Global Activities for Clean Coal Technology

September 9, 2015

Yozaburo Mabuchi
Senior Executive Vice President
Mitsubishi Hitachi Power Systems, LTD
1. Conventional Clean Coal Technology
   1-1. Supercritical / Ultra-Supercritical Power Plant
   1-2. Small Class Coal Fired Power Plant

2. Air Quality Control System

3. Advanced Clean Coal Technology
1. Conventional Clean Coal Technology
1-1. 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
### Improvement of Coal-Fired SC/USC Plant in Japan

<table>
<thead>
<tr>
<th>Year</th>
<th>Project</th>
<th>Power Plant</th>
<th>Steam Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>J-Power/Matsushima#1</td>
<td>500MW/24.1MPa</td>
<td>538/538°C</td>
</tr>
<tr>
<td>1989</td>
<td>KyushuEPCO/Matsuura#1</td>
<td>700MW/24.1MPa</td>
<td>538/566°C</td>
</tr>
<tr>
<td>1991/1992</td>
<td>ChubuEPCO/Hekinan#1(Boiler Supply)</td>
<td>700MW/24.1MPa</td>
<td>538/566°C</td>
</tr>
<tr>
<td>1993</td>
<td>TohokuEPCO/Noshiro#1(Boiler Supply)</td>
<td>600MW/24.5MPa, 538/566°C</td>
<td></td>
</tr>
<tr>
<td>1994/1995</td>
<td>Soma KyodEPCO Shinchi#1&amp;B2(Boiler Supply)</td>
<td>1,000MW/24.1MPa, 538/566°C</td>
<td></td>
</tr>
</tbody>
</table>

**SC Introduction Stage**

**Growth Stage**

- 1995 HokurikuEPCO Nanao-Ohta#1 500MW/24.1MPa 593/593°C
- 1997 TohokuEPCO Haramachi#1 (Boiler Supply) 1,000MW/24.1MPa 593/593°C
- 1997 J-Power Matsuura#2 1,000MW/24.1MPa 593/593°C
- 2000 ShikokuEPCO Tachibana#1 (Boiler Supply) 700MW/24.1MPa 593/593°C
- 2000 HokurikuEPCO Tsuruga#2 (Boiler Supply) 700MW/24.1MPa 593/593°C
- 2002 Kyushu Reihoku#2 1,000MW/24.1MPa 593/593°C
- 2004 KansaiEPCO Maizuru#1 900MW/24.5MPa 595/595°C

**USC 600°C USC**

**Maturity Stage**

- 1998 TohokuEPCO Haramachi#2 1,000MW/24.5MPa 600/600°C
- 2000 J-Power Tachibana#2 1,050MW/25.0MPa 600/610°C
- 2003 TokyoEPCO Hitachinaka#1 1,000MW/24.5MPa 600/600°C
- 2013 TokyoEPCO Hitachinaka#2 1,000MW/24.5MPa 600/600°C
- 2004 TokyoEPCO Hirono#5 600MW/24.5MPa 600/600°C
- 2013 TokyoEPCO Hirono#6 600MW/24.5MPa 600/600°C

**Further Improvement**

- MHPS Since Feb. 2014

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Coal-Fired SC/USC Plant in overseas

- **Germany**: 14 units
  - Boxberg R

- **Netherlands**: 2 units

- **Italy**: 3 units
  - ENEL Torrevaldaliga Nord #2-4

- **Greece**: 1 unit

- **Poland**: 2 units
  - Henung Yuhuan #1 to #4

- **Japan**: 26 units
  - Misumi #1

- **Korea**: 4 units

- **Taiwan**: 8 units
  - Taiwan Power Co., Ltd. LIN KOU #1-3

- **Malaysia**: 1 unit

- **Canada**: 2 units

- **China**: 63 units (by MHPS / Licensee)
  - Henung Yuhuan #1 to #4

- **India**: 15 units (by L&T-MHPS Boilers Pvt. Ltd. as JV)
  - Jaypee Nigrie #1,2
  - Mahagenco Koradi #8,9,10
  - Rajpura #1,2

