Clean Coal Technologies for IGCC Power Plants

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1. Introduction
2. Features of IGCC system
3. Development
4. Commercial Plant
5. Examples of Feasibility Study
6. Future Applications
7. Conclusion
Product Lines utilizing Gasification Technology

Coal

Gasifier

Gas Clean-up (Dust Removal, Desulfurization)

Syngas (CO, H2)

Gas Clean-up (Deep Sulfur Removal)

CO₂ Removal (Shift Reaction + CO₂ Capture)

Syngas (H₂)

Absorbed into solvent & Sequestrated in underground

GT & ST (IGCC)

SOFC + GT + ST (IGFC)

GT & ST (IGCC w/CCS)

Ammonia Synthesis

Fertilizer Synthesis

SNG Synthesis

CTL

Chemical Synthesis

Fuel Production

SNG: Substitute Natural Gas
CTL: Coal to Liquids

Overview of IGCC (Integrated coal Gasification Combined Cycle) Technology

Why IGCC?

IGCC is the cutting-edge technology:

- High Efficiency
- Lower CO₂ Emission & Ash Volume
- Fuel Flexibility
- Highly Reliable System

Its demonstration successfully finished and commercial projects have started.
Why IGCC has high efficiency?

Higher efficiency through coal gasification process coupled with a combined cycle (CC) system.

IGCC Projects in Japan

Fukushima Revitalization Power

Nakoso IGCC Power, 540 MW (COD: 2020.9)

Hirono IGCC Power, 540 MW (COD: 2021.9)

Osaki CoolGen Corp.
Osaki CoolGen Project
166 MW (Demo. 2017)

Joban Joint Power Co.
Nakoso #10, 250 MW
(Demo. 2007-, COD: 2013)
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Air-blown IGCC System Configuration

**MHPS can supply entire IGCC plants with single point responsibility**

**Gasifier / Gas Clean-up**: Clean fuel gas generation from coal with high efficiency

- **Highly Efficient Gasifier**: Coal is converted to syngas fuel of gas turbine.
- **Wet Gas Clean-up (MDEA)**: Contaminant in syngas is cleaned up.
- **Air Separation Unit (ASU)**: ASU for N2 Generation
  - Inerting N2 for coal transportation is produced.
  - O2 as a by-product is mixed with air and efficiently utilized as gasification reaction enhancer.
- **GTCC is fueled with syngas.**

**Combined Cycle**: Efficient Power Generation by fuel syngas
Features of IGCC system (How the gasifier works)

1. **Combustor (1st Stage)**
   - **Function:**
     - Combustion of coal and char (Exothermic reaction)
     - C + O₂ → CO₂
     - Stable discharge of molten slag down into the water bath

2. **Reductor (2nd Stage)**
   - **Function:**
     - Gasification utilizing sensible heat of high temp. gas from Combustor (Endo-thermic reaction)
     - C + CO₂ → 2CO / C + H₂O → CO + H₂
     - No quench steam / gas is injected for cooling syngas because of the endothermic reaction in the Reductor. Waterwall - wall composed of water tubes - also works for cooling.

3. **SGC (SynGas Cooler)**
   - SGC (SynGas Cooler) works as a heat exchanger where heat from syngas is absorbed by water and steam.

4. **Char recycling system**
   - Recovers almost all amount of char (mixture of ash and unburnt carbon) and recycles it into the Combustor so as to minimize the unburnt carbon.

Features of IGCC system (Environmental Performance)

**Higher Efficiency and Least Environmental Impact**

<table>
<thead>
<tr>
<th>Plant Efficiency</th>
<th>CO₂ Emission</th>
<th>Ash Volume</th>
<th>Circulating Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal-fired USC power plant (steam at 600°C)</td>
<td>▲ 10~20%</td>
<td>▲ 60%</td>
<td>▲ 60%</td>
</tr>
<tr>
<td>Fly-ash (Conventional Boiler)</td>
<td>▲ 10~20%</td>
<td>▲ 10~20%</td>
<td></td>
</tr>
<tr>
<td>Glassy Molten Slag (IGCC)</td>
<td>▲ 30%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Approx. 60% decrease in volume

Utilization as a pavement material are possible.
Features of IGCC System (Fuel Flexibility)

**Flexibility to “Variety of Coal”**

<When conventional PC boiler uses Low-Rank Coals that have Low Ash Fusion Temp.>

Low ash fusion temperature causes slagging problem
⇒ Enlarged furnace volume or derating 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. Molten cinder ash runs down through the slag tap into water.
⇒ Preventing the slagging with low ash fusion temp without enlarged gasifier.

