Korean Oxy Fuel Demonstration

Korea Electric Power Corporation
Korea Electric Power Research Institute

2009. 2. 6

Advanced Power Generation & Combustion Group
Dr. Sung-Chul Kim
Contents

- Status of Electric power Capacity & Power Generation
- CO₂ Capture Research Activities
  - Oxy- Fuel Combustion Research Activities in KEPCO
  - Brief Review of Research on First Year
# Electric Power Companies in Korea

<table>
<thead>
<tr>
<th>Company</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro &amp; Nuclear Power (KHNP)</td>
<td>Hydro (0.5GW) &amp; Nuclear (17.7GW)</td>
</tr>
<tr>
<td><strong>Korea South-Eastern Power (KOSEP)</strong></td>
<td>Thermal Power Generation</td>
</tr>
<tr>
<td>East-Western Power (EWP)</td>
<td>- Steam Power : Coal &amp; Oil</td>
</tr>
<tr>
<td>Western Power (WP)</td>
<td>- NGCC</td>
</tr>
<tr>
<td><strong>Korea Middle Power (KOMIPO)</strong></td>
<td>- 8 GWe for each company</td>
</tr>
<tr>
<td><strong>Southern Power (KOSPO)</strong></td>
<td>Main Coal Power Stations</td>
</tr>
<tr>
<td><strong>Korea Power Engineering Co. (KOPEC)</strong></td>
<td>- 6~10 units per one site</td>
</tr>
<tr>
<td><strong>Korea Electric Power Research Institute</strong></td>
<td>Engineering Company</td>
</tr>
<tr>
<td>(KEPRI)</td>
<td>Research Wing</td>
</tr>
</tbody>
</table>
The State of Capacity & Power Generation

Power Plant (the end of 2006)

- **Power Capacity**
  - Nuclear: 4,790 MW (26.6%)
  - Hydraulic: 18,465 MW (28.2%)
  - Oil: 5,485 MW (8.4%)
  - Gas: 17,716 MW (27.0%)
  - Total: 65,514 MW

- **Power Generation**
  - Coal: 18,465 TWh (36.5%)
  - Renewal Energy Capacity: 240 MW
  - Renewal Energy Power Generation: 511 GWh
  - Total: 380,964 GWh
# Industry Sector of coal in Korea

<table>
<thead>
<tr>
<th>Nation</th>
<th>Iron and Steel</th>
<th>Power generation</th>
<th>Cement, Others</th>
<th>Total</th>
<th>Proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>9,929,158</td>
<td>19,488,947</td>
<td>361,014</td>
<td>29,779,119</td>
<td>43.0</td>
</tr>
<tr>
<td>China</td>
<td>1,858,261</td>
<td>10,428,538</td>
<td>5,824,926</td>
<td>18,111,725</td>
<td>26.1</td>
</tr>
<tr>
<td>Indonesia</td>
<td>0</td>
<td>12,847,471</td>
<td>37,700</td>
<td>12,885,171</td>
<td>18.6</td>
</tr>
<tr>
<td>Russia</td>
<td>461,004</td>
<td>2,497,738</td>
<td>531,967</td>
<td>3,490,709</td>
<td>5.0</td>
</tr>
<tr>
<td>Canada</td>
<td>3,842,202</td>
<td>275,708</td>
<td>0</td>
<td>4,117,910</td>
<td>5.9</td>
</tr>
<tr>
<td>U.S.A</td>
<td>795,442</td>
<td>0</td>
<td>0</td>
<td>795,442</td>
<td>1.2</td>
</tr>
<tr>
<td>Switzerland</td>
<td>56,397</td>
<td>0</td>
<td>0</td>
<td>56,397</td>
<td>0.1</td>
</tr>
<tr>
<td>Singapore</td>
<td>32,909</td>
<td>0</td>
<td>0</td>
<td>32,909</td>
<td>0.0</td>
</tr>
<tr>
<td>India</td>
<td>0</td>
<td>60,623</td>
<td>0</td>
<td>60,623</td>
<td>0.1</td>
</tr>
<tr>
<td>Total (ton)</td>
<td>16,975,373</td>
<td>45,599,025</td>
<td>6,755,607</td>
<td>69,330,005</td>
<td>100.0</td>
</tr>
<tr>
<td>Prop.(%)</td>
<td>24.5</td>
<td>65.8</td>
<td>9.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Oxy-Fuel Combustion Research Activities in KEPCO
The Present State of Green House Gas in Korea

Korea is expected to be the obligatory reduction country by Tokyo Protocol during 2\textsuperscript{nd} commitment period; 2013-2018