- **Indonesia**: 1 unit

- **Australia**: 1 unit
  - CS Energy Kogan Creek #1

- **Mexico**: 1 unit
  - CFE Pacifico #1

- **South Africa**: 12 units

- **Germany**: 14 units
  - Boxberg R

- **Netherlands**: 2 units

- **Italy**: 3 units
  - ENEL Torrevaldaliga Nord #2-4

- **Greece**: 1 unit

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  - Jaypee Nigrie #1,2
  - Mahagenco Koradi #8,9,10
  - Rajpura #1,2

- **Indonesia**: 1 unit

- **Australia**: 1 unit
  - CS Energy Kogan Creek #1

- **Mexico**: 1 unit
  - CFE Pacifico #1

- **South Africa**: 12 units

**Total**: 160 units
- **MHPS**: 110 units
- **Others**: 50 units (Chinese licensee)

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MHPS has contributed to Indian power generation CCT originated from Japan through the JV with Indian company, Larsen & Toubro, Ltd.
Indian Project Rajpura #1

- Rajpura #1 was placed under commercial operation from Feb 1st, 2014
- This unit was constructed by joint venture established by MHPS and Indian local company Larsen & Toubro, Ltd.
- Fuel is Indian high ash content bituminous coal (ash content is 30%)
- Local staff performed engineering/manufacturing/construction/commissioning works under MHPS’s instruction
- High efficiency and reliability of Japanese leading CCT were also proved in India

Output: 700MW
Main Steam Flow: 2,322 t/h
Main Steam: 565 °C / 24.1 MPag
Reheat Steam: 593 °C
Thermal efficiency: Approx. 4 ~ 5% better*1

<table>
<thead>
<tr>
<th>Fuel Property</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHV (kcal/kg, A.R.)</td>
<td>4,560</td>
</tr>
<tr>
<td>Fuel Ratio (-)</td>
<td>1.20</td>
</tr>
<tr>
<td>Moisture (A.R. %)</td>
<td>11.8</td>
</tr>
<tr>
<td>Ash (A.R. %)</td>
<td>27.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler Efficiency</td>
<td>90.08%</td>
</tr>
<tr>
<td>NOx</td>
<td>116 ppm</td>
</tr>
<tr>
<td>UBC</td>
<td>0.85%</td>
</tr>
</tbody>
</table>

Project Schedule & Operation Data

- Output: 700MW
- Main Steam Flow: 2,322 t/h
- Main Steam: 565 °C / 24.1 MPag
- Reheat Steam: 593 °C
- Thermal efficiency: Approx. 4 ~ 5% better*1

Project Schedule
- 48.5 months from LNTP to COD was achieved.

Performance
- Boiler Efficiency: 90.08%
- NOx: 116 ppm
- UBC: 0.85%

Availability
- Approx. 90% is achieved.
- Main reason of plant shut down is shortage of coal.

*1: Relative value as compared with Sub-critical plant (16.7MPag, 538/538°C)
# Global Activity with USC Technology

**Tokyo Electric Power Co., Ltd**  
**Hirono #6**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>600 MW</td>
</tr>
<tr>
<td>Main Steam Flow</td>
<td>1,770 t/h</td>
</tr>
<tr>
<td>Main Steam</td>
<td>600 °C / 24.5 MPag</td>
</tr>
<tr>
<td>Reheat Steam</td>
<td>600 °C</td>
</tr>
<tr>
<td>Commercial Operation</td>
<td>2013/12</td>
</tr>
<tr>
<td>Fuel</td>
<td>Bituminous Coal</td>
</tr>
</tbody>
</table>

**NTPC Khargone**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>660 MW</td>
</tr>
<tr>
<td>Main Steam Flow</td>
<td>2,038 t/h</td>
</tr>
<tr>
<td>Main Steam</td>
<td>600 °C / 26.4 MPag</td>
</tr>
<tr>
<td>Reheat Steam</td>
<td>600 °C</td>
</tr>
<tr>
<td>Commercial Operation</td>
<td>2019/03</td>
</tr>
<tr>
<td>Fuel</td>
<td>Indian Coal</td>
</tr>
</tbody>
</table>
MHPS dispatched approx. 20-40 technical advisor to Indian JV works. MHPS instructed boiler welding technique and steam turbine fabrication and etc.

