Session Theme: Clean Coal saving the Earth and Economy

High Performance Coal Fired Thermal Power Plant, Achievement and R&D for Future

8th September, 2010

Toshiba Corporation
Contents

1. Introduction of Steam Turbine & Generator Achievements
2. Efficiency Improvement by Innovative Thermal Cycle
3. Development of Advanced-USC & CCS technologies
Contents

1. Introduction of Steam Turbine & Generator Achievements
2. Efficiency Improvement by Innovative Thermal Cycle
3. Development of Advanced-USC & CCS technologies
Turbine Power Plants supplied by Toshiba

As of March 2010

Total: 1,890 Units, 160GW in 37 countries since 1927

© TOSHIBA CORPORATION 2010, All rights reserved.
Recent EPC Thermal Power Projects in the World

Bulgaria – Maritsa East 2 #1,3,4 3x177MW Coal Fired Plant Rehabilitation (COD:#1 Sep.2007, #3 Nov.2008, #4 Feb.2009)

China – Taizhou #1,#2 2x1000MW Coal Fired USC 25MPa600/600℃ (COD:#1 Dec.2007/#2 Mar.2008)

Japan – Maizuru #2 900MW Coal Fired USC 24.5MPa595/595℃ (COD: Aug. 2010)

USA – Iatran 2x1000MW Coal Fired USC 25.5MPa582/582℃ (Under Construction)

India – Mundra 5x800MW Coal Fired USC 24.2MPa565/593℃ (Under Construction)

Malaysia – Tanjung Bin 3x700MW Coal Fired (COD:#1 Oct.2006/#2 Feb./#3 Aug.2007)

Malaysia – Jimah 2x700MW Coal Fired (COD:#1 Jan./#2 Jul.2009)

Rumania – Paroseni #4 1x150MW Coal Fired Plant Rehabilitation (COD: Aug.2007)

Indonesia – Tanjung Jati B Extension 2x660MW Coal Fired (Under Construction)
Profile of the Project (1)

KEPCO Maizuru #2 Power Plant (COD August, 2010)

Customer: Kansai Electric Power Co., Japan
Turbine: Cross Compound, Four Flow (CC4F-43’’)
Generator: Pri./Sec.: 670MVA/370MVA
Output: 900 MW
Main Steam: 25 MPag, 595°C
Reheat Steam: 595°C
Rotation Speed: Pri./Sec.: 3,600rpm/1,800rpm

Features
◆ Top Level Plant Performance
◆ Various Coals Available
◆ High-efficiency on Various Coals
◆ Sustainability and Landscape-Reserve, considering the Location adjacent to the quasi-national park

Coal Fired Plant with the Latest Technologies
Profile of the Project (2)

Eraring 660MW Thermal Power Station, Australia

The record of continuous operation in the World (at 2003)
Eraring Unit 4 & 10 (Australia): manufactured by Toshiba
The continuous operation: 673 days (from Feb 26, 1995 to Dec 31, 1996)
Availability: 99.63%

The most reliable turbine & generator in the world
Profile of the Project (3)

Anpara #4,#5 Power Station, India

8 years continuous commercial operation without major overhaul

<table>
<thead>
<tr>
<th>Customer</th>
<th>Uttar Pradesh State Electricity Board, India</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taking over</td>
<td>Unit # 4: Feb 1994</td>
</tr>
<tr>
<td></td>
<td>Unit # 5: Oct 1994</td>
</tr>
<tr>
<td>Turbine</td>
<td>Tandem Compound, Double Flow, Reheat Type (TCDF-42”)</td>
</tr>
<tr>
<td>Output</td>
<td>500 MW</td>
</tr>
<tr>
<td>Main Steam</td>
<td>166 barg, 538 °C</td>
</tr>
<tr>
<td>Reheat Steam</td>
<td>538 °C</td>
</tr>
<tr>
<td>Rotation Speed</td>
<td>3000 rpm</td>
</tr>
</tbody>
</table>

Robust-Designed Turbine for Breakdown Maintenance
Contents

1. Introduction of Steam Turbine & Generator Achievements
2. Efficiency Improvement by Innovative Thermal Cycle
3. Development of Advanced–USC & CCS technologies
Growth of Thermal Power Plant (2007→2015)

- **Europe**
  - Shift to Low Emission Power Plants
- **China**
  - Mega Market more than 50% in the World
  - Local Manufactures Supplied Equipment
- **Middle East**
  - Shift from Oil Fired to Natural Gas Fired
- **India**
  - Large Scale Coal Fired Thermal Plant
- **Japan**
  - Construction of Combined Cycle Plant
- **America**
  - Shift from Coal to CC in North America
  - Large Scale Thermal Plant in South America
- **Asia & Oceania**
  - Large Scale Thermal Power Plant
  - Geo Thermal

