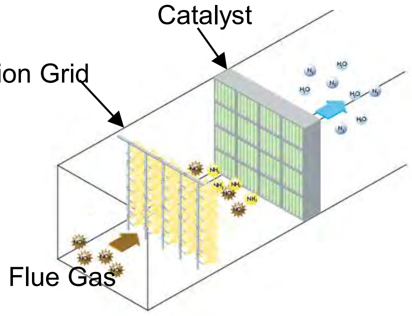
## Abstract of Product /Technology

SCR (Selective Catalytic Reduction) system reduces nitrogen oxides ($NO_X$) in the flue gas from fossil fuel combustion boiler into harmless nitrogen and water vapor through the catalyst.
Mitsubishi Hitachi Power Systems (MHPS) is a pioneer of SCR technology and is distributing honeycomb and plate catalyst. On both type of catalyst, MHPS has the largest market share in the world and we contribute to global environmental conservation.

## Detail introduction of Product/Technology

SCR system consists of reactor, catalysts, ammonia injection system etc. and generally installed between economizer and air preheater. Ammonia is injected upstream the catalyst and reacts with nitrogen oxides on the surface of the catalyst, then nitrogen oxides are decomposed into hamless gas.




Reaction Formula

$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$

$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$

$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$

Catalyst type is selected based on flue gas condition. Best selection of catalyst provides benefit on plant operation and maintenance costs. MHPS has own catalyst factory for plate type catalyst.

Honeycomb Type Catalyst

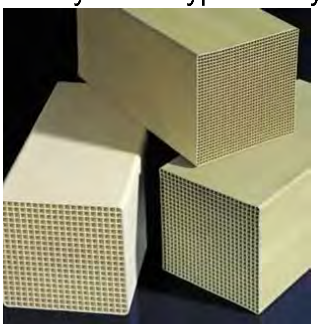
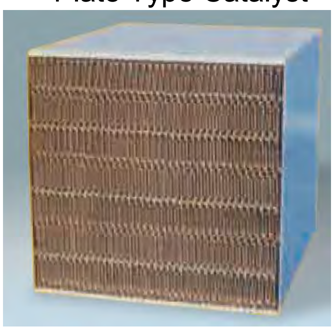


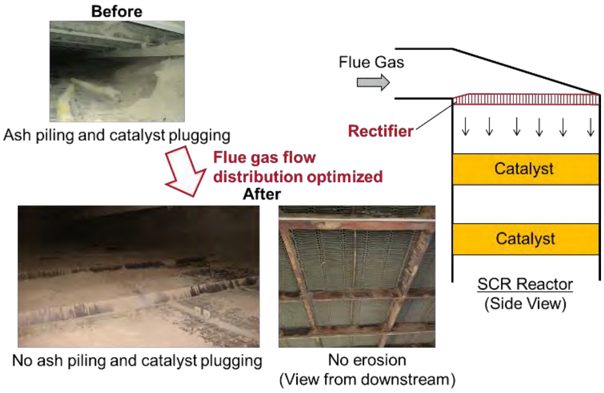
Plate Type Catalyst

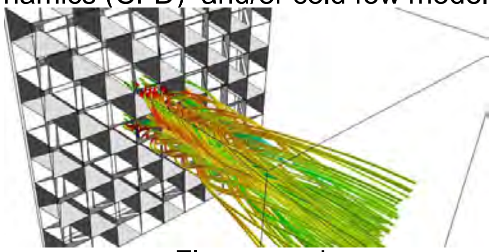


Advantage & Experience:

SCR design

The optimization of flue gas flow distribution and ammonia flow distribution are considered in the SCR design. By the optimization of flue gas flow and ammonia flow distribution, ash plugging and erosion of catalyst are mitigated, and catalyst performance are improved. Flue gas flow and ammonia distribution shall be verified and optimized by computerized fluid dynamics (CFD) and/or cold fow model test.



Flue gas mixer

Flue gas mixer generates turbulence to obtain better mixture of flue gas and ammonia.

The installation of flue gas mixer improves $NH_3/NO_X$ molar ratio unbalance and achieves high $DeNO_X$ efficiency.

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MITSUBISHI HITACHI POWER SYSTEMS ENVIRONMENTAL SOLUTIONS

JCOAL Japan Coal Energy Center

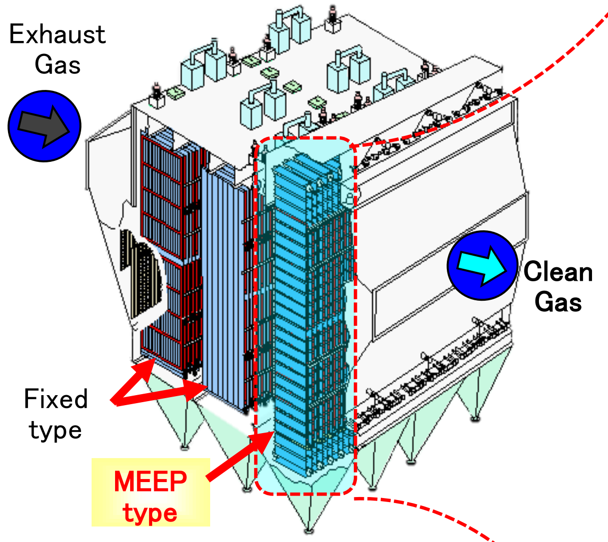
# Moving Electrode type Electrostatic Precipitator (MEEP)

## Abstract of Product /Technology

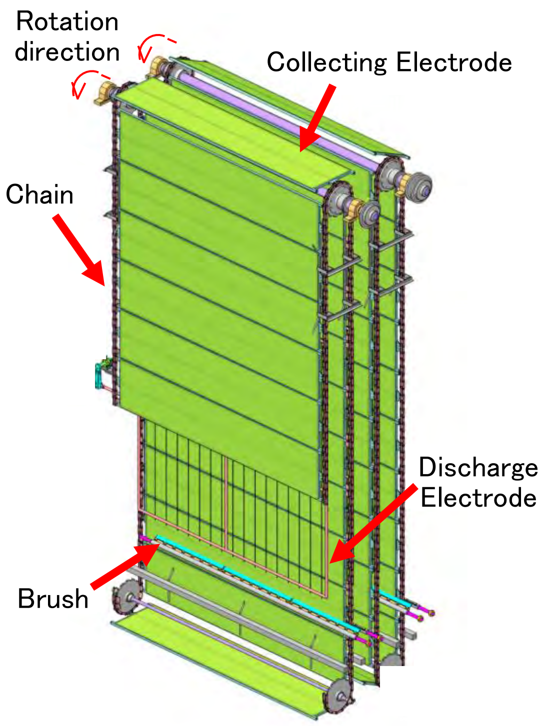
Electric resistivity, one of the characteristics specific to dust, exerts influences on the performance of electrostatic precipitators (ESP). In collecting high resistivity dust, especially that of greater than $10^{11}\Omega$cm, the conventional ESP (fixed electrode type) becomes tightly covered with layers of dust deposit.

Further operation of the ESP without removing the deposit retrogrades its collection performance remarkably, because the deposit tends to develop high resistivity and the back corona ionization problems, which will in turn cause the corona current at the discharge electrode become abated and the dielectric strength of the adhesive dust become broken down. "Hitachi Moving Electrode Type Electrostatic Precipitator" embodies a new system to separate the dust deposit by both the moving type electrode and the brush mechanism. And we have made it possible to realize down-sizing of the precipitator itself as well as the effective collection of high resistivity dust in the Dry Type ESP.

## Detail introduction of Product/Technology




*Overview of ESP*




*Detail of MEEP structure*

The right figure shows the MEEP structure. MEEP shall be generally adopted for the final field of ESP. MEEP collecting electrode Plate comprised of rectangular strips is driven by means of a chain wheel very slowly toward the bottom roller. The collected dust shall be scraped off by Means of two brushes just before it re-enters the collection zone.

Advantage & Experience:

***Advantage:***

(1) High collecting efficiency

- Because of the complete dust (including "High electric resistivity" and "Fine particlate" dust) removal from the surface of the MEEP collecting electrode plate, those can keep the clean surface condition therefore the high collecting efficiency can be kept.
- Dust scraping shall be executed the out of collecting zone, therefore the high collecting efficiency can be realized without the dust re-scattering influence.

(2) Saving the space and energy

- Because of the high collecting efficiency, the ESP size can be downsized, moreover saved the power consumption.

***Experience:***

| Application | Quantity | Year |
|---|---|---|
| Coal Fired Boiler | 38 | 1981～ |
| Steel Plant (Sinter Machine) | 9 | 1991～ |
| Non-Steel Plant | 2 | 1991～ |
| Glass melting Furnace | 2 | 1982～ |
| Cement Kiln | 2 | 1989～ |
| Sewage Sludge Treatment | 5 | 1982～ |
| Oil (FCC) | 2 | 1979～ |
| Total | 60 | |

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Remarks

Wet Limestone-Gypsum
Flue Gas Desulphurization(FGD) System

## Abstract of Product /Technology

In the early 1960s, before other commercial enterprises got on the bandwagon, Mitsubishi Hitachi Power Systems (MHPS) began developing Flue Gas Desulfurization systems (FGD).
Our first commercial system went into operation in 1964. Then, as a result of continuous technical improvements, our FGD for 1,050 MW coal fired power plant, world's largest class started operation in 2000. FGD system technology of MHPS is contributing to the prevention of air pollution not only in Japan but also in European countries, the USA and Asian countries.

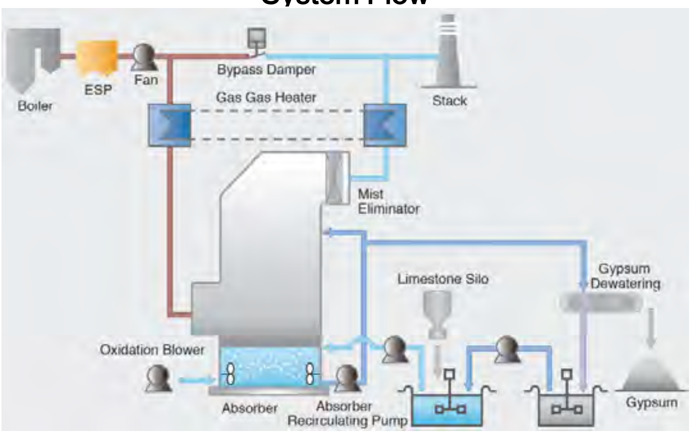
## Detail introduction of Product/Technology

MHPS's FGD system uses the advanced latest type of spray tower having combined three important functions; $SO_2$ removal, oxidation to gypsum and particulates removal. This advanced system requires less equipment, less space and fewer utilities than its predecessors.

**Wet Limestone-Gypsum FGD**

This process is suitable for large scale flue gas treatment and can use low cost absorbent (Limestone) and produce stable and valuable by-product (Gypsum).