Furthermore, MHPS dispatched technical advisor to the construction site to instruct construction work.
Global Activity with SC/USC Technology

Chinese Project Huaneng Anyuan #1,2

- First double reheat system for large capacity coal-fired boiler with USC steam condition
- MHPS has been responsible for basic engineering as licenser

Output: 2 x 660MW
Main Steam Flow: 1,938 t/h
Main Steam: 600 °C / 30.9 MPag
Reheat Steam: 620 °C / 620 °C
Commercial Operation: 2015/6&7
Fuel: Bituminous coal
Global Activity with SC/USC Technology

Indonesian Project Paiton III

- First coal-fired SC plant in Indonesia
- MHPS supplied boiler and steam turbine including construction work

Output: 866MW
Main Steam Flow: 2,695 t/h
Main Steam: 538 °C / 24.9 MPag
Reheat Steam: 566 °C
Commercial Operation: 2012/4
Fuel: Sub-bituminous coal
Thermal efficiency: Approx. 2 ~ 3% better

Fuel Property

<table>
<thead>
<tr>
<th>Property</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHV (kcal/kg, A.R.)</td>
<td>4,852</td>
</tr>
<tr>
<td>Fuel Ratio (-)</td>
<td>0.90</td>
</tr>
<tr>
<td>Moisture (A.R. %)</td>
<td>26.30</td>
</tr>
<tr>
<td>Ash (A.R. %)</td>
<td>2.61</td>
</tr>
</tbody>
</table>

Performance

<table>
<thead>
<tr>
<th>Property</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler Efficiency</td>
<td>88.68%</td>
</tr>
<tr>
<td>NOx</td>
<td>40 ppm</td>
</tr>
<tr>
<td>UBC</td>
<td>0.2 %</td>
</tr>
</tbody>
</table>

Project Schedule

45 months from LNTP to COD was achieved.

AR: As Received
Fuel Ratio = Fixed Carbon / Volatile Matter

*1: Relative value as compared with Sub-critical plant (16.7MPag, 538/538°C)
Germany Project Boxberg R

- USC steam condition was applied to German lignite-fired boiler
- Water content in the coal is approx. 60% and LHV is approx. 2000kcal/kg

Output: 1 x 670MW
Main Steam Flow: 1,760 t/h
Main Steam: 600 °C/ 29.3 MPag
Reheat Steam: 610 °C
Commercial Operation: 2012/10
Fuel: German Lignite coal
Thermal efficiency: Approx. 5 ~ 6% better*1

*1: Relative value as compared with Sub-critical plant (16.7MPag, 538/538°C)
Global Activity with SC/USC Technology

South Africa Project Medupi, Kusile

- SC technology is applied to South African Project
- 2 projects, total 12 boilers are under construction and commissioning

**Medupi**

- Output : 6 x 800MW
- Main Steam Flow : 2,288 t/h
- Main Steam : 564 °C/ 25.7 MPag
- Reheat Steam : 572 °C
- Fuel : Bituminous Coal

**Kusile**

- Output : 6 x 800MW
- Main Steam Flow : 2,288 t/h
- Main Steam : 564 °C/ 25.7 MPag
- Reheat Steam : 572 °C
- Fuel : Bituminous Coal
1. Conventional Clean Coal Technology
1-2. Small Class Coal Fired Power Plant
Small Class Coal Fired Power Plant

Backup for increase of renewable energy
- Role to compensate for output fluctuation of renewable energy e.g. wind power, solar energy generation on a regional basis
- Significant contribution to the grid stabilization by synchronous generator connected to steam turbine