Gas Turbine – IGCC Application

- **F4-type Gas Turbine** is applied to 500MW-class IGCC plant.
- Combustor is the only part of enhancement from natural gas firing gas turbine.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Compressor</th>
<th>Combustor</th>
<th>Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
</tr>
<tr>
<td>Gasification syngas</td>
<td><strong>Same</strong> (Addition of Air Extraction Port)</td>
<td><strong>Fuel Nozzle Modification</strong></td>
<td><strong>Same</strong></td>
</tr>
</tbody>
</table>
Fuel Gas Characteristics Applied to IGCC Gas Turbine

- Syngas of IGCC has same calorie as BFG but superior ignitability.
- Its combustibility is ensured by using the diffusion combustor though high calorie natural gas applies the pre-mix combustor.

### 1. Introduction

### 2. Features of IGCC system

### 3. Development

### 4. Commercial Plant

### 5. Examples of Feasibility Study

### 6. Future Applications

### 7. Conclusion
IGCC/Gasification Technology Development

- Accumulated Original Technologies through Long Term R&D Activities since Early 1980’s
- Achievement of High Reliability in Operation at Nakoso 250MW Demo. Plant
- Osaki CoolGen, is in the course of demonstration.

Output (MW)

<table>
<thead>
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<tbody>
<tr>
<td>Scale up: 100 times</td>
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</table>

Development History of MHPS Air-blown IGCC

- 200 t/d Nakoso Pilot Plant (1991-)
- EAGLE Pilot Plant (2002-2013, 2017-)
- Osaki CoolGen Project (Demo. 2017-)
- 500MW-Class Commercial Plant

Coal Consumption (t/d)

- 2t/d PDU* (CRIEPI Yokosuka)
- 8.5 times
- 24t/d Verification Plant (MHI Nagasaki)
- 24 times
- 1,000 t/d PDU
- 5,000 t/d

Design & Construction

Operation

Commercial Operation

Fukushima IGCC Project

2020 2021

Next Plants

Sponsored by NEDO

Sponsored by METI

Sponsored by METI and NEDO
Development History of MHPS Oxygen-blown IGCC

**PDU test (Process Development Unit)**
(1t/d 1981 ~ 1985 at Katsuta)

**HYCOL pilot test (Hydrogen from Coal)**
(50t/d 1990 ~ 1993 at Sodegaura)

**EAGLE pilot test (Coal Energy Application for Gas, Liquid and Electricity)**
(150t/d 2002 ~ 2013, 10t/d 2017 at Wakamatsu)

**OCG Project (Osaki CoolGen)**
(1,180t/d 2017 ~ Demo. Operation onward at Osakikamijima-cho)

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: (High Efficiency, Less Environmental impact)
- Higher Reliability: (World record of continuous operation, 3,917 hrs
Cumulative operation hrs. exceeded 38,000 hrs.)
- Fine Operability: (Load change rate >3%/min)
- Fuel Flexibility: (Verified applicability for low-rank coal)

Converted to the First Commercial IGCC Plant in Japan.
## Achievements of Nakoso 250MW IGCC Plant