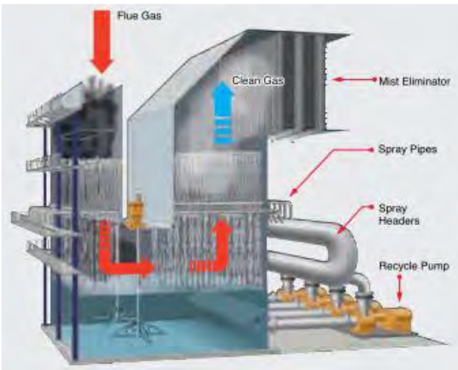
**System Flow**




**Absorber type**

**Double Contact Flow Scrubber**

Double-contact liquid columns (Rising up/Falling down) result in high performance and low L/G.
(L/G stands for ratio of liquid / gas flow rate)




**Spray Tower Scrubber**

Making fine liquid droplets by pressurized spray


**Chemical Principle of FGD**

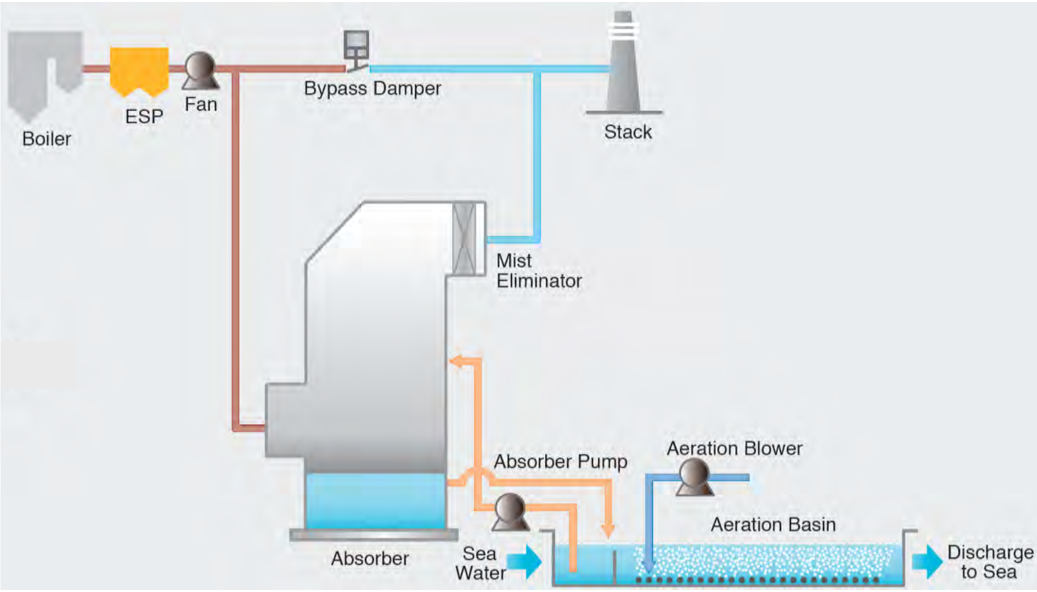
| $SO_2$ Absorption and Oxidation |
| --- |
| $SO_2+2H_2O+CaCO_3$ (Limestone) $+{}^1/{}_2O_2$ ▶▶▶ $CaSO_4 \cdot 2H_2O$ (Gypsum) $+CO_2$ |

Detail introduction of Product/Technology

## Seawater FGD Process

This process is very simple, requiring only Seawater and Air. (No additional chemicals, No by-products) And the same scrubber type of Wet Limestone-Gypsum FGD Process can be applied.

**System Flow**

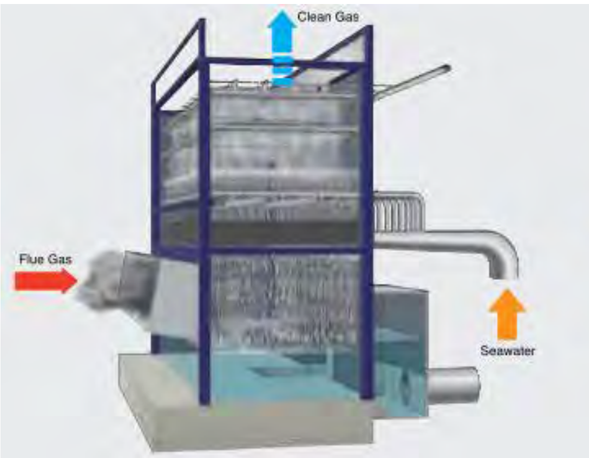


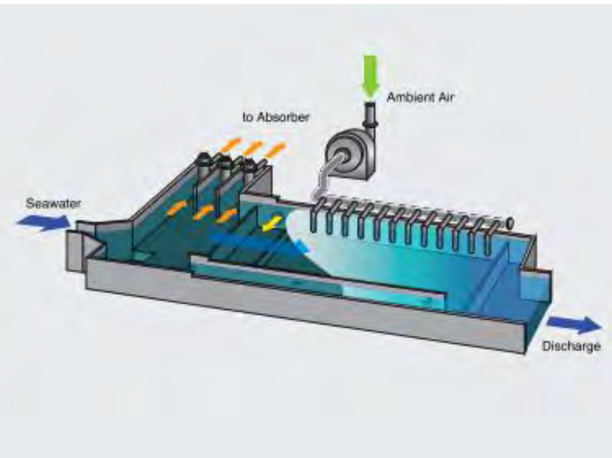

**Grid Packed Absorber**

Grid-packed absorber provides large gas-liquid contact area for efficient $SO_2$ absorption with a low gas pressure loss requirement and is suitable to handle a large amount of flue gas.

**Aeration Basin**

The purpose of this system is oxidation and neutralization of seawater which is treated to make it suitable for discharge to the sea.

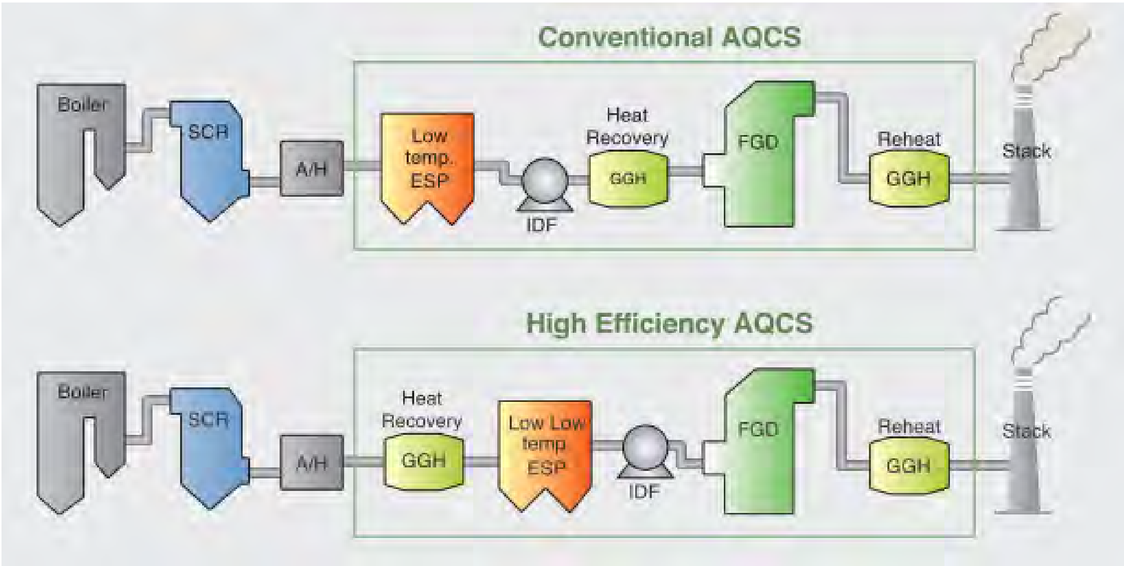


Detail introduction of Product/Technology

## Ultra Low Particulate Emission Control

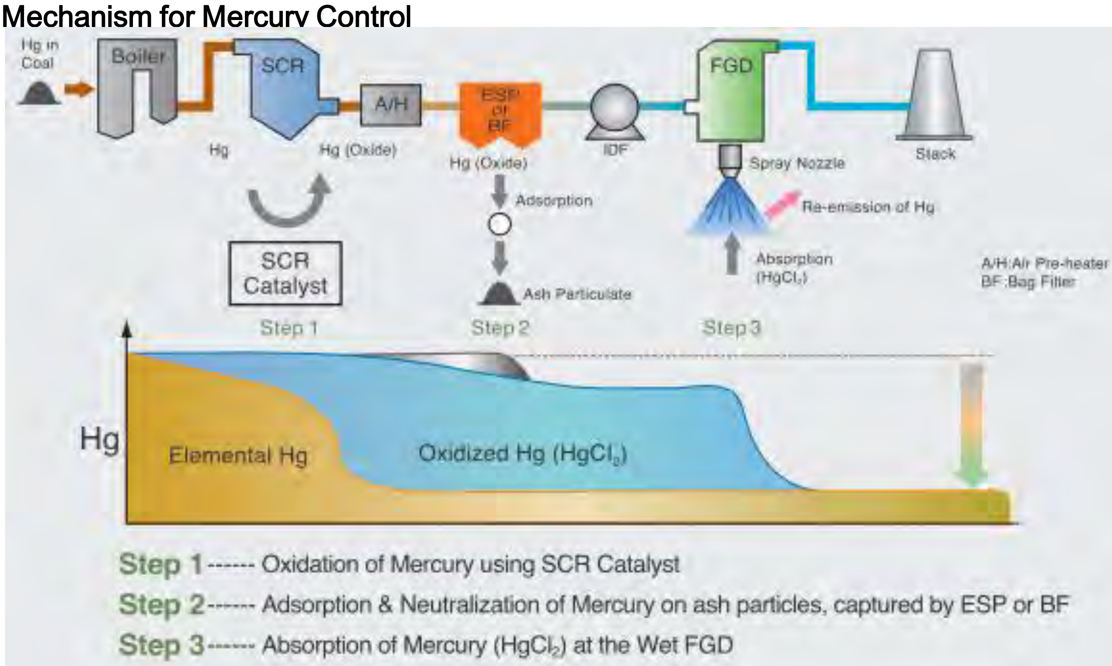
We developed a new flue gas treatment system consisting of ESP, FGD and non-leakage gas-gas heater (GGH), which realizes effective treatment of flue gas so that the system can keep particulate emission well within stringent regulations. "Furthermore, in such case as more stringent regulations being required in urban area, Wet ESP will be installed at the downstream of FGD"



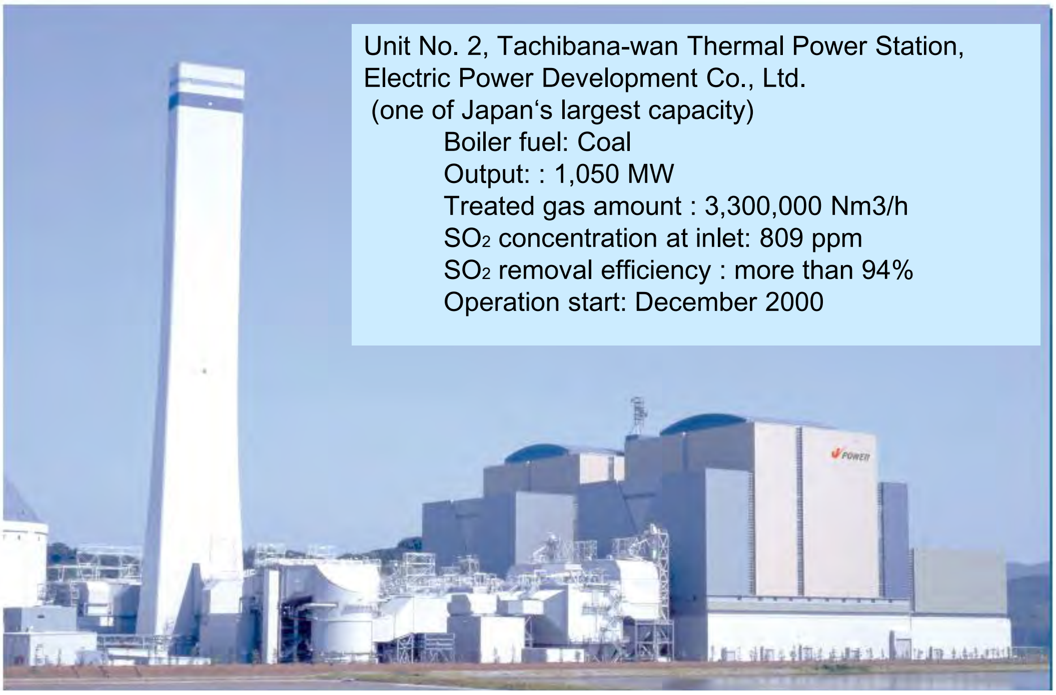

## Mercury Control in Total AQCS

We developed not only NOx, $SO_2$ , $SO_3$ , Particulate control technology but also Mercury (Hg) control technology to satisfy multiple pollutant control needs.