Source: IEA World Energy Outlook 2009
Towards Clean Coal Thermal Power Plants

**Methods**
- **Performance Improvement (57%)**
- **Baseline Temperature Increase 6 deg C**
- **Renewable Energy (23%)**
  - Hydro, CSP, Geothermal
  - CCS (10%)
- **450 ppm Stabilization Scenario temperature Increase 2.0 – 2.4 deg C**

**TOSHIBA activities**
- **High-efficiency Equipment supply**
  - Advanced Countries
- **Rehabilitation of decrepit plants**
  - Advanced Countries
- **Hydro, CSP, Geothermal**
  - Emerging Countries
- **Thermal Plant with CCS**
  - Advanced Countries

**Efficiency Improvement for CO2 Reduction**
- **26 Gt @2030**

(Source: World Energy Outlook 2009)
Coal-Fired Plant Efficiency in the World

The Latest Plant Efficiency Level

Gross Efficiency (LHV)

Source: Ecofys International Comparison of Fossil Power Efficiency and CO2 Intensity 2009

Top Level Efficiency as Coal Fired Thermal Plant

© TOSHIBA CORPORATION 2010, All rights reserved.
CO2 Reduction by Efficiency Improvement

World Total coal-fired thermal plant capacity: 1,440GW
(1/3 of entire power plants capacity)

Coal-Fired Thermal Plants in the World

- China: 35%
- USA: 23%
- India: 5%
- Others: 37%
- Total: 1,440GW

Efficiency and CO2 emissions of Coal-Fired Thermal Plants

The Latest Plant Efficiency Level

- Base Efficiency: 35%
- Efficiency Improvement: 41.6%
- CO2 emissions: +760kt

Source: IEA World Energy Outlook 2009
- ECOFYS, INTERNATIONAL COMPARISON OF FOSSIL POWER EFFICIENCY (2008)

Efficiency Improvement Technology
Contributes to Reduction of CO2 emissions

*Gross efficiency (LHV)
*CO2 emissions from a 1,000MW plant
Steam Cycles and Efficiency Gains

Higher the Pressure, Higher the Temperature
More Gains on Efficiency and Subsequent CO₂ Reduction
Super Critical Turbine Experience

Over 81 units of Toshiba’s Super Critical STG have been operating since 1969. (except China)

World Share of Supercritical Steam Turbine
(Among Major Manufactures, Past 20 Years)

as of 2009

Top Level efficiency Steam Turbines Supplied to the Markets
Transition of Steam Conditions

**MST/RST**

- **600/610 °C**
  - KAWAGOE #1,#2 700MW (TC) (31MPag 566/566/566 °C)
  - NANA O TA #2 700MW (TC) (24.1MPag 593/593 °C)
- **593/593 °C**
  - NOSHIRO #2 600MW (TC) (24.1MPag 566/593 °C)
- **566/593 °C**
  - TSURUGA #1 500MW (TC) (24.1MPag 566/566 °C)
  - HARAMACHI #1 1000MW (CC) (24.5MPag 566/566 °C)
  - HAKINAN #1#5 700MW (TC) (24.1MPag 566/593 °C)
  - TACHIBANA BAY 700MW (TC) (24.1MPag 566/566 °C)
- **566/566 °C**
  - CALLIDE #3,#4 420MW (TC) (25MPag 566/566 °C)
  - WESTON #4 5834MW (TC) (24.7MPag 582/582 °C)
  - HEKINAN #4 1000MW (TC) (24.5MPag 566/593 °C)
  - IATAN 914MW (TC) (24.5MPag 595/595 °C)

TC : TANDEM COMPOUND
CC : CROSS COMPOUND

Towards to Top Level Steam Conditions

© TOSHIBA CORPORATION 2010, All rights reserved.
Steam Turbine Development based on CFD

HP Steam Valve
HP Turbine 1st Stage Nozzle
Cross-Over Piping

Nozzle Box
IP Exhaust
LP Inlet

Lead Piping

IP Inlet

RH Steam Valve

Abradable Seal

LP Exhaust Casing
Efficiency Improvement of Generator

High-efficiency, large-capacity indirectly hydrogen-cooled turbine generator

Reduce losses compared to water-cooled generators

Generators: Primary 670MVA(600MW) Secondary 370MVA(300MW)

Achieved the largest capacity and highest-efficiency in the world by indirectly hydrogen-cooled method
Steam Turbine Efficiency Improvement

Steam Turbine Test Facility

Mikawa Power Station
Unit 2 Turbine Test Facility (since June 2008)

HP Turbine
- Speed: 6,000 rpm
- Stages: 16

LP Turbine
- Speed: 3,600 rpm
- Stages: 6
- LSB: up to 50 in.

