Clean Coal Technologies for IGCC Power Plants

Sep 6, 2017

Yoshiyuki Wakabayashi
Executive Vice President
Mitsubishi Hitachi Power Systems, LTD
Contents

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 → Power Generation

- GT & ST (IGCC)
- SOFC + GT + ST (IGFC)
- GT & ST (IGCC w/CCS)

Chemical Synthesis
- Ammonia Synthesis
- Fertilizer Synthesis
- SNG Synthesis
- CTL

Fuel Production
- SNG: Substitute Natural Gas
- CTL: Coal to Liquids

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 )
1. Introduction
2. Features of IGCC system
3. Development
4. Commercial Plant
5. Examples of Feasibility Study
6. Future Applications
7. Conclusion
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.

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.

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

② 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.

① 2-Chamber/2-Stage Configuration

Reducer (2nd Stage)

Function:
• Gasification utilizing sensible heat of high temp. gas from Combustor (Endo-thermic reaction)
  C+CO₂→2CO / C+H₂O→CO+H₂

Combustor (1st Stage)

Function:
• Combustion of coal and char (Exothermic reaction)
  C+O₂→CO₂
• Stable discharge of molten slag down into the water bath

③ 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>Feature</th>
<th>Coal-fired USC power plant (steam at 600°C)</th>
<th>IGCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Efficiency</td>
<td>+10~20%</td>
<td>Glassy Molten Slag (IGCC)</td>
</tr>
<tr>
<td>CO2 Emission</td>
<td>40%</td>
<td>Glassy Molten Slag (IGCC)</td>
</tr>
<tr>
<td>Ash Volume</td>
<td>60%</td>
<td>Approx. 60% decrease in volume</td>
</tr>
<tr>
<td>Circulating Water</td>
<td>▲60%</td>
<td>Utilization as a concrete aggregate are possible.</td>
</tr>
<tr>
<td>Emission</td>
<td>▲30%</td>
<td>Utilization as a pavement material</td>
</tr>
</tbody>
</table>

Fly-ash (Conventional Boiler)
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: Natural gas</th>
<th>Fuel: Gasification syngas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressor</td>
<td>Base</td>
</tr>
<tr>
<td>Combustor</td>
<td>Base (Addition of Air Extraction Port)</td>
</tr>
<tr>
<td>Turbine</td>
<td>Base</td>
</tr>
<tr>
<td>Fuel Nozzle</td>
<td>Fuel Nozzle Modification</td>
</tr>
<tr>
<td>Modification</td>
<td>Same</td>
</tr>
</tbody>
</table>
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
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.
Development History of MHPS Air-blown IGCC

- 2t/d PDU* (CRIEPI Yokosuka)
- 200t/d Nakoso Pilot Plant (Joban JPC., Nakoso P/S)
- 1,700t/d (250MW) Demo. Plant ⇒ Joban JPC. Nakoso #10
- 24t/d Verification Plant (MHI Nagasaki)
- Design & Construction: Operation
- Scale up: 100 times
- Operation
- 8.5 times
- 2013
- 2 times
- 500MW-Class Commercial Plant
- Fukushima IGCC Project 2020 2021
- Next Plants
- Commercial Operation
- 2015
- 2013
- Verification Plant
- Design & Construction Operation
- 2015
- 2010
- 2005
- 2000
- 1995
- 1990
- 1985
- 1980
- Coal Consumption (t/d)
- 5,000
- 1,000
- 500
- 100
- 50
- 10
- 1
- 500MW-Class Commercial Plant
- Fukushima IGCC Project 2020 2021
- Next Plants
- Commercial Operation
- 2015
- 2013
- Verification Plant
- Design & Construction Operation
- 2015
- 2010
- 2005
- 2000
- 1995
- 1990
- 1985
- 1980
- Coal Consumption (t/d)
- 5,000
- 1,000
- 500
- 100
- 50
- 10
- 1

*PDU: Process Development Unit
Development History of MHPS Oxygen-blow 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)