### Mechanism for Mercury Control



Advantage & Experience:



Unit No. 2, Tachibana-wan Thermal Power Station,
Electric Power Development Co., Ltd.
(one of Japan's largest capacity)

Boiler fuel: Coal
Output: : 1,050 MW
Treated gas amount : 3,300,000 Nm3/h
$SO_2$ concentration at inlet: 809 ppm
$SO_2$ removal efficiency : more than 94%
Operation start: December 2000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TSK TSUKISHIMA KIKAI

JCOAL Japan Coal Energy Center

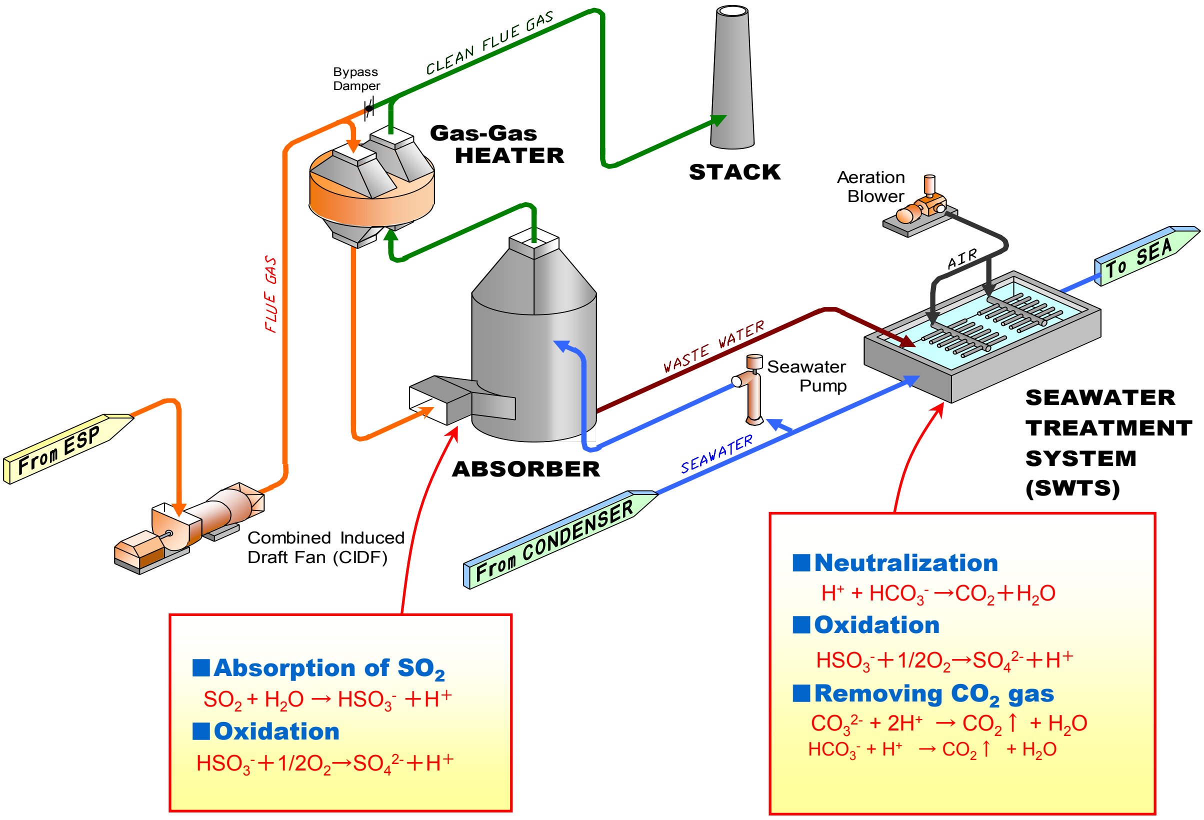
# Seawater Flue Gas Desulfurization System (SWFGD)

## Abstract of product / technology

Since establishment of Tsukishima Kikai Company Ltd. (TSK) in 1905, we have been continuing to develop our technologies to meet the needs of the times. TSK's SWFGD technology has been continuously improved with the rich experience gained from the plants built for the power producers of the world and excels in such aspects as low investment cost, high energy efficiency, easy operation + maintenance and environment friendliness.
TSK has now 27 installation records for SWFGD.

## Details of product / technology

In this SWFGD system, seawater is used as the absorbent, using alkalinity that is naturally rich in seawater. The SWFGD is suitably applicable when a large amount of seawater can be used as cooling water in coal fired power plants.




$SO_2$ is removed in the absorber where seawater and flue gas are contacting in a countercurrent flow. The effluent seawater from the absorber mixes with the fresh seawater and aerated in a latter Seawater Treatment System (SWTS). Generated sulfate through the SWFGD completely dissolves in seawater. Since its increase is quite slight compared to abundant amount of sulfate naturally exists in fresh seawater, there is no adverse effect against marine environment.

TSK TSUKISHIMA KIKAI

JCOAL Japan Coal Energy Center

## Advantage & Features:

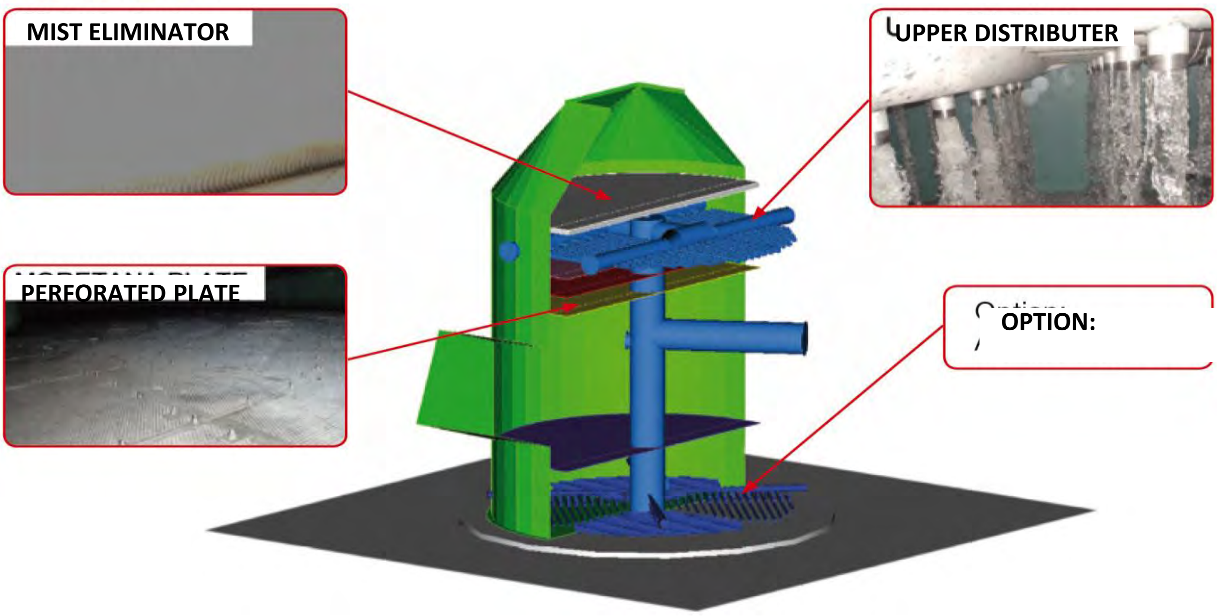
The SWFGD technology requires no by-product treatment and is highly cost competitiveness compared to a conventional lime-gypsum process.

- **No Chemical Absorbent (only seawater and air)**
- **No By-products**
- **No Material Handling System**
  For SWFGD, no material handling and lime handling facility are required.
- **No Clogging**
  It is very difficult to avold the clogging and scaling problem when the lime is used for the absorbent. To the contrary, seawater has no clogging problem.
- **Fewer Operator (during normal operation)**
  Due to the material handling (gypsum) and continuous lime charge, many operators for gypsum recovery plant is required.

## Process Comparison

| Item | Gypsum Recovery Process | Seawater Process |
|---|---|---|
| Absorbent | $CaCO_3$ | Seawater |
| By-Product | Gypsum | - |
| Initial Cost | ×1.0 | ×0.9 |
| Running Cost | ×1.0 | ×0.6 |
| Total Cost | 100% | 70% |

## Absorber



TSK TSUKISHIMA KIKAI

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Experience:

## TSK's SWFGD Actual Records

| Location | Contract Type | No. of Plant | Gas Flow Rate ($Nm^3$/hr/plant) | Constructed Year |
|---|---|---|---|---|
| Japan | EPC | 3 | 67,000 , 355,000 , 255,000 | 1978, 1979 |
| Thailand | EP+S/V | 1 | 280,000 (54MW/Plant) | 1994 |
| Taiwan | EP+S/V | 7 | 1,915,900 (600MW/Plant) | 1999 ~ 2002 |
| China | EP+S/V | 6 | 1,915,900 (600MW/Plant) | 1999 ~ 2004 |
| Thailand | EP+S/V | 2 | 2,246,800 (717MW/Plant) | 2007 |
| Mexico | EPC | 1 | 74,000 | 2008 |
| Thailand | EP+S/V | 1 | 280,000 (54MW/Plant) | 2013 |
| Morocco | EP+S/V | 2 | 1,021,000 (350MW/Plant) | 2013, 2014 |
| Norway | EP+S/V | 1 | 45,000 (16MW/Plant) | 2015 |
| Morocco | EP+S/V | 2 | 2,370,000 (693MW/Plant) | Under Construction |
| Vietnam | EP+S/V | 1 | 2,370,000 (688MW/Plant) | Under Construction |

350MW Power Plant in Morocco

54MW Power Plant in Thailand


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IHI Realize your dreams

JCOAL Japan Coal Energy Center

# Total Coal Handling System

Abstract of Product /Technology

Through our long experience provinding the coal handling equipment such as;
Ship Unloader, Stacker, Reclaimer, Conveyor System, Coal Storage System, Loader and other equipment and facilities, we have been providing the best total coordination for your coal yard.

