MHPS's Activity for Clean Coal Technologies

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1. Corporate Profile
Mitsubishi Hitachi Power Systems, Ltd (MHPS)

Integration in the Thermal Power Generation Systems Field
Head Office & Main Works in Japan

- Kure Works
- Takasago
- Hitachi Works
- Nagasaki Works
- Yokohama Works
- Yokohama Head Office
Global Network of MHPS

MHPS has 56 companies in 23 countries.
MHPS’s Business Field

Products & Services

Gas Turbine Combined (GTCC) Power Plant

Boiler & Turbine Generation Plants

Integrated coal Gasification Combined Cycle (IGCC) Power Plants

Environmental Equipment (SCR/ESP/FGD)

Geothermal Power Plants

Generators

Gas Turbines

Boilers

Steam Turbines

Power Generating Plant Peripheral Equipment

Plant Control Systems

Fans

Fuel Cells (SOFC)
2. Japan’s Energy Policy and Position of Coal Fired Power Plant
Japan’s New Energy policy

Important decisions on Japan’s energy policy were made from June to July, 2015

a. Optimum energy mix
   Target on power source composition in 2030 was made in line with basic policy of “3E+S” (Energy Security, Economic Efficiency, Environment and Safety).

b. Reduction target of greenhouse gas by 2030: 26% (based on 2013 level)

2013
- Fossil Fuel: 88%
- Coal: 30%
- LNG: 43%
- Oil: 15%
- Renewable: 11%
- Nuclear: 1%

2030
- Fossil Fuel: 56%
- Coal: 26%
- LNG: 27%
- Oil: 9%
- Renewable: 22-24%
- Nuclear: 20-22%
Position of Coal-Fired Power Plant

Coal fired power plant is positioned as an important baseload electricity source from the viewpoint of basic policy of “3E+S” (Safety, Energy Security, Economic Efficiency and Environment).

[Feature of Coal]
1) Affordable (one third compared to oil and natural gas price as of 2014)
2) Stably available (not unevenly distributed, lower geopolitical supply risk)
3) Easily storable

[Concern of Coal-fired power plant]
1) Higher amount of carbon dioxide emissions per unit of heat energy

✓ Highly efficient coal fired power plant is necessary
✓ Not only CO2 reduction domestically, but also international cooperation, e.g. Joint Crediting Mechanism, is required
✓ MHPS will contribute to the environment preservation and energy supply through achievement of the highest and best performance coal fired power plant
Roadmap on next-generation thermal power generation technology

Power generation efficiency

- **Gas Turbine Fuel Cell Combined Cycle (GTFC)**
  - Efficiency: 63%
  - CO₂ emissions: 280 g/kWh
  - Target: Around 2025
  - Reduction of CO₂ by 20%

- **A-USC (Advanced Ultra Super Critical)**
  - Efficiency: 46%
  - CO₂ emissions: 710 g/kWh
  - Target: Around 2016

- **IGFC (Integrated Coal Gasification Fuel Cell Combined Cycle)**
  - Efficiency: 55%
  - CO₂ emissions: 590 g/kWh
  - Target: Around 2025

- **IGCC (Integrated Coal Gasification Combined Cycle)**
  - Efficiency: 46 to 50%
  - CO₂ emissions: 650 g/kWh
  - Target: Around 2020

- **Gas Turbine Combined Cycle (GTCC)**
  - Efficiency: 52%
  - CO₂ emissions: 340 g/kWh
  - Target: Around 2020

- **Ultrahigh Temperature Gas Turbine Combined Cycle**
  - Efficiency: 57%
  - CO₂ emissions: 310 g/kWh
  - Target: Around 2020

- **Advanced Humid Air Gas Turbine (AHAT)**
  - Efficiency: 51%
  - CO₂ emissions: 350 g/kWh
  - Target: Around 2017

- **IGCC (Verification by blowing air)**
  - Efficiency: 40%
  - CO₂ emissions: 820 g/kWh