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

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

Photos courtesy of Osaki CoolGen Corp.
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>Performance</th>
<th>Targets</th>
<th>Achievements</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output (Gross) (Net)</td>
<td>250MW 220MW</td>
<td>250MW 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>Emission (@dry, 16%O2)</td>
<td>SOx &lt; 8 ppm, 5 ppm</td>
<td>1.0 ppm 3.4 ppm</td>
<td>10 kinds of coal in total</td>
</tr>
<tr>
<td></td>
<td>NOx &lt; 4 mg/m^3N</td>
<td>&lt; 0.1 mg/m^3N</td>
<td>6 Sub-bituminous 4 Bituminous have been used.</td>
</tr>
<tr>
<td>Operational Flexibility</td>
<td>Coal Kinds</td>
<td>Bituminous Sub-bituminous Chinese, Canadian 2 US (including PRB) 3 Indonesian (Adaro, etc.) Colombian, 2 Russian</td>
<td></td>
</tr>
<tr>
<td>Start-up Time</td>
<td>&lt; 18 hr</td>
<td>15 hr</td>
<td></td>
</tr>
<tr>
<td>Minimum Load</td>
<td>50%</td>
<td>36%</td>
<td></td>
</tr>
<tr>
<td>Ramping Rate</td>
<td>3%/min</td>
<td>3%/min</td>
<td></td>
</tr>
<tr>
<td>Reliability</td>
<td>Long-term Continuous Operation</td>
<td>2,000 hr 3,917 hr</td>
<td>Cumulative operating hours : &gt; 38,000 hrs.</td>
</tr>
</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

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

**Second step**: IGCC with CO₂ Capture

- Add installing CO shift reactor and CO₂ capture unit

**Third step**: IGFC with CO₂ Capture

- CO₂ Transport and Storage (1)

- (1) Demo. Operation of Second step will start in FY 2019

- (2) Demo. Operation of Third step will start in FY 2021

- (3) CO₂ Transportation and Storage are outside of the Osaki CoolGen Project.
Osaki CoolGen Project

The gasifier was erected vertically and moved up to a designed position. 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>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Detailed design and construction of oxygen-blown IGCC units and facilities

Demonstration

Photos courtesy of Osaki CoolGen Corp.

Inside grounds of Chugoku Electric’s Osaki Power Station
1. Introduction
2. Features of IGCC system
3. Development
4. Commercial Plant
5. Examples of Feasibility Study
6. Future Applications
7. Conclusion
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
Fukushima Revitalization Power IGCC Project

Production of Pressure Vessel for IGCC Plants Now Underway
Japan’s IGCC Technology Contributes to Global Solution for Environment

**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)

**IGCC Commercial Projects**
1. Introduction
2. Features of IGCC system
3. Development
4. Commercial Plant
5. Examples of Feasibility Study
6. Future Applications
7. Conclusion
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×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 ×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

View of Existing Plant / Coal Mine
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 × 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</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

View of Existing Plant
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

No significant slag deposits in the gasifier

Glassy slag discharged
MHPS IGCC has successfully operated in using world-wide variety of coal.

Variety of Coal Experience and Capability

MHPS IGCC has successfully operated in using world-wide variety of coal.

Fuel Ratio (Fixed Carbon / Volatile)

Ash Fluid Temperature [deg-C]
1. Introduction
2. Features of IGCC system
3. Development
4. Commercial Plant
5. Examples of Feasibility Study
6. Future Applications
7. Conclusion
IGCC System Configuration with CO2 Capture (Pre Combustion)

Coal Gasifier

H2O

CO Shift

Desulfurization

CO2 Comp

CO2 Absorption

GT: Gas Turbine
ST: Steam Turbine

CO Shift: CO + H2O → CO2 + H2
Improvement of Thermal Efficiency

Gross efficiency vs. LHV %

- **GTCC (Natural gas)**
  - ① A-USC
  - ② Super high-temperature gas turbines (1,700°C)
  - ③ GTCC + SOFC (Coal)
  - ④ IGCC + SOFC (Hybrid cycle)

**USC (Coal)**

- **IGCC (Coal)**
  - ① A-USC
  - ② GTCC applying super high-temperature gas turbine (1,700 °C class)
  - ③ GTCC + SOFC (Hybrid cycle)
  - ④ IGCC + SOFC (Hybrid cycle)

**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
IGFC (Integrated coal Gasification Fuel Cell combined cycle)

Integrated coal Gasification Fuel Cell combined cycle (IGFC)

**Diagram Description:**

- **Gasifier**
  - Coal input
  - Air from ASU
  - N2 input
  - Slag output
  - Heat exchange

- **Desulfurization system**
  - Dust remover
  - From *1

- **SOFC**
  - Gas Turbine
  - Heat Recovery Steam Generator
  - Exhaust gas
  - Condenser

- **Inverter**

**Combined Cycle System:**
SOFC+G/T+S/T
1. Introduction
2. Features of IGCC system
3. Development
4. Commercial Plant
5. Examples of Feasibility Study
6. Future Applications
7. Conclusion
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.
Power for a Brighter Future