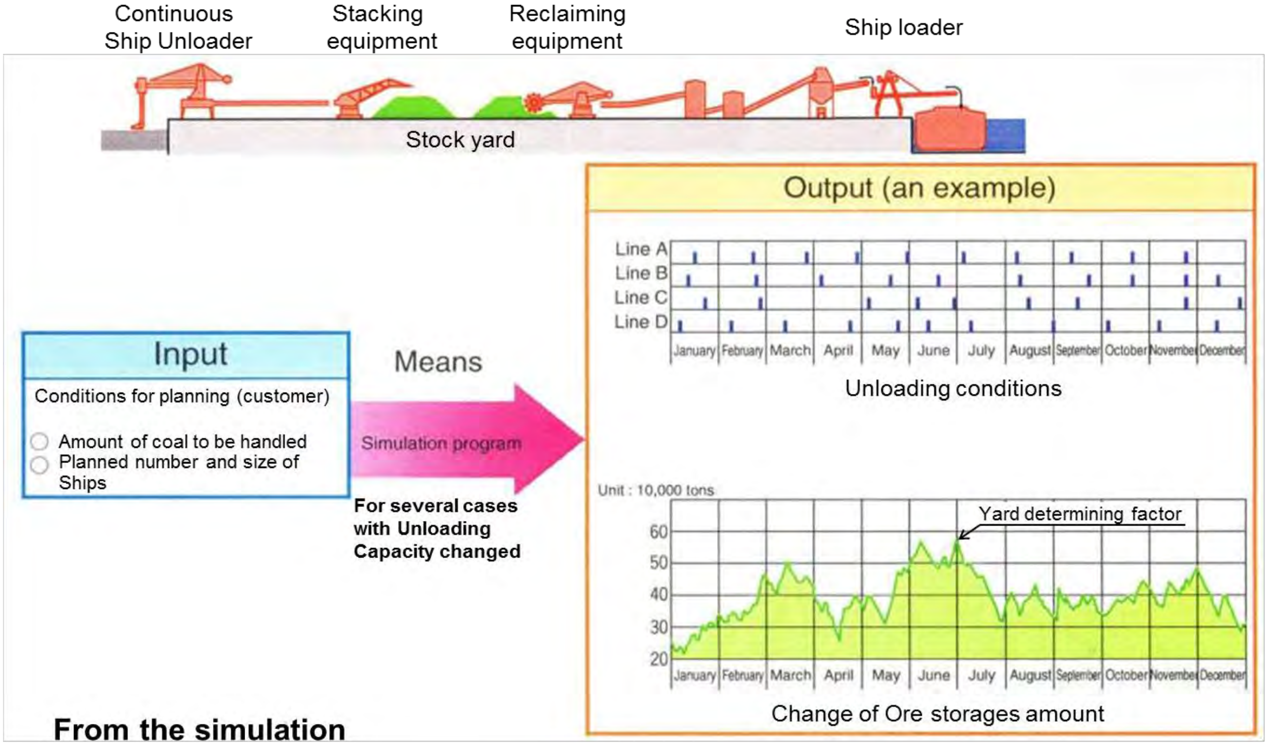
**IHI's Total Engineering for Coal Hanling System contribute to cost minimization and optimized coal handling for your long term port operation.**

Detail introduction of Product/Technology

**<Suitable Bulk Handling System for All Customers>**

**IHI provide the total engineering for the coal handling system through the simulation and detail engineering for the arragnement of the below facilities;**

- **Unloading Facilities (Ship Unloader)**
- **Storage Hacilities (Silo, Dome, Longer Building)**
- **Transport Facilities (Conveyor Sytstem)**
- **Shipping Facilities (Loader)**




## From the simulation

○The required unloading capacity will be selected to ensure adequate arrival and departure of the ship.
○The optimum coal storage amount will be selected to meet the terminal operation requirements.

IHI
Realize your dreams

JCOAL
Japan Coal Energy Center

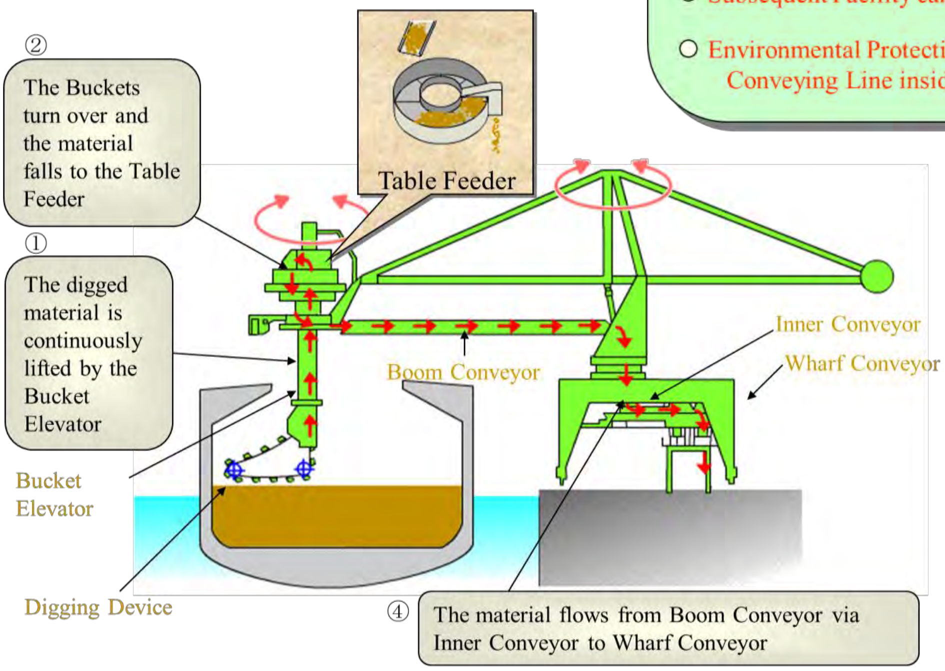
# Continuous Ship Unloader (CSU)

## Abstract of Product /Technology

IHI Countinuous Ship Unloader(CSU) was born in 1966. We have been providing the Continuous Ship Unloader as the World No. 1 Supplier.
High efficiency of the coal unloading realizes your ideal port operation in terms of the minimization of cost and unloading time. The CSU contribute to not only the cost and time saving but also environment by the fully covered path of bulk.
IHI CSU is the solution of bulk unloading.

## Detail introduction of Product/Technology


- High Unloading Efficiency of 70 - 80%
- No Need for High Skilled Operator
- Simple Operation using High Technology
- High Clean-up Efficiency greatly reduces Assistance of Bulldozer
- Energy Saving by Constant Volume Unloading
- Subsequent Facility can be Compact
- Environmental Protection by Fully Enclosed Conveying Line inside the Machine



Advantage & Experience:

**IHI has supported Bulk Handling in the world over a century and continues to do in next 100 years.**

**IHI provides not only equipment but also the best solution of bulk handling system and its reliability for your long year port operation.**

**<u>IHI Product Line up</u>**

- **Continuous Ship Unloader (CSU)**
- **Bridge Type Ship Unloader**
- **Mobile Multi-Purpose Crane**
- **Stacker**
- **Reclaimer**
- **Stacker-Reclaimer**
- **Conveyor**
- **Ship Loader**

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Remarks

OKINOYAMA COAL CENTER UBE INDUSTRIES

Ube Industries, originally a coal mining company, has been utilizing coal for a long time as a reliable energy source and raw material for chemicals.
In October 1980, after the second oil crisis, Ube Industries constructed Okinoyama Coal Center at a vast reclaimed land in Ube city,Yamaguchi prefecture, and commenced its operation as a distribution center of imported coal from around the world.

## Details of product / technology


courtesy of UBE INDUSTRIES, LTD.

Okinoyama Coal Center is the largest coal center in Japan,and can handle 7.3 million tons of coal annually. It has No.1 and No.2 storage yards,and its coal storage capacity is two million tons in total.

courtesy of UBE INDUSTRIES, LTD.

UBE

JCOAL
Japan Coal Energy Center

## TECHNICAL INFORMATION

Handling Capacity:
7.3 million tons per annum

Storage Capacity
- No.1 storage yard: 1.1 million tons
- No.2 storage yard: 1.15 million tons
- Nishioki storage yard: 0.55 million tons

Characteristics of the port and berth
- Maximum size of vessel: 90,000 DWT
- Channel Width: 250m
- Channel Depth: −11m
- Berth Depth: −14m
- Berth Length: 325m

Equipment
- No.1 Unloader (Bucket type): 2,000 t/h 1set
- No.2 Unloader (Bucket type): 2,200 t/h 1set
- Conveyor Line (Receiving): 3,600 t/h
  (Discharging): 1,300 t/h
- Stacker: 3,600 t/h 2sets
- Reclaimer: 1,000 t/h 2sets
- Stack/reclaimer: 3,600/1,300 t/h 1set
- Ship Loader: 1,300 t/h 2sets
- Truck Hopper: 200 t 3sets
- Blending and Screening Facility: 500 t/h 1set

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Remarks

KOBELCO
-Upgrading the Future-

JCOAL
Japan Coal Energy Center

# UBC® (Upgraded Brown Coal) Process

## Abstract of product / technology

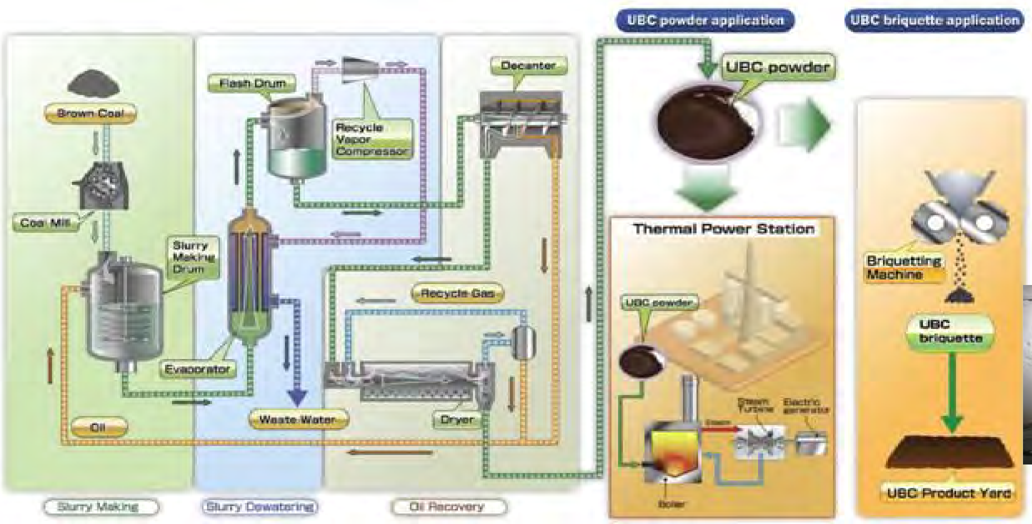
UBC® (Upgraded Brown Coal) technology has been developed in order to dewater low rank coal and increase the calorific value of it. UBC® process is based on the principle of "tempura (Japanese battered deep-fried food)" and efficiently removes the water contained in low rank coal in heated light oil. There are two kinds of applications, namely; 1) UBC Briquette for transportation, 2)UBC Powder for UBC based power generation.

## Details of product / technology

By reducing the moisture in lignite, Kobe Steel's UBC Process increases the calorific value, thereby converting the lignite into high - grade energy resources.