- **Ultra Super Critical (USC)**
  - Efficiency: 40%

*The prospect of power generation efficiencies and discharge rates in the above Figure were estimated based on various assumptions at this moment.*

3. Supercritical / Ultra-Supercritical Power Plant
Higher steam temperature and pressure improve thermal plant efficiency
In other words, SC/USC technology provides economical power production, fuel energy saving, lower carbon emission and environment-friendly
Coal-Fired SC/USC Plant in overseas

Total: 164 units

MHPS units: 114
Others: 50 units (Chinese licensee)

- **Japan**: 26 units
- **China**: 63 units (by MHPS / Licensee)
- **Germany**: 14 units
- **Poland**: 2 units
- **Italy**: 3 units
- **Greece**: 1 unit
- **South Africa**: 12 units
- **India**: 15 units (by L&T-MHPS Boilers Pvt. Ltd. as JV)
- **Korea**: 5 units
- **Taiwan**: 8 units
- **Canada**: 2 units
- **Taiwan Power Co., Ltd. LIN KOU #1-3**
- **Philippines**: 1 unit
- **Malaysia**: 1 unit
- **Australia**: 1 unit
- **Mexico**: 1 unit
- **USA**: 4 units
- **Midamerican Energy, Walter Scott Jr. Energy Center #4**
- **Germany**: 14 units
- **Poland**: 2 units
- **Italy**: 3 units
- **South Africa**: 12 units
- **India**: 15 units (by L&T-MHPS Boilers Pvt. Ltd. as JV)
- **Korea**: 5 units
- **Taiwan**: 8 units
- **Canada**: 2 units
- **Philippines**: 1 unit
- **Malaysia**: 1 unit
- **Australia**: 1 unit
- **Mexico**: 1 unit
- **USA**: 4 units
Activities at Indian Market

MHPS has contributed to Indian power generation by CCT originated in Japan through the JV with Indian company, Larsen & Toubro, Ltd.
Global Activity with SC/USC Technology

USC steam condition (600 °C steam temp) was first applied in Taiwan and Korea

- **Taiwan Linkou #1**
  - Output: 800 MW
  - Main Steam Flow: 2,404 t/h
  - Main Steam: 604 °C / 25.38 MPag
  - Reheat Steam: 602 °C
  - Commercial Operation: 2016/6
  - Fuel: Bituminous Coal, Sub-bituminous coal

- **Korea Taean #9**
  - Output: 1050 MW
  - Main Steam Flow: 3,145 t/h
  - Main Steam: 603 °C / 25.94 MPag
  - Reheat Steam: 613 °C
  - Commercial Operation: Under commissioning
  - Fuel: Bituminous Coal, Sub-bituminous coal

Korea Taean #9

USC steam condition (600 °C steam temp) was first applied in Taiwan and Korea
Successful Test of Automated Combustion Tuning System Using AI Technology

Yokohama, January 10, 2017 -- A newly developed system from Mitsubishi Hitachi Power Systems, Ltd. (MHPS) which aims to automate combustion tuning in boilers using artificial intelligence (AI) has undergone verification testing in Taiwan, and demonstrated results that are comparable to those that could be achieved by a highly experienced engineer.
MHPS-TOMONI ICT Solution

Through partnership, we ensure customer satisfaction throughout strategic development to expand mutual benefits in a sustainable way.

Operability Improvement

Performance Enhancement

O&M Optimization

Autonomous Operation

O&M Advancement

O&M Support

O&M Monitoring

- Fleet Efficiency optimization
  Autonomous operation, O&M optimization

- Extension of Planned Outage Interval
  Damage prediction and automated advice, Life extension, Spare parts ordering system

- Inspection Time reduction
  Accurate life time prediction, AI combustion tuning

- Digitalization of data accumulation&evaluation

- Remote Operation
  O&M Support

- Unit/Plant Upgrades &Improvement
  Automatically optimized Operation, Multi-Coal Fired Operation