Full-scaled Turbine Test Facility for R&D to Boost Up
Performance Improvement R&D Process

New Technology R&D Planning

① Blade loss reduction
- Optimized Reaction Stage Design
- Surface friction loss reduction
- Longitudinal flow distribution control

② Pressure drop loss reduction
- Inlet/Exhaust scroll
- Steam valve
- Piping connection part
- Section joint piping, duct

③ Leakage loss reduction
- Seal fin profile improvement
- Clearance reduction

④ Last stage blade development
- High efficiency LSB series
- Increased annulus area
- Exhaust steam speed reduction
- Loss reduction
- High mach number blades
- Smaller radical clearance

Verification Phase

Analysis & Simulation

Performance Improvement Cycle

Practical Operation

Mikawa P/S Unit #2 Actual size test facility

Utilization of the test results for Analysis & Simulation
Latest Development – Steam Turbine Technology

- **Optimal Reaction Blade**
  - Verified High Efficiency

- **Drum-type Rotor**
  - Confirm Rotor Dynamics

- **Direct Lubricated Bearings**
  - Confirm 30% Loss Reduction

- **35in LSB**
  - Measure Moisture Coefficient

- **Abradable Coating Seal**
  - Confirm Low Leakage

- **Welded Rotor**
  - Loss and good Shaved Surface

- **Corrosion-Resistant Coating**
  - Good Inspection Result after Long Operation

Various Technical Improvements for Both Performance & Reliability
Steam Turbine World Market Share

**Worldwide**
(Yr03-09 Except China, >100MW)

- **Others**
- **B**
- **C**
- **D**
- **E**
- **TOSHIBA** 8%

Total: 362,393MW

**US Market**

- **Others**
- **F**
- **D**
- **B**
- **C**
- **E**
- **TOSHIBA**

No. 4 Share worldwide

No.1 Share in US for 7 years

© TOSHIBA CORPORATION 2010, All rights reserved.
Advanced Technology for Plant Rehabilitation

450MW 169atg - 538/538degC TC4F-26”

**HIP Section Replace = Increased Heat Rate 0.8%**

1% efficiency improvement on 1,000MW rating coal-fired plant means about 46,000t CO2 reduction per year.

780MW 246atg - 538/538degC TC4F-30”

**LP Section Replace = Increased Power Output 18.6MW**

Latest Technology for High-efficiency & Life Extension
Profile of the latest Project (4)

Bulgaria – Maritsa East 2 #1-#6 6x177MW Plant Rehabilitation

Customer     Maritsa East II TPP
Taking Over   #1 Sep.2007, #2 Jan.2007
              #3 Nov.2008, #4 Feb.2009
              #5 (Mar.2011), #6 (Aug.2010)
              (under construction) (under construction)

#1-4 : 4x150 MW STG Replacement
Turbine: LMZ Make → Toshiba Latest Turbine
Generator: LMZ Make → Toshiba Air Cooling Generator for unit2
→ 40 Years old Machine to Latest

#3,4 : 2x210 MW LMZ Make Turbine Rehabilitation
HP IP LP Blade Nozzle, LP Rotor Replacement
→ 24 Years old Machine to renewal

Rehabilitation of decrepit Units to Improve Efficiency
Contents

1. Introduction of Steam Turbine & Generator Achievements
2. Efficiency Improvement by Innovative Thermal Cycle
3. Development of Advanced-USC & CCS technologies
Further material development is underway to meet 700°C condition.
A-USC (Advanced Ultra Super Critical) Turbines

Overall system
- Steam condition
- Heat balance

Steam Valve
- High temperature material

Steam Turbine
- High temperature material
- Turbine Structure / Flowpath

Drive towards Advanced USC technology for future low CO2 emissions
CCS Pilot Plant

**Plant Overview**
- Location: Sigma Power Mikawa, Omuta, Fukuoka, Japan
- Post Combustion Method
- Capacity: 2,100 Nm$^3$/hr (Feed)
  (10 t-CO$_2$/day)
- Exhaust Flow: 2,100 Nm$^3$/h
- Commenced: September, 2009

**Objectives**
- Testing using the actual flue gas of live thermal power plant
- Verification of performance, operability, maintainability, etc. in view of scaled up plant design.

---

**Development in Progress for Full-Scaled Plant**
Thermal Power Plant with CCS

Comparison of CO2 Discharge

R&D for High Performance Solvent
Clean Coal Thermal Power Plant is realized by Integration and Optimization of both High efficiency Turbine Cycles and CCS technology.
Toshiba Steam Turbine for Solar Power Plant

Axial Flow Turbine (Below 100-150MW)

Double Flow Turbine (Over 100-150MW)

Four Flow Turbine (Over 400MW)

Moisture Extraction Blade (MEB)

- MEB from Geothermal Technology

Steam turbine line-up for Renewable Energy Plant