UBC Process uses light oil as a dewatering agent. UBC process includes crushing low rank coal, dispersing the crushed coal in light oil and dewatering the dispersion at a temperature of 130 to 160℃ under a pressure of 400 to 450 kPa. Moisture content of lignite over 60% can be reduced to the 8% level with no reabsorption of water. Dewatered UBC has a heat value of 6,000kcal/kg(AR) level.
The briquettes of UBC can be shipped overseas without spontaneous combustion. UBC produced by the demonstration plant has been transported and test-used at three different commercially operated power stations, once at Kobe Steel’s steel works and twice at third parties’ power stations.

On the other hand UBC right after dewatered is powder shape and its moisture content is 0%.
Feeding the UBC powder directly into the high efficiency boiler such as Ultra Super Critical boiler which is to be built adjacent to UBC plant enables the high efficiency power generation at lignite mine site and to reduce $CO_2$ emission. Testing to collect data for design of UBC-fired Ultra Super Critical boiler has been conducted successfully with testing facility of boiler manufacturer.





<Discharging operation in Japan>


<Boiler test in Japan>

KOBELCO
-Upgrading the Future-

JCOAL
Japan Coal Energy Center

Features, advantages & experience:

The unique and innovative UBC Process was developed by Kobe Steel, LTD. with the support of both the Japanese and tekMIRA of Indonesian governments. The 600t/day Demonstration Plant has been operated for two years at Satui, South Kalimantan, Indonesia in order to confirm the process and operation cost in corporation with PT Bumi Resources Tbk and its coal subsidiary PT Arutomin Indonesia.

The UBC process gives heat value and monetary value to unutilized high moisture lignite. UBC process upgrades the future for both mine owners and coal users all over the world.

Dewatering and Increasing Calorific Value

- 60% moisture coal can be dewatered to 0% as powder and 8% level as briquette
- CV increases to 6,000kcal/kg level

Stabilizing

- Prevention of spontaneous combustion

Exportable Briquettes

- Waterproof
- Good combustibility

**Lignite & UBC spec.**

| | | Coal (Indonesian Lignites) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Type A | | Type B | | Type C | |
| | | Raw | UBC | Raw | UBC | Raw | UBC |
| Moisture | wt% ar | 33.6 | <10 | 34.0 | <10 | 60.5 | <10 |
| Heating Value | kcal/kg | 4,460 | 6,380 | 4,200 | 5,810 | 2,328 | 6,020 |
| Ash | wt%db | 2.5 | 2.7 | 4.6 | 4.6 | 7.7 | 7.8 |
| Volatile Matter | wt%db | 51.2 | 52.5 | 48.5 | 50.9 | 43.3 | 47.3 |
| Fixed Carbon | wt%db | 46.3 | 44.8 | 46.9 | 44.5 | 34.2 | 38.6 |
| Sulfur | wt%db | 0.48 | 0.49 | 0.17 | 0.19 | 0.26 | 0.27 |

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Remarks

# JGC Coal Fuel (JCF®)

・ JCF® Process is a unique process for producing slurry fuel from low rank coals, which overcomes coal's handling disadvantage as a solid and enables easier handling, like fuel oil, with convenience in storage, transportation and combustion.

・ Slurry fuel produced by JCF® Process is a mixture of powdered coal and water with a small amount of additive, which maintains a stable state over a long period.

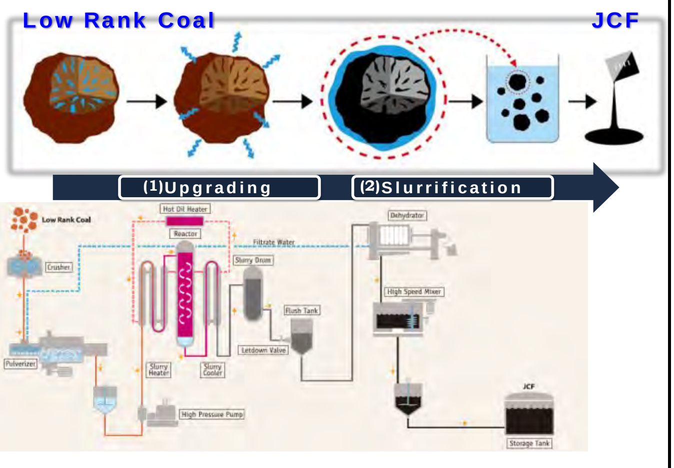
## ●Technology

Coal is formed from plant biomass through hundreds of millions of years of exposure to heat and pressure, deep underground. The JCF process artificially accelerates the natural coalification process, using HWT (Hot Water Treating) Upgrading Technology.

## ●Process

(1) Upgrading (HWT)

When LRC (Low Rank Coal) is immersed in high-temperature, high-pressure water (15 MPa at 330 °C), its properties change from hydrophilic to hydrophobic, and the water held in numerous pockets within LRC is expelled. At the same time, some of the LRC undergoes a reaction and breaks up to form tar which fills the pockets, preventing the water from seeping back in while simultaneously increasing the caloric value of the coal.




(2) Slurrification

With the addition of special additives, the water expelled from LRC can be used to convert the newly upgraded LRC into slurry, which is composed of small solid particles suspended in a liquid and which has fluid-like properties.

With Upgrading and Slurrification, LRC is transformed into JCF – removing the disadvantages inherent in LRC. JCF coal slurry can be handled just as if it were heavy oil (Marine Fuel Oil, MFO), with storage tanks and pipeline transportation adopted.

## ●JCF® Properties

| | |
|---|---|
| Calorific Value (HHV) | 3,800 – 4,500 kcal/kg |
| Coal Concentration | 58 – 65 % |
| Density | 1.2 |
| Viscosity (25℃) | < 1,200 cp |
| Mean Particle Size | 20 µm |

JGC CORPORATION

JCOAL Japan Coal Energy Center

**●Features**

- Transportable by tanker or pipeline
- Smaller area for a coal storage yard and dust free
- Permits spray combustion, like fuel oil, and a good load response to boiler load operability
- Not spontaneously combustible; not flammable

**●Advantages**

- Usage of un-utilized coal (LRC)
- Substitute boiler fuel as a coal or fuel oil

**●Experience**

- Demonstration plant (to be updated)

JCF Production Plant (10,000 t-JCF/y) over 7,500 hrs

JCF Fired Power Plant (700 kw) over 3,000 hrs

**Demonstration Plant**

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Remarks

WATER TREATMENT TECHNOLOGY

## 1. Necessity of Water Treatment for Boilers

Waters used as boiler feedwater, such as tap water, industrial water, underground water and river water, usually contain various substances such as suspended solids, dissolved solids and gases. The amounts of these substances vary largely depending on the sources of raw waters, as shown in Table 1.

**Table 1 Examples of raw water qualities**

| Water source | River | | | | Lake | | Well | |
|---|---|---|---|---|---|---|---|---|
| Location | Osaka, Japan | Seria, Burunei | Shanghai, China | Bratislava, Slovakia | Perth, Australia | Kaohsiung, Taiwan | Milano, Italy | Jakarta, Indonesia |
| pH | 7.0 | 5.3 | 8.1 | 8.1 | 6.8 | 8.0 | 7.6 | 8.4 |
| Electrical conductivity (μS/cm) | 175 | 28 | 490 | 361 | 453 | 299 | 260 | 529 |
| M-alkalinity (mg $CaCO_3$/l) | 52 | 1 | 92 | 161 | 31 | 120 | 142 | 296 |
| Total hardness (mg $CaCO_3$/l) | 44 | 8 | 16 | 230 | 76 | 150 | 190 | 24 |
| Ca-hardness (mg $CaCO_3$/l) | 34 | 1 | 100 | 172 | 43 | 100 | 130 | 5 |
| Chloride ion (mg/l) | 23 | 1 | 81 | 22 | 124 | 2 | 17 | 5 |
| Sulfate ion (mg/l) | 33 | 7 | 41 | 39 | 23 | 45 | — | — |
| Silica (mg $SiO_2$/l) | 20 | 6 | 7 | 9 | 9 | 7 | 25 | 13 |
| Total iron (mg Fe/l) | < 0.2 | 4.0 | 3.7 | 0.47 | < 0.1 | 0.25 | 0.1 | — |

The use of such raw water without the pretreatment may result in problems, such as scale, corrosion and carryover, in boilers and the auxiliary equipments.
Table 2 shows the troubles in boiler operation caused by water.

**Table 2 Troubles in the operation of boiler systemus and their causes**

| Classification of problems | Troubles in operation of boiler system | Causes of troubles |
|---|---|---|
| Scaling | Reduction of boiler efficiency by adhesion of hardness or silica scale<br>Expansion or bursting of evaporation tubes by heavy scale adhesion | Leakage of hardness and/or silica from softener or demineralizer<br>Inadequate quality control of feedwater or boiler water<br>Application of inadequate chemical treatment |
| Corrosion | Corrosion damage of pipings of feedwater and condensate, evaporation tube, etc., by dissolved oxygen and/or carbon dioxide<br>Corrosion damage of evaporation tube under deposition of metal oxides | Insufficient deaeration of feedwater<br>Reduction of boiler water or condensate pH<br>Iron contamination of feedwater from condensate line<br>Oxygen incoming to boiler during the idle time |
| Carryover | Reduction of steam purity<br>Reduction of turbine efficiency by silica scale<br>Deterioration of product quality treated with the steam | Rapid fluctuation of boiler operation load<br>Excess concentration of boiler water<br>Boiler water contamination with organic matters |

Most of low pressure boilers use raw water or softened water as the feedwater and usually no deaerator is employed. Therefore, those boilers are subject to troubles such as hardness and silica scale adhesion, corrosion due to dissolved oxygen and corrosion by carbon dioxide in the condensate line.
Medium or high pressure boilers* are generally supplied deaerated and demineralized water as the feedwater. However, since they are operated at the high temperature and high pressure, the presence of a small amount of impurities causes problems, such as metal oxide deposits on the heating surface of the boiler, the corrosion of the auxiliary equipments, and scale adhesion in the superheaters or on turbine blades.
In order to prevent these problems and to operate the boilers safely and efficiently, the application of suitable water treatment is required for each boiler. The water treatment for boilers is divided into the external (mechanical) and internal (chemical) treatment. The mechanical treatment is to remove the impurities in water by applying coagulation, sedimentation, filtration, ion exchange, deaeration treatments, etc.
The chemical treatment is divided into the treatment for the feedwater and condensate lines, and for the boiler itself.
The chemical treatment for the feedwater and condensate lines aims to control corrosion by adding oxygen scavengers and corrosion inhibitors to the lines, and to supply water containing as little impurities as possible into the boiler. Boiler compounds, oxygen scavengers, sludge dispersants and so on are used for the chemical treatment of boilers. Those chemicals prevent corrosion and make the scale forming components the water insoluble and dispersed particles to discharge them from the boiler with the blowdown water.
Those water treatments are indispensable for operating boilers safely and efficiently.

## 2. Internal Boiler Water Treatment

Even if the external boiler water treatment is employed, it is difficult to perfectly prevent the boiler water contamination with substances which cause the corrosion and scale problems.
Boiler water treatment chemicals are used for protecting whole boiler systems including the feedwater and the steam condensate line from those problems.