- Availability Improvement
  Preventive maintenance recommendation, Remote Monitoring, Short-term operation for peak demand, Eco operation, Spare part recommendation for inspection

Through partnership, we ensure customer satisfaction throughout strategic development to expand mutual benefits in a sustainable way.
4. Air Quality Control System
Air Quality Control System (AQCS) for Coal Fired Plant

Harmful NO is decomposed into harmless N2 and H2O by catalytic action

\[ 4\text{NO} + 4\text{NH}_3 + \text{O}_2 \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O} \]

Harmful SO2 is recovered as harmless gypsum (CaSO4)

\[ \text{SO}_2 + \text{CaCO}_3 + 2\text{H}_2\text{O} \rightarrow \text{CaSO}_4 \cdot 2\text{H}_2\text{O} + \text{CO}_2 \]

One-stop AQCS solution by MHPS
World lowest level emission (SOx, NOx, PM) can be achieved by applying the integrated AQCS system

Low NOx Combustion

SCR

GGH Heat Extractor

ESD

FGD

Harmful NO is decomposed into harmless N2 and H2O by catalytic action

* ESP will be supplied by MHPS Environmental Solutions Ltd.
World-class Combustion Test Facility

- Combustion test facility upgraded in October 2014 with more sophisticated instrumentation equipment to evaluate combustion and fluid characteristics.
- Development of high efficiency low NOx combustion (burners and systems) for both of tangential and opposed firing boilers.
- Advanced and speedy developments by integration of combustion test and CFD simulation.
- Accommodation of various fuels - coal, cokes, biomass, oil, residual oil, vacuumed residue (VR), solvent de-asphalting (SDA), and so on.

**Combustion test furnace (4 t/h)**

- Actual flame
- CFD simulation

**CFD simulation**
- Case study of test in advance
- Selection of optimum conditions
- Evaluation of actual boiler performance

**Combustion test**
- Detailed measurement
- Verification of combustion performance

**Upgrade of CFD**

**Advanced and Speedy test**

**Low NOx Burner**
- Ignition in the flame to reduce NOx
- 1st Air + Pulverized Coal
- 2nd Air

**CFD: Computational Fluid Dynamics**
MHPS is a pioneer of SCR technology and is producing & distributing both honeycomb and plate catalyst. Either type of MHPS catalyst is the largest market share in the world and we contribute to global environmental conservation.

MHPS won the chairman prize of JSIM* for developing a new high mercury oxidation catalyst.

* The Japan Society of Industrial Machinery Manufacturers
Wet FGD (Flue Gas Desulfurization) System

Chemical Reaction in Absorber

SO$_2$ + CaCO$_3$ (limestone) + 2H$_2$O
→ CaSO$_4$・2H$_2$O (gypsum) + CO$_2$

FGD Performance

More than 95% SO$_2$ removal efficiency can be achievable.
Dust removal efficiency and SOx removal efficiency were drastically improved through the package contract of AQCS renovation.

<table>
<thead>
<tr>
<th>Output:</th>
<th>1000 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site:</td>
<td>the province of Shangtung</td>
</tr>
<tr>
<td>Fuel:</td>
<td>Bituminous Coal</td>
</tr>
<tr>
<td>SOx removal efficiency</td>
<td>98.8%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Before</th>
<th>SO₂</th>
<th>Dust</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;50mg/Nm³</td>
<td>14mg/Nm³</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>After</th>
<th>SO₂</th>
<th>Dust</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≤35mg/Nm³</td>
<td>≤5mg/Nm³</td>
</tr>
</tbody>
</table>

- Renovation of FGD
- Addition of GGH (Re-heat)

Addition of GGH (heat extractor)
MHPS’s AQCS Global Activities

MHPS Delivered AQCS units all over the world

- SCR: 1,023 Units (20 Countries)
- ESP: 3,276 Units (32 Countries)
- FGD: 323 Units (26 Countries)

Map showing delivery locations across the world.
5. Advanced Clean Coal Technology