Decentralized generation
- Reduction of transmission loss by generating electricity near the consuming region
- Necessity of Power supply to each production and/or manufacturing facility

Reduction of CO2 emission
- Reduction of CO2 emission by biomass co-firing as carbon neutral fuel
- Small class thermal power plant which can be installed regionally is effective in terms of biomass fuel supply

International contributions for small power grid countries
- Minimum unit capacity of USC/SC power plant is too large for small grid countries
- International contributions with small class coal fired power plant which applies Japanese highly efficient power generation technology

Necessity of Small Class Highly Efficient Coal Fired Power Plant

Decentralized generation
- Reduction of transmission loss by generating electricity near the consuming region
- Necessity of Power supply to each production and/or manufacturing facility

Backup for increase of renewable energy
- Role to compensate for output fluctuation of renewable energy e.g. wind power, solar energy generation on a regional basis
- Significant contribution to the grid stabilization by synchronous generator connected to steam turbine

Reduction of CO2 emission
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International contributions for small power grid countries
- Minimum unit capacity of USC/SC power plant is too large for small grid countries
- International contributions with small class coal fired power plant which applies Japanese highly efficient power generation technology
Small Class Highly Efficient Coal Fired Power Plant

- Achievement of more than 36% of overall net plant efficiency (HHV basis) to be the top class in small-sized thermal power plant
- Achievement of CO2 emission comparable to natural gas firing GTCC because of maximum 50% wood pellet co-firing as carbon neutral biomass fuel
- Pulverizing system exclusively used for either coal or wood pellet by switching between each fuel

Output: 112 MW
Main Steam Flow: 355 t/h
Main Steam: 566 °C/16.7 MPa
Reheat Steam: 566 °C
Fuel: Bituminous Coal, Wood Pellet
Example of Biomass Co-firing Technology applied to Coal Fired Boiler
“Wood Pellet 30% Co-firing”

<110MW Biomass Co-firing Boiler>
Realization of operability for each fuel co-firing ratio and/or pulverizer applicability to various fuel including biomass based on pulverizer grindability tests and co-firing ratio verification test results

Example of Usable Biomass fuel

White Pellet

Black Pellet

<table>
<thead>
<tr>
<th>Pulverizer Operation Pattern</th>
<th>No.1 Mill</th>
<th>No.2 Mill</th>
<th>No.3 Mill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Combustion</td>
<td>Coal</td>
<td>Coal</td>
<td>Coal</td>
</tr>
<tr>
<td>Pellet Co-firing (≤30%)</td>
<td>Coal</td>
<td>Pellet</td>
<td>Coal</td>
</tr>
</tbody>
</table>

Pellet will be exclusively crushed with one out of pulverizers in the case of 30% co-firing.
2. Air Quality Control System
Air Quality Control System 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
MHPS has reduced boiler outlet NOx emission through continuous development of low NOx combustion technology.

In combination with SCR system, world lowest level NOx emission is achieved.
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:
- Detailed measurement
- Verification of combustion performance

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

Upgrade of CFD
Advanced and Speedy test
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

FGD Absorber

Chemical Reaction in Absorber

SO₂ + CaCO₃ (limestone) + 2H₂O → CaSO₄・2H₂O (gypsum) + CO₂

FGD Performance

More than 95% SO₂ removal efficiency can be achievable.
AQCS in Japan commercialized from 1970’s
High Efficiency AQCS with Low Low temperature EP has been developed to meet the severe environmental demand
Emission level now reaches world lowest level

- SO2: 100ppm
- SO2: 50ppm
- PM: <20mg/m³N
- SO2: 24ppm
- PM: <7mg/m³N

Non Leak GGH applied to prevent dirty gas leakage.
High Efficiency system with low-low temperature EP applied.