## 3. Kinds of Boiler Treatment Chemicals and Their Functions

The kinds, functions and typical chemical names of boiler treatment chemicals are summarized in Table 3
The main purposes of these chemical application are as follows:

1 The scaling components are converted to the suspended fine sludge so as to be easily discharged from boiler with blowdown water to prevent the scale formation on the heating surface of boilers.

2 The pH of boiler water is maintained in an adequate alkaline range to prevent the corrosion and silica scale formation by keeping silica in the water soluble form.

3 Dissolved oxygen is removed from feedwater and boiler water to prevent the corrosion.

4 The pH of condensate is kept in an appropriate range to prevent the corrosion of condensate line by oxygen and carbon dioxide.

5 Prevention of carryover problems.
The quality control criteria of boiler water have been established to attain these purposes. These chemicals show the insufficient effects if the application conditions are inadequate. Therefore, the sufficient attention must be paid for the chemical injection control and the quality control of feedwater and boiler water.

Table 3 Kinds, functions and typical names ob boiler treatment chemicals

| Kind | Function | Chemical name |
|---|---|---|
| Alkalinity and pH control agents | Control of the pH and alkalinity of feedwater and boiler water to prevent corrosion and scaling | Sodium hydroxide<br>Sodium carbonate<br>Sodium phosphates<br>Sodium polyphosphates<br>Phosphoric acid |
| Scale inhibitors | Scale control by converting the hardness components in boiler water to insoluble precipitates to discharge from system with blowdown water | Sodium hydroxide<br>Sodium phosphates<br>Sodium polyphosphates<br>Potassium phosphates |
| Sludge dispersants | Dispersion of suspended solids in boiler water so as to be easily discharged by blowdown to prevent the scaling | Synthetic polymers<br>Tannins<br>Sodium lignin sulfonates<br>Starches |
| Oxygen scavengers | Removal of dissolved oxygen from feedwater and boiler water to prevent corrosion | Sodium sulfite<br>Hydrazine<br>Saccharides<br>Tannins<br>Amines<br>Polyphenols |
| Antifoaming agents | Prevention of foaming of boiler water for preventing carryover problems | Surfactants |
| Corrosion inhibitors for condensate line | pH control of condensate and protective film formation to prevent corrosion | Ammonia<br>Morpholine<br>Cyclohexylamine<br>Alkylamines<br>Hydroxyl amines |

**4. Management of boiler water treatment**

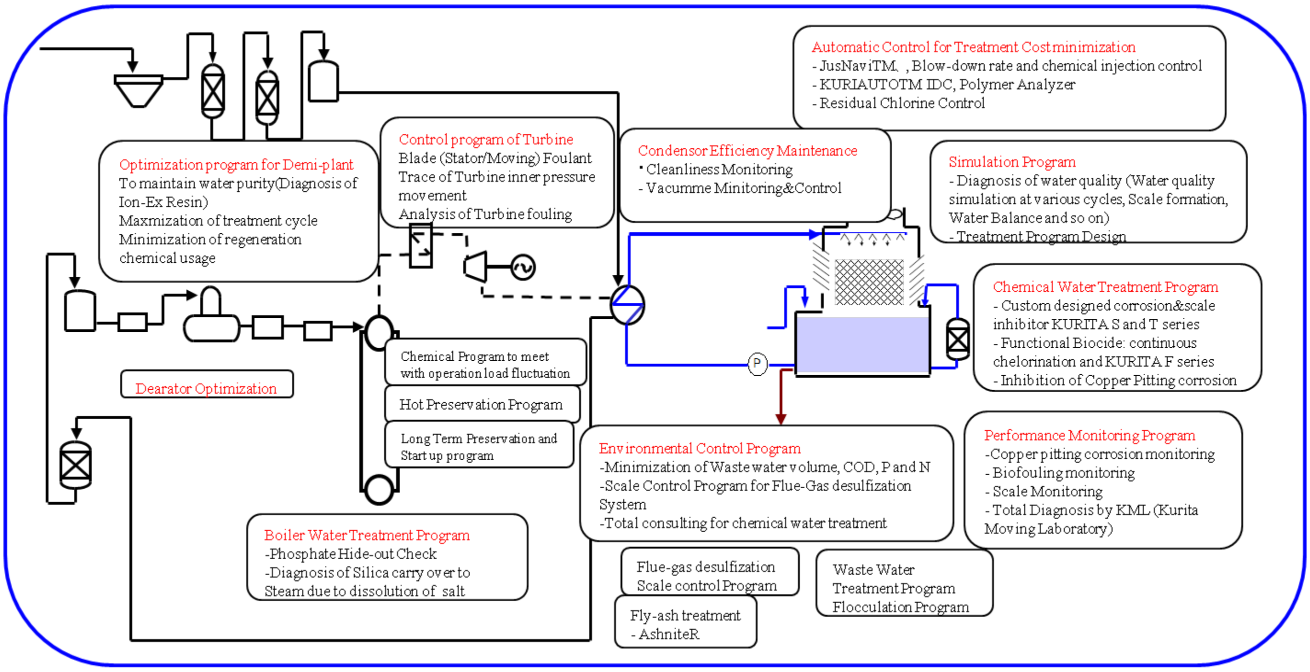
Kurita can serve for boiler water treatment as below,

1 Determination of the control ranges of feedwater and boiler water qualities according to the structure, pressure and so on of an aimed boiler,

2 Selection of a suitable water treatment method, blowdown method, chemical injection method, etc., to maintain the target water qualities,

3 Monitoring of the water qualities and the treatment effects by the water analyses, etc., and an improvement of the operation control method if necessary.

Advantage & Experience:
KURITA can serve total consulting service for power plants.

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Remarks

Kawasaki Powering your potential

JCOAL Japan Coal Energy Center

# Kawasaki ASH HANDLING SYSTEMS

Abstract of Product /Technology

Kawaswaki can supply the following systems.

**【BOTTOM ASH SYSTEMS】**

1.Dry Bottom Ash Handling System

2.SCC System

3.Hydraulic Systm

**【FLY ASH SYSTEMS】**

Dilute Phase Conveying System

1. Negative Pressure System
2. Positive Pressure System
3. Combination System

In the following section, we introduce ″Dry Bottom Ash Handling System (latest technology)″ and ″Dilute Phase Conveying System″ .

Detail introduction of Product/Technology

**【BOTTOM ASH SYSTEMS】**

Dry Bottom Ash Handling System

The Magaldi Ash Cooler (the MAC) is a dry ash mechanical transport system using air for cooling and no water developed by Magaldi Co. in Italy. This system consists of an ash hopper, a heat-resistant stainless steel belt in an airtight housing and a primaly crusher.

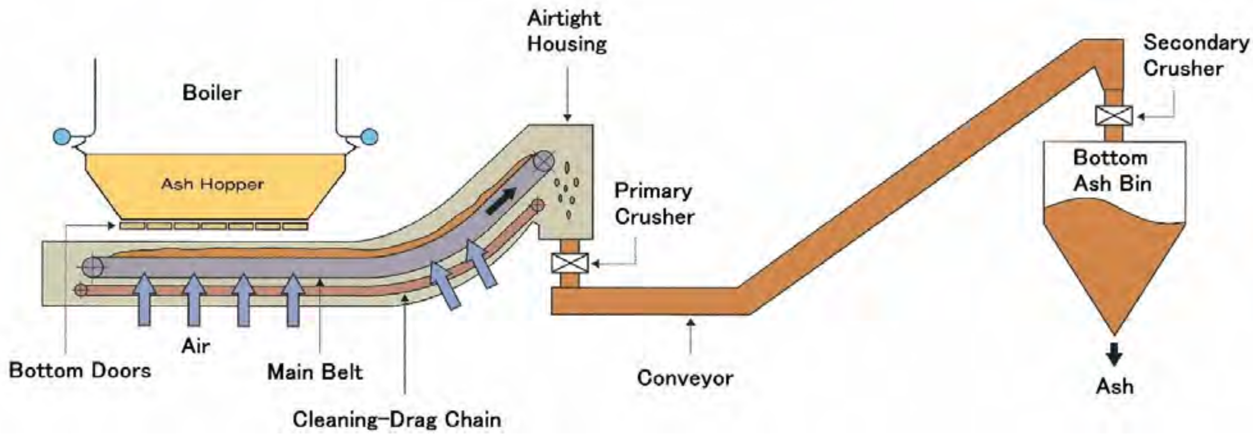
It has many advantages in conveying,collecting and discharging the bottom ash as listed below. By adopting this system, you can avoid the problems that are caused by using cooling water.

## Features

1 **No water for cooling /conveying**
- Water saving
- No need for equipment for water treatment
- Environmentally conscious by no water discharge

2 **Bottom ash in a dry state**
- Bottom ash can be mixed with fly ash and reused like fly ash

3 **Simplicity**
- Reduces electric power consumption and O&M cost
- Space saving
- Easy installation




### Process Description

The bottom ash falls on an ash hopper, which is made of steel lined with heat-resistant material. The function of this hopper is to lighten the straight shock to the main belt caused by the bottom ash. There are bottom doors, which open in normal operation, at the bottom of the ash hopper. If conveying equipment, for instance, malfunctions, the doors close and the bottom ash is stored temporarily.

After that, the bottom ash is conveyed to a primary crusher by the main belt as it is cooled by the air.

Detail introduction of Product/Technology

## 【FLY ASH SYSTEMS】

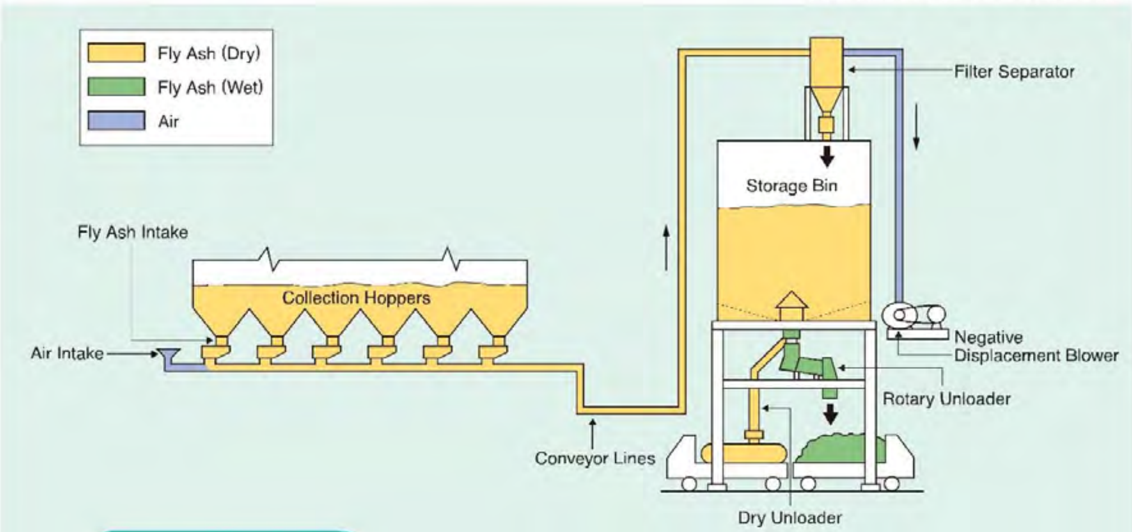
Negative Pressure System

This system is the simplest to operate and requires minimum headroom. Tonnage and distance capabilities, however, are limited. The application ranges of Negative Pressure systems are expanded by developing high-capacity equipment for this service.