5-1. IGCC
Outline of IGCC System

**Integrated coal Gasification Combined Cycle**

1. **Conventional Coal Firing System**
   - Coal
   - Air
   - Coal Firing Boiler
   - Steam Turbine
   - Power
   - Condenser Loss
   - Entropy

2. **Integrated Coal Gasification Combined Cycle (IGCC)**
   - Coal
   - Air
   - Coal Gasifier
   - Clean up
   - Filter
   - Combustor
   - Gas Turbine
   - HRSG
   - Flue Gas
   - Power
   - High efficiency

*Integrated coal Gasification Combined Cycle Outline of IGCC System*
Features of IGCC system (Environmental Performance)

Higher Efficiency and Least Environmental Impact

- **Plant Efficiency**: +10~20%
- **CO2 Emission**: ▲10~20%
- **Ash Emission**: ▲60%
- **Circulating Water Emission**: ▲30%

Coal-fired USC power plant (steam at 600°C)

Fly-ash (Conventional Boiler) and Grassy Molten Slag (IGCC)

Approx. 60% decrease in volume

Utilization as a pavement material and Utilization as a concrete aggregate are possible.
Features of IGCC system (Fuel Flexibility)

**Flexibility to “Variety of Coal”**

- **LRC (Low-Rank coals)**, that have low ash fusion temperatures, are not suitable for conventional boiler 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.
Nakoso 250MW IGCC Plant

Major Specification

- Output: 250 MW (gross)
- Gasifier: Air-blown Dry Feed
- Gas Clean-Up: MDEA (Methyl diethanol amine)
- Gas Turbine: M701DA GT (1 on 1)
- Plant Efficiency: 42% (LHV, net)

Project Schedule

- Operation Started: Sep. 2007
- Commercial Operation: July. 2013

Nakoso 250MW IGCC Demonstration Plant achieved all the following targets.

- Excellent Performance (Highest Efficiency, Less Environmental impact)
- Higher Reliability (World record of continuous operation 3,917hr)
- Fine Operability (Load change rate >3%/min)
- Fuel Flexibility (Verified applicability for low-rank coal, 10 kinds coals)

Converted to the First Commercial IGCC Plant in Japan.
(Total operating hours are approx. 36,400 hrs.)

This project was sponsored by METI

* Japan Society of Mechanical Engineering

(Raw Text)

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Achievements of Nakoso 250MW IGCC Plant

<table>
<thead>
<tr>
<th>Performance</th>
<th>Targets</th>
<th>Achievements</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output (Gross)</td>
<td>250MW</td>
<td>250MW</td>
<td></td>
</tr>
<tr>
<td>(Net)</td>
<td>220MW</td>
<td>225MW</td>
<td></td>
</tr>
<tr>
<td>Efficiency (Net, LHV)</td>
<td>&gt; 42.0%</td>
<td>42.9%</td>
<td></td>
</tr>
<tr>
<td>Carbon Conversion</td>
<td>&gt; 99.9%</td>
<td>&gt; 99.9%</td>
<td></td>
</tr>
</tbody>
</table>

| Emission (@dry, 16%O2) | SOx         | < 8 ppm      | 1.0 ppm         | 10 kinds of coal in total |
|                        | NOx         | < 5 ppm      | 3.4 ppm         | 6 Sub-bituminous          |
|                        | Dust        | < 4 mg/m³N   | < 0.1 mg/m³N    | 4 Bituminous              |

| Operational         | Coal Kinds   | Bituminous   | Chinese, Canadian | 6 Sub-bituminous |
| Flexibility         |              | Sub-bituminous | 2 US (including PRB) | 4 Bituminous |
|                     |              |               | 3 Indonesian (Adaro, etc.) | have been used. |
|                     |              |               | Colombian, 2 Russian |                  |

| Start-up Time       | < 18 hr      | 15 hr        |                                                                     |
| Minimum Load        | 50%          | 36%          |                                                                     |
| Ramping Rate        | 3%/min       | 3%/min       |                                                                     |

| Reliability         | Long-term Continuous Operation | 2,000 hr | 3,917 hr | Cumulative operating hours : |
|                     |                             |          |          | > 36,400 hrs. |
Osaki CoolGen Project