EP: Electrostatic Precipitator
GGH: Gas Gas Heater
RGGH: Rotary GGH
H/E: Heat Extractor
R/H: Re Heater
3. Advanced Clean Coal Technology
Outline of IGCC System

① Conventional Coal Firing System

② Integrated Coal Gasification Combined Cycle (IGCC)

Gas Turbine (Brayton Cycle)

High efficiency
Features of IGCC system (Environmental Performance)

**Higher Efficiency and Least Environmental Impact**

- **Coal-fired USC power plant (steam at 600°C)**
  
- **Approx. 60% decrease in volume**

<table>
<thead>
<tr>
<th>Plant Efficiency</th>
<th>CO2</th>
<th>Ash</th>
<th>Circulating Water</th>
<th>Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>+10~20%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>▲ 10~20%</td>
<td>▲ 60%</td>
<td>▲ 30%</td>
<td></td>
</tr>
</tbody>
</table>

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

Flexibility to “Variety of Coal”

<Coal Available for Import to Japan>

Domestic consumption is dominant

More imports are expected to Japan

Easy to import to Japan

Coal with High Ash Fusion Temp. Already Utilized at conventional boiler (Applicable also for IGCC)

Coal with Low Ash Fusion Temp. Newly Available (Ideal for IGCC)

<When conventional boiler uses Coal with Low Ash Fusion Temp.>

Ash adhering on the furnace wall which causes output reduction and chunky slag formation (slagging) needs to be taken care of.

⇒ Enlarged furnace volume is required.

Merits of IGCC

① Combustor makes coal ash molten form and collects it on furnace wall by centrifugal force of tangential flow.

② Coal injection at Reductor works as quench to reduce gas temperature below the ash fusion temp.

⇒ Preventing the slagging and allowing the use of coal with low ash fusion temp without enlarged gasifier.

Confirmed the gasification / IGCC operation of sub-bituminous coal with low ash fusion temp. in Indonesia, the United States, etc. at Nakoso 250MW IGCC plant.
Nakoso 250MW IGCC Plant

### Major Specification

<table>
<thead>
<tr>
<th>Output</th>
<th>250 MW (gross)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasifier</td>
<td>Air-blown Dry Feed</td>
</tr>
<tr>
<td>Gas Clean-Up</td>
<td>MDEA (Methyl diethanol amine)</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>M701DA GT (1 on 1)</td>
</tr>
<tr>
<td>Plant Efficiency</td>
<td>42% (LHV, net)</td>
</tr>
</tbody>
</table>

### 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.

(Japan Society of Mechanical Engineering)
Osaki CoolGen Project

Major Specification
- Output: 166 MW (gross)
- Gasifier: Oxygen-blown Dry Feed
- Gas Clean-Up: MDEA (Methyldiethanol Amine)
- Gas Turbine: H-100 GT (1 on 1)
- Plant Efficiency: 40.5% (HHV, net)

Project Schedule
- Construction Started: March 2013
- Demo. Operation Start: March 2017
## Osaki CoolGen Project

### Schedule for oxygen-blown IGCC demonstration (Step1)

<table>
<thead>
<tr>
<th>FY</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work to be implemented</td>
<td>Detailed design and construction of oxygen-blown IGCC units and facilities</td>
<td>Demonstration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Design &amp; Manufacturing</td>
<td>• Design &amp; Manufacturing</td>
<td>• Design &amp; Manufacturing</td>
<td>• Design &amp; Manufacturing</td>
<td>• Design &amp; Manufacturing</td>
<td>• Equipment &amp; electrical work</td>
<td>• Verification of basic performance Plant performance</td>
<td></td>
</tr>
<tr>
<td>• Civil work</td>
<td>• Civil work</td>
<td>• Civil work</td>
<td>• Civil work</td>
<td>• Civil work</td>
<td>• Gasification Operation</td>
<td>Environmental performance</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Equipment &amp; electrical work</td>
<td>• Equipment &amp; electrical work</td>
<td>• Equipment &amp; electrical work</td>
<td>• Completion of equipment work</td>
<td>• Verification of coal variety compatibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Hydraulic tests</td>
<td>• Power reception</td>
<td></td>
<td></td>
<td>• Verification of plant reliability Prolonged endurance test</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Verification of controllability &amp; operability Load change rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Starting/stopping times Economy evaluation</td>
<td></td>
</tr>
</tbody>
</table>
**IGCC Commercial Plant**