**Features**

- Used to convey ash served from many hoppers

Adjustable Air Intake and Fly Ash Intake




**Process Description**

Fly ash is pneumatically conveyed in a pipeline by vacuum force produced by a negative displacement blower up to a strage bin to be temporarily stored ash separators on the top of the bin.

When the ash is to be disposed of, it is conditioned by mixing it with water through a rotary unloader and then transferred to belt conveyors or trucked away to the disposal point or a high-concentration ash-water slurry system.

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Detail introduction of Product/Technology

【FLY ASH SYSTEMS】

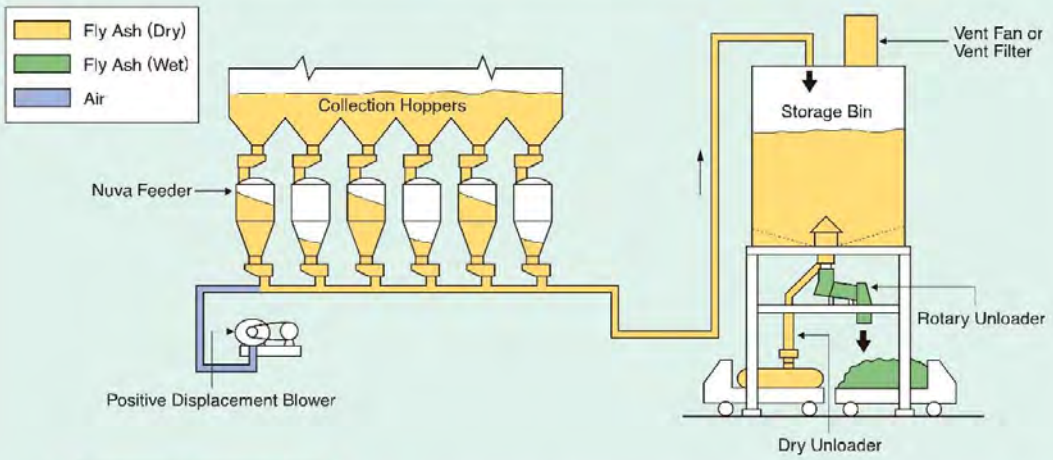
Positive Pressure System

This system is suitable for high tonnage requirements and long conveying distances. It is also well-suited when material must be conveyed to multiple storage points and where jobsite elevation restricts the use of a vacuum system. These systems eliminates the need for ash separation equipment remotely located at the dry storage bin.

**Features**

- Suitable for use in high capacity and long distance conveying

Nuva Feeder




**Process Description**

Fly ash is removed and supplied through nuva feeders into a pressurized air stream produced by a positive displacement blower, then conveyed into a strage bin to be stored.
Process after the strage bin is the same as that used in the Negative Pressure System.

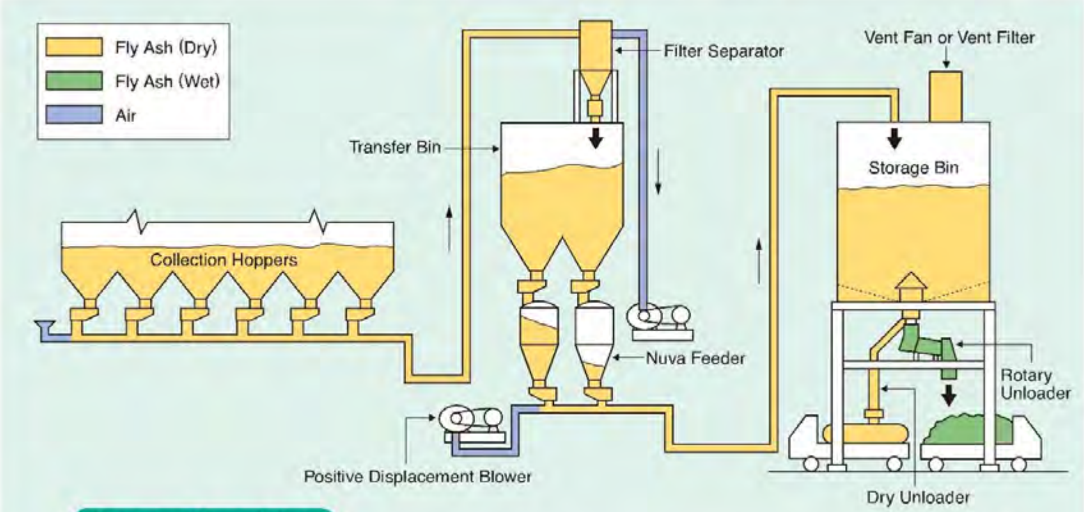
Detail introduction of Product/Technology
**【FLY ASH SYSTEMS】**
Combination System

This system is used when system economies can be realized by taking advantage of the simplicity and lower cost of the equipment of Negative Pressure System, while providing the benefits of Positive Pressure System— high capacity and long distance conveying. The system is effectively applied where a large number of ash hoppers are served and fly ash must be conveyed to remote storage bins.


Strage Bin

## Features

- Possesses the both merits of the two systems shown in the left




### Process Description

Fly ash is once conveyed to a transfer bin by applied negative pressure system and after that, it is transferred to the positive pressure system and then conveyed to a strage bin.

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Advantage & Experience:

# ASH HANDLING SYSTEMS DESIGNED TO FIT YOUR NEEDS

With the recent trend toward more diversified fuels and combustion technologies, such as coal produced at various overseas and domestic mines, fluidized bed boilers and coal gasification plants, the call for more intense development of new technologies in ash handling systems is growing stronger every day.

Kawasaki is meeting this need, based on its abundant experience as Japan's leading and most sophisticated ash handling system supplier and boiler manufacturer. To date, Kawasaki has supplied over 80% of the ash handling systems in operation at coal-fired power stations in Japan ranging from 75MW to 1,050MW unit capacities.

Kawasaki custom designs and engineers each ash handling system to fit all the performance requirements for each application by thoroughly evaluating such factors as site, environmental impact, fuel types, unit size, energy availability, economy, plant facilities, ultimate disposal and/or utilization of ash, and any other items pertinent to the final selection of the optimum ash conveying system.

Whatever your job, whatever your needs, you can be sure there's a Kawasaki ash handling system that will fit your requirements exactly.

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Remarks

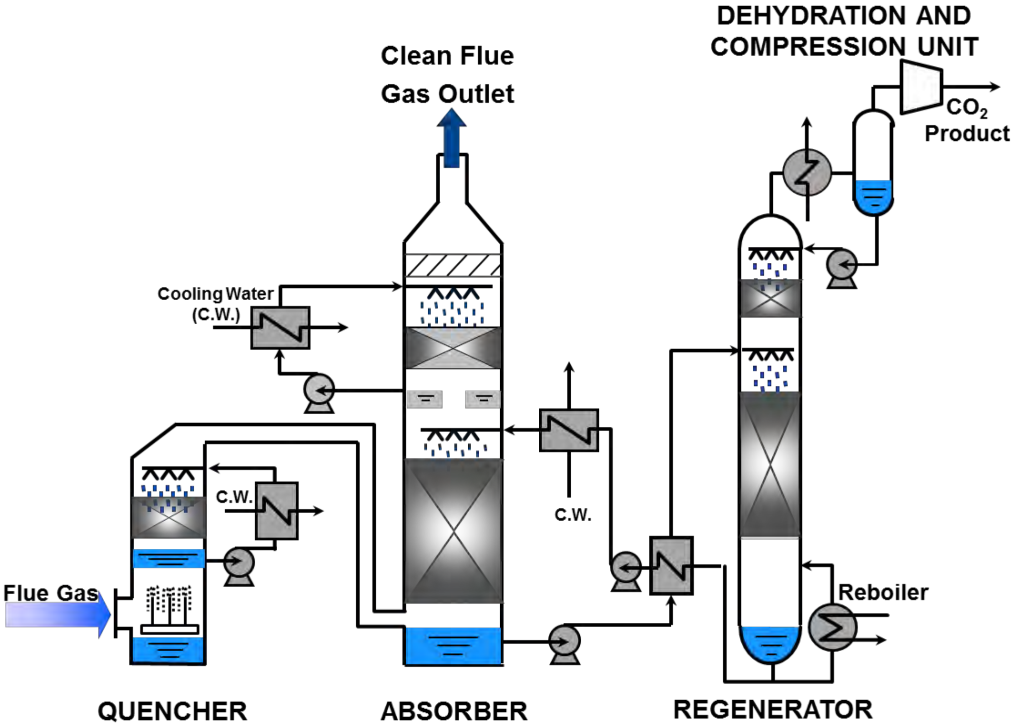
# MHI's KM CDR Process®

## Abstract of product / technology

The Kansai Mitsubishi Carbon Dioxide Recovery process (KM CDR process®) is an advanced, commercially proven $CO_2$ capture process which delivers economic performance for plants of wide ranging capacities. The KM CDR process® utilizes the regenerable "KS-1™ solvent", an advanced sterically hindered amine solvent, in conjunction with a line of special proprietary equipment. The technology is developed through cooperation between MHI and Kansai Electric Power Company, Inc., the second largest eletric utility in Japan.

## Details of product / technology

The KS-1™ solvent has features of low energy consumption, minimal solvent loss and low corrosivity. A unique proprietary energy-saving measures is applied for the process in addition to the KS-1™ solvent to reduce the amount of steam consumption further.
The figure below illustrates the process flow scheme of the KM CDR process® simply.




PROCESS FLOW

Details of product / technology

The KM CDR process® has also commercially proven, superior technologies using several special proprietary equipment as follows.

- Amine Emission Reduction Technology
- Auto Load Adjustment Control System

**Amine Emission Reduction Technology**

MHI started the R&D activity related to reducing amine emission from the $CO_2$ capture process since 1994. The proprietary Amine Emission Reduction System from top of the absorber, is developed and commercially delivered for MHI commercial plants.
It is able to remove amine aerosol and vapor almost completely even for the flue gas containing $SO_3$ content and achieve negligible emission level.

**Auto Load Adjustment Control System**

The KM CDR Process® equips the Auto Load Adjustment Control System and is able to precisely follow inlet flue gas flow rate or $CO_2$ production demand depending on project needs. Thus, the KM CDR Process® is constantly being optimized to minimize energy use.