Major Specification

- **Output**: 166 MW (gross)
- **Gasifier**: Oxygen-blown Single-chamber Two-stage Entrained-flow
- **Gas Clean-Up**: MDEA (Methyldiethanol Amine)
- **Gas Turbine**: H-100 GT (1 on 1)
- **Plant Efficiency**: 40.5% (HHV, net) (42.7% (LHV, net))

Project Schedule

- **Construction Started**: March 2013
- **Demo. Operation Start**: March 2017
- **Coml. Operation Start**: April 2019

First step 1: Oxygen-blown IGCC

IGCC: 166 MW (Coal feed rate: 1180 t/d)
Gasifier: Single Chamber with Two Stages Spiral Flow Gasifier

Second step 2: IGCC with CO₂ Capture

Add installing CO shift reactor and CO₂ capture unit

Third step 3: IGFC with CO₂ Capture

(*) CO₂ Transportation and Storage are outside of the Osaki CoolGen Project.
Expected Performance of IGCC Plants

<table>
<thead>
<tr>
<th>Item</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>Bituminous</td>
</tr>
<tr>
<td>Output Gross</td>
<td>540 MW</td>
</tr>
<tr>
<td>Net</td>
<td>480 MW</td>
</tr>
<tr>
<td>Gasifier Oxidizer</td>
<td>Air-blown (O2 Enriched)</td>
</tr>
<tr>
<td>Coal Feed</td>
<td>Dry Feed</td>
</tr>
<tr>
<td>Gas Clean-Up</td>
<td>MDEA (Methyl Di-ethanol Amine)</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>M701F4 ×1 (1 on 1)</td>
</tr>
<tr>
<td>Net Plant Eff. (LHV)</td>
<td>48 %</td>
</tr>
</tbody>
</table>

Note: Plant performance like output and efficiency depends on site conditions including coal properties.
High Efficiency by using state of the art Gas Turbine
Lower CO2 emission intensity than the latest USC coal fired power plant.
Fuel Flexibility for high moisture Low Rank Coal
Highly Reliable system verified in Nakoso 250MW IGCC plant
IGCC Projects around the world

MHPS develop IGCC technology originated in Japan to around the world

Fukushima Revitalization Power IGCC Project

Osaki CoolGen Project

Nakoso 250MW IGCC Plant
5. Advanced Technology

5-2. SOFC
Composition of Hybrid System

Principle of Solid Oxide Fuel Cell (SOFC)

SOFC and Micro Gas Turbine Hybrid System
SOFC-MGT Hybrid System Line-up

250kW class Demonstration system

- **Model**: HYBRID-FC
- **Rated output**: 250 kW
- **Efficiency at sending end**: 55 %LHV
- **Outside dimension (m)**: [W]3.2 [L]9.5

1,000kW class Hybrid System (image)

- **Model**: HYBRID-FC
- **Rated Output**: 1200 kW
- **Efficiency at sending end**: 57 %LHV
- **Outside dimension (m)**: [W]9.5 [L]18 [H]3.8
SOFC-MGT Hybrid System Projects in Japan

- The demonstration 250kW class system started operation from March 2015 in Kyushu university and has been performed up to now.
- 6 demonstration projects will be conducted to verify performance under each operation condition.

Total: 7 systems

- Finished, 1 system, 2012~2013
- In operation, 2 systems, 2015~
- In preparation, 4 systems, 2016~

Technical development of SOFC is sponsored by NEDO
Conclusion

◆ MHPS shall be continuously developing clean coal technology to improve plant efficiency and reduce carbon emission

◆ MHPS shall contribute to environmental conservation and carbon emission reduction to provide Japanese clean coal technology worldwide

◆ MHPS shall work to promote IGCC and SOFC as highly efficient power generation technologies in addition to conventional clean coal technology