<table>
<thead>
<tr>
<th></th>
<th>Targets</th>
<th>Achievements</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Performance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output (Gross) (Net)</td>
<td>250MW</td>
<td>250MW</td>
<td></td>
</tr>
<tr>
<td></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>
<tr>
<td><strong>Emission</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOx (@dry, 16%O2)</td>
<td>&lt; 8 ppm</td>
<td>1.0 ppm</td>
<td>10 kinds of coal in total 6 Sub-bituminous</td>
</tr>
<tr>
<td>NOx</td>
<td>&lt; 5 ppm</td>
<td>3.4 ppm</td>
<td>4 Bituminous have been used.</td>
</tr>
<tr>
<td>Dust</td>
<td>&lt; 4 mg/m³N</td>
<td>&lt; 0.1 mg/m³N</td>
<td></td>
</tr>
<tr>
<td><strong>Operational Flexibility</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal Kinds</td>
<td>Bituminous</td>
<td>Chinese, Canadian</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub-bituminous</td>
<td>2 US (including PRB)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>3 Indonesian (Adaro, etc.)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Colombian, 2 Russian</td>
<td></td>
</tr>
<tr>
<td><strong>Start-up Time</strong></td>
<td>&lt; 18 hr</td>
<td>15 hr</td>
<td></td>
</tr>
<tr>
<td><strong>Minimum Load</strong></td>
<td>50%</td>
<td>36%</td>
<td></td>
</tr>
<tr>
<td><strong>Ramping Rate</strong></td>
<td>3%/min</td>
<td>3%/min</td>
<td></td>
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<tr>
<td><strong>Reliability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long-term Continuous</td>
<td>2,000 hr</td>
<td>3,917 hr</td>
<td>Cumulative operating hours : &gt; 38,000 hrs.</td>
</tr>
<tr>
<td>Operation**</td>
<td></td>
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</tbody>
</table>

## 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 Started: March 2017 (First step)

- **First step**: Oxygen-blown IGCC
- **Second step**: IGCC with CO₂ Capture
  - Add installing CO shift reactor and CO₂ capture unit
  - IGCC; 168MW (Coal feed rate: 1180t/d)
  - Gasifier: Single Chamber with Two Stages Spiral Flow Gasifier
  - Steam turbine
  - Gas turbine
  - Generator
  - Stack
  - Air separation unit
  - Oxygen
- **Third step**: IGFC with CO₂ Capture
  - H₂
  - CO₂ Transport and Storage
  - CO₂ Capture Unit
  - Add installing CO shift reactor and CO₂ capture unit
  - (*3) CO₂ Transportation and Storage are outside of the Osaki CoolGen Project.

- (*1) Demo. Operation of Second step will start in FY 2019
- (*2) Demo. Operation of Third step will start in FY 2021
- (*3) Sponsored by METI and NEDO
A crane lifted the gasifier and placed it on a dolly on a track.

**Schedule for oxygen-blown IGCC demonstration (First step)**

<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>
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<tr>
<td><strong>Detailed design and construction of oxygen-blown IGCC units and facilities</strong></td>
<td></td>
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<td></td>
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<tr>
<td><strong>Demonstration</strong></td>
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</tr>
</tbody>
</table>

Photos courtesy of Osaki CoolGen Corp.

1. Introduction
2. Features of IGCC system
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Fukushima Revitalization Power IGCC Project

Major Specification
- Output: 540 MW (gross) 480 MW (net)
- Gasifier: Air-blown
- Gas Clean-Up: MDEA
- Gas Turbine: M701F GT (1 on 1)

Project Schedule
- Operation Start: 2020 (Nakoso site)
- 2021 (Hirono site)

Schedule
- 2014.8 Engineering Work Started
- 2016.9 EIA Completed / Permit Obtained
- 2016.10 Site Mobilization Started
- 2017.4 Construction Started
- Commercial Operation (Scheduled)
  - 2020.9 Nakoso IGCC
  - 2021.9 Hirono IGCC

Production of Pressure Vessel for IGCC Plants Now Underway
MHPS supports IGCC projects in the world

Fukushima Revitalization Power
- Nakoso 540MW
- Hirono 540MW
Joban JPC. Nakoso #10 250MW
Osaki CoolGen Project 166MW (Demo. Operation ongoing)

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Examples of Feasibility Study ~ Thailand