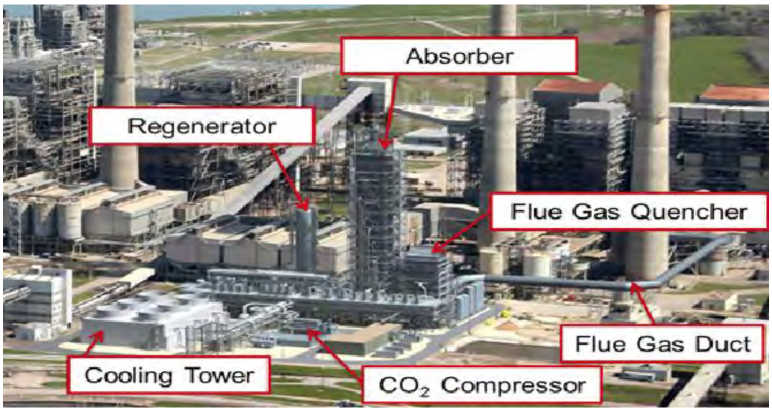
**Features, advantages & experience:**

Since 1999, MHI has provided the KM CDR Process® for industrial projects on natural gas and fuel oil process exhaust. To date, MHI has provided Licensing, Engineering, and/or full EPC services for nearly a dozen commercial KM CDR Process® projects in eight countries at capacities of 210 to 500 tpd. These projects were driven by the need for $CO_2$ to balance production.

| $CO_2$ Capacity (tpd) | Flue Gas Source | Application | Status (as of June, 2016) |
|---|---|---|---|
| 210 | Natural Gas Fired Steam Reformer | Urea Production | Operation |
| 330 | Natural Gas and Heavy Oil Boiler | General Use | Operation |
| 450 | Natural Gas Fired Steam Reformer | Urea Production | Operation |
| 450 | Natural Gas Fired Steam Reformer | Urea Production | Operation |
| 450 | Natural Gas Fired Steam Reformer | Urea Production | Operation |
| 450 | Natural Gas Fired Steam Reformer | Urea Production | Operation |
| 400 | Natural Gas Fired Steam Reformer | Urea Production | Operation |
| 240 | Natural Gas Fired Steam Reformer | Urea Production | Operation |
| 340 | Natural Gas Fired Steam Reformer | Urea Production | Operation |
| 450 | Natural Gas Fired Steam Reformer | Urea Production | Operation |
| 500 | Natural Gas Fired Steam Reformer | Methanol Production | Operation |
| 4776 | Coal Fired Boiler | $CO_2$ EOR | Under Pre-commissioning |
| 283 | Furnace Gas | General Use | Under Construction |

<u>World's Largest $CO_2$ Capture Project from Coal-Fired Flue Gas</u>

Currently under Pre-commissioning in Texas, the Petra Nova project will remove 4,776 tpd (240 MW-equiv) of $CO_2$ from coal exhaust. Operation is expected to start in late 2016.

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Remarks

TOSHIBA Leading Innovation

JCOAL Japan Coal Energy Center

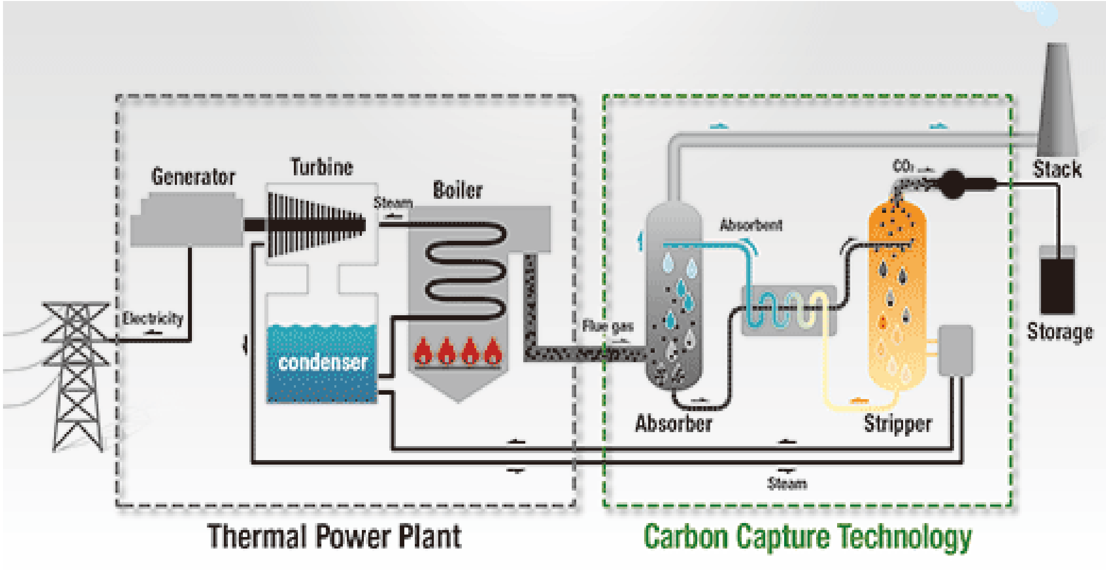
# CCS System : Post Combustion Capture Technology

## Abstract of Product /Technology

Toshiba employs post combustion capture technology based on amine based chemical absorption process. This technology can be applied not only to new build coal fired power plants, but can be retrofitted onto existing plants. Technology also applies to other $CO_2$ emitting plants such as oil fired, gas fired, gas combined cycle, biomass fired plants. The portion of $CO_2$ emission to be captured from the power plant is selectable, giving this technology the flexibility to answer to various needs of the market and regulations.

## Detail Introduction of Product/Technology

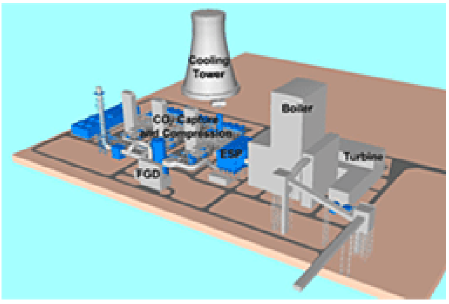
Post combustion capture technology uses chemical absorbents which selectively capture $CO_2$ in the flue gas at a certain condition in the absorber tower, and release it under a different condition in the stripper tower, $CO_2$ is continuously separated from the flue gas of the thermal power plant.

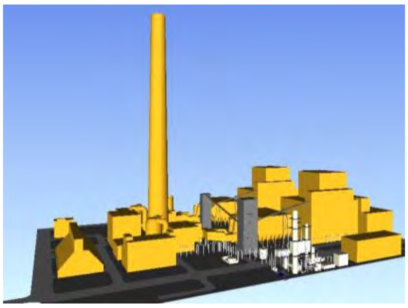



To demonstrate, verify, and continuously improve the performance, operability and maintainability of this system, Toshiba owns and operates a $CO_2$ Capture Pilot Plant at Sigma Power Ariake Mikawa Power Plant, in Fukuoka, Japan. Facility captures 10 tons of $CO_2$ per day from live flue gas of the coal fired power plant. It has accumulated more than 9480 hours of operational experience to date (as of November 2015).The various learnings attained here is applied to planning of various projects utilizing this carbon capture technology.

Advantage & Experience:

Toshiba is continuously improving the performance of the system. By introduction of novel solvents and optimization of system heat interaction, Toshiba has achieved and demonstrated 2.4 GJ/ton-$CO_2$ (at 12% $CO_2$ concentration and 90% capture) at the Mikawa Pilot Plant under actual live flue gas of coal fired thermal power plant.
Toshiba is engaging potential customers around the world in studying the implementation of this technology to the different needs of each power plants. In doing so, Toshiba has conducted feasibility studies, entered into collaborative working frameworks, utilized the Mikawa Pilot Plant to verify the proposed concepts.
Toshiba can tailor the technology to be optimally integrated into each power plant application, fully utilizing the breadth of knowledge and experienece in the power industry, as well as the wealth of know-how attained in constructing, operating and maintenaining the Mikawa Pilot Plant.



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Remarks

IHI

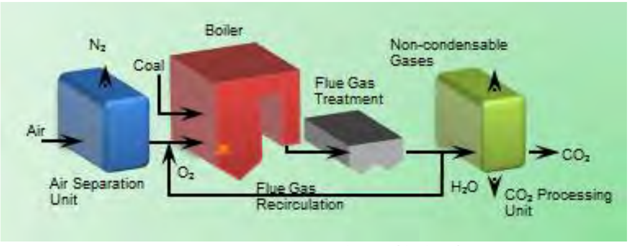
JCOAL Japan Coal Energy Center

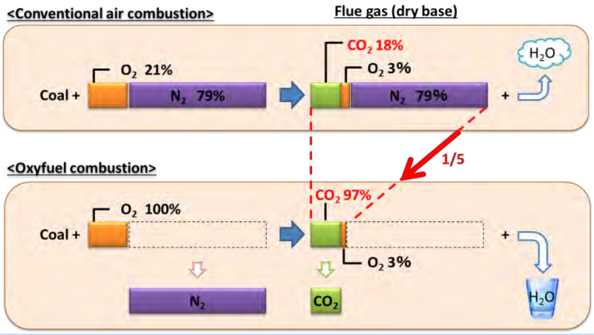
# CO2 Capture and Storage (CCS)

To reduce CO2 emissions, IHI provides CO2 capture technologies, which are applicable to both new and exiting power plants. By adopting oxy-fuel combustion, and chemical absorption, IHI offers an effective business model to sell the captured CO2 as well as practically contribute to global environments.

## Oxyfuel Combustion

- ✓ Oxyfuel combustion can drastically reduce $CO_2$ emissions to atmosphere, and can achieve zero emission regarding NOx, SOx and Hg.
- ✓ Optimal retrofit plan to existing unit can be proposed.
- ✓ Demonstration in Callide-A was successfully



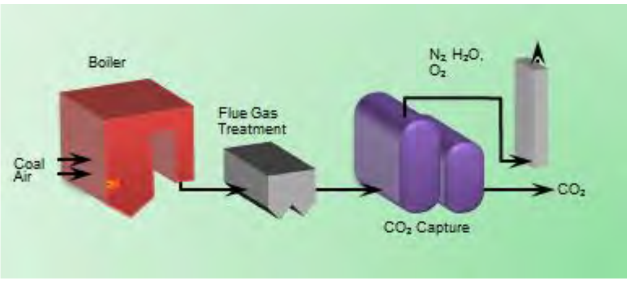



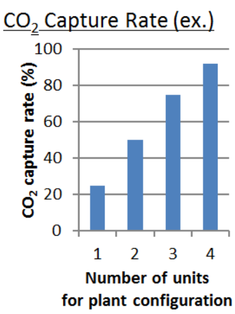


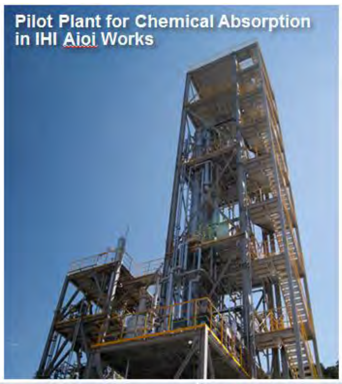
| | |
|---|---|
| Site location | Queensland, Australia |
| Objective | Callide A PS Unit No.4 |
| Rated power | 30MWe |
| $CO_2$ capture capacity | 165,300 lb-$CO_2$/ day (75 tonnes-$CO_2$/day) |
| Demonstration | Mar. 2012 ~ Mar. 2015 |
| Operation record | Generation : 14,800 hrs<br>Oxyfuel power plant : 10,200 hrs<br>$CO_2$ capture plant : 5,600 hrs |

## Post Combustion (Chemical Absorption)

- ✓ IHI system uses advanced solvent with low energy demand.
- ✓ IHI system is optimized with boiler and flue gas treatment system without affecting impact on power plant availability.




| | |
|---|---|
| Source of treated flue gas | Coal combustion |
| $CO_2$ capture capacity | 44,000 lb-$CO_2$/ day (20 tonnes-$CO_2$/day) |
| $CO_2$ capture rate | >90% |

- ✓ IHI system can be tailored to meet the customer's demand for the amount of $CO_2$ captured. Partial $CO_2$ capture is available.

IHI

JCOAL
Japan Coal Energy Center

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