**Net Plant Efficiency (LHV %)**

- **250 MW**
- **460 MW**
- **540 MW**

**Gross Output (MW)**

- **250 MW**
- **460 MW**
- **540 MW**

<table>
<thead>
<tr>
<th>Item</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>60Hz</strong></td>
</tr>
<tr>
<td>Coal</td>
<td>Bituminous</td>
</tr>
<tr>
<td>Output Gross</td>
<td>460 MW</td>
</tr>
<tr>
<td>Net</td>
<td>410 MW</td>
</tr>
<tr>
<td>Gasifier</td>
<td>Air-blown Dry Feed</td>
</tr>
<tr>
<td>Gas Clean-Up</td>
<td>MDEA (Methyl Di-ethanol Amine)</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>M501GAC×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

Tokyo Electric Power Co. Fukushima IGCC Project
Osaki CoolGen Corp. Osaki CoolGen Project

IGCC Commercial Projects
MHPS has dominantly developed large scale SOFCs with the governmental support by METI / NEDO in Japan.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>MGT Hybrid System for Distributed Power Source</td>
<td>Demonstrations @ Kyushu Univ.</td>
<td>Demonstrations @ several sites in 2 years</td>
<td>Commercialization</td>
<td>Multi station Tri-generation demonstration</td>
<td>Commercialization</td>
<td>Multi Energy Station</td>
<td>(NEDO: New Energy and Industrial Technology Development Organization)</td>
<td>(Bringing stationary fuel cells for commercial and industrial use to the market)</td>
<td>In 2017: Bringing stationary fuel cells for commercial and industrial use to the market</td>
</tr>
</tbody>
</table>

| 250kW class SOFC-MGT hybrid system | Multi Energy Station | | | | | | | |
|-----------------------------------|---------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 1300kW class SOFC-MGT hybrid system | Multi Energy Station | | | | | | | | | |
Principle of SOFC

Electricity Generating Part

Cell-Stack

Length: 1500mm
Diameter: 28mm

【Model 10】

Cathode (LaSrCaMnO₃)

Inter-connector (Titanate)

Electrolyte (YSZ)

Anode (Ni/YSZ)

Substrate tube (CSZ)

Fuel

Air

O₂

H₂

H₂O

CH₄
etc.

O₂⁻

O₂⁻

O₂⁻

O₂⁻
The demonstration 250kW class system started operation from March 2015 in Kyushu university.
Commercialized in 2017 as a 250kW class co-generation system.

250kW class Demonstration system in Ito campus of Kyushu Univ.

(Specifications for the hybrid systems (expected))

<table>
<thead>
<tr>
<th>Output power</th>
<th>250kW class (in demonstration)</th>
<th>1.3MW class (planned)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOFC/MGT</td>
<td>kW</td>
<td>kW</td>
</tr>
<tr>
<td>Efficiency at sending end</td>
<td>%-LHV</td>
<td>55</td>
</tr>
<tr>
<td>Total efficiency</td>
<td>%-LHV</td>
<td>73 (Hot water)</td>
</tr>
<tr>
<td>Outside dimension</td>
<td>m</td>
<td>11 × 4</td>
</tr>
<tr>
<td>Fuel</td>
<td>-</td>
<td>City gas (13A)</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>MPa</td>
<td>0.23</td>
</tr>
<tr>
<td>NOx</td>
<td>ppm</td>
<td>15≤</td>
</tr>
<tr>
<td>Noise</td>
<td>dB</td>
<td>70≤</td>
</tr>
</tbody>
</table>
Demonstration system in Ito campus of Kyushu Univ. 2015

Real-time information panel for the energy supply in Ito campus, Kyushu university.
Demonstration in Kyushu university has been performed for over 2,500 hrs. SOFC is durable enough to instantly restart after several stops originating in the troubles by grid.

Operation time: 2,625 hrs @ 4:30 PM August 21st 2015 JST.
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.