**IGCC Principal Specification**

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>User</td>
<td>EGAT</td>
</tr>
<tr>
<td>Site</td>
<td>Mae Moh PP (For #8-#9 Replacement)</td>
</tr>
<tr>
<td>Output</td>
<td>500MW-class IGCC x 1unit</td>
</tr>
<tr>
<td>Fuel</td>
<td>Mae Moh Lignite</td>
</tr>
<tr>
<td>Main Component</td>
<td>Air-blown Gasifier</td>
</tr>
<tr>
<td></td>
<td>M701F Type Gas Turbine x 1</td>
</tr>
</tbody>
</table>

**Schedule**

2015/4～2016/3 : NEDO* Feasibility Study
2015/12 : Mae Moh Lignite Gasification Verification in Nagasaki, Japan
2016/2 : Reported Feasibility Study Result to EGAT

(*) NEDO : New Energy and Industrial Technology Development Organization

Examples of Feasibility Study ~ Poland

**IGCC Principal Specification**

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>User</td>
<td>EW (Enea Wytwarzanie sp. z o.o.)</td>
</tr>
<tr>
<td>Site</td>
<td>Kozienice Power Plant or Green Field Investment</td>
</tr>
<tr>
<td>Output</td>
<td>500MW-class IGCC x 1unit</td>
</tr>
<tr>
<td>Fuel</td>
<td>Bogdanka Coal</td>
</tr>
<tr>
<td>Main Component</td>
<td>Air-blown Gasifier</td>
</tr>
<tr>
<td></td>
<td>M701F Type Gas Turbine x 1</td>
</tr>
</tbody>
</table>

**Schedule**

2015/10～2016/6 : NEDO* Feasibility Study
2016/4 : Bogdanka Coal Gasification Verification in Nagasaki, Japan
2016/6 : Reported Feasibility Study Result to EW

(*) NEDO : New Energy and Industrial Technology Development Organization
The gasification verification of each coal was conducted by using the gasification verification facilities at MHI Research & Innovation Center, Nagasaki.

Example of Gasification test result

- **Stable slag discharge**
  - Glassy slag discharged
  - Slag hole real-time monitor
  - Water bath real-time monitor

- **No significant slag deposits in the gasifier**
  - Reductor, Upper direction
  - Reductor, Lower direction
  - Combustor, water-wall
MHPS IGCC has successfully operated in using world-wide variety of coal.

Variety of Coal Experience and Capability

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IGCC System Configuration with CO2 Capture (Pre Combustion)

CO2 Comp

Desulfurization

CO Shift

Coal Gasifier

H2O

CO Shift: CO+H2O→CO2+H2

GT: Gas Turbine

Comp.

ST: Steam Turbine

Generator

Stack

HRSG

GT

Compressor

Air

Improvement of Thermal Efficiency

GTCC: Gas Turbine Combined Cycle

IGCC: Integrated coal Gasification Combined Cycle

SOFC: Solid Oxide Fuel Cell

USC: Ultra Super Critical pressure Coal-fired plant

A-USC: Advanced-Ultra Super Critical pressure Coal-fired plant

GTCC: (Natural gas)

IGCC: (Coal)

A-USC

GTCC applying super high-temperature gas turbine (1,700 °C class)

IGCC + SOFC (Hybrid cycle)

IGCC + SOFC (Coal)

Super high-temperature gas turbines (1,700°C)

GTCC + SOFC (Natural gas)
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Conclusion

- The 250MW Air-blown IGCC demonstration plant, operating now as Joban JPC Nakoso #10 - the first IGCC commercial plant in Japan, successfully achieved all of its purpose and targets.
- MHPS has started Air-blown IGCC commercial projects represented by Nakoso & Hirono IGCC Powers 540MW × 2 aiming at CO2 reduction by 10-20%.
- Oxygen-blown IGCC, Osaki CoolGen, is in the course of demonstration.
- MHPS expects that our IGCC technology will contribute to the solution of energy and environmental issues in the world, with full reflection of the accumulated experiences at IGCC projects in Japan.