Actual technology needed to correspond with the state of obligatory reduction

<table>
<thead>
<tr>
<th>GHG Emission</th>
<th>State of Korea</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG exhaustion: 10\textsuperscript{th} in the world</td>
<td></td>
</tr>
<tr>
<td>• 590mil-ton/yr(’04)</td>
<td></td>
</tr>
<tr>
<td>CO\textsubscript{2}: 510 mil-tonCO\textsubscript{2}/yr</td>
<td></td>
</tr>
<tr>
<td>Coal firing power plant: 115 Mil-tonCO\textsubscript{2}/yr</td>
<td></td>
</tr>
<tr>
<td>• 23% of total CO\textsubscript{2} emission</td>
<td></td>
</tr>
<tr>
<td>• 75% of total power generation</td>
<td></td>
</tr>
<tr>
<td>• In case of including Heavy oil, Max. 84</td>
<td></td>
</tr>
</tbody>
</table>

\textbf{84% CO\textsubscript{2} from Electric Power Generation}

\textbf{Fixed Source}
3.2 Mil-tCO\textsubscript{2}/500MWe-unit

\textbf{Ideal target for Apply CCS Technology}
CO\textsubscript{2} Capture & Storage
Power Generation Industry

- **Major contributor to CO$_2$ emissions**
- **Pathway to zero emission for fossil fuels**

**CO$_2$ emissions from fossil fuel combustion (reference scenario)**

Source: IEA

- Includes agriculture and public sector
- Includes international marine bunkers, other transformation and non-energy use

![Graph showing CO$_2$ emissions from fossil fuel combustion](attachment:carbon_emissions_graph.png)
Concept of Oxy-Fuel Combustion Technology

- Oxidant for Coal: Air → Pure Oxygen
- Condensation of flue gas: capturing most of CO2 & Environmental effect material
- Recycle of flue gas: matching for heat transfer characteristics & CO2 condensation (>80%)
- No CO2 exhaustion by capturing
Oxy-fuel Combustion: Problems

① Oxygen Production Cost
- Cost Reduction (PSA, ITM)
  ▶ Future CO₂ Regulation
  (Climate Exchange Trading, Carbon Tax)

② High Temperature
- Materials Limit, Additional Cooling
  ▶ Flue Gas Recirculation

N₂ in Produced Oxygen: 3~5%  
Air Leakage in Boiler
## Trend of CO2 Capture Technologies in the World

<table>
<thead>
<tr>
<th>CO₂ Technology</th>
<th>Company</th>
<th>Country</th>
<th>Capacity (Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-combustion</td>
<td>BP, Chevron</td>
<td>USA</td>
<td>400MW (2014)</td>
</tr>
<tr>
<td></td>
<td>Alliance, FutureGen</td>
<td>USA</td>
<td>350MW (2012)</td>
</tr>
<tr>
<td></td>
<td>BP, GE</td>
<td>UK</td>
<td>350MW (2010)</td>
</tr>
<tr>
<td></td>
<td>RWE</td>
<td>Germany</td>
<td>450MW (2014)</td>
</tr>
<tr>
<td></td>
<td>E.on</td>
<td>UK</td>
<td>350MW (2011)</td>
</tr>
<tr>
<td></td>
<td>Progressive Energy</td>
<td>UK</td>
<td>800MW (2009)</td>
</tr>
<tr>
<td></td>
<td>Powerful</td>
<td>UK</td>
<td>900MW (2010)</td>
</tr>
<tr>
<td></td>
<td>Nuon</td>
<td>Dutch</td>
<td>1200MW (2014)</td>
</tr>
<tr>
<td>Post-combustion</td>
<td>Shell, Statoil</td>
<td>Norway</td>
<td>860MW (2011)</td>
</tr>
<tr>
<td></td>
<td>Statoil</td>
<td>Norway</td>
<td>230MW (2014)</td>
</tr>
<tr>
<td></td>
<td>Vattenfall AB</td>
<td>Germany/Sweden</td>
<td>30MW (2008)/1000MW (2020)</td>
</tr>
<tr>
<td></td>
<td>SaskPower</td>
<td>Canada</td>
<td>350MW (2014)</td>
</tr>
<tr>
<td></td>
<td>Jupiter Oxygen</td>
<td>USA</td>
<td>45MW (2011)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>France</td>
<td>30MW (2008)</td>
</tr>
<tr>
<td>Oxy-fuel combustion</td>
<td>RWE En power</td>
<td>UK</td>
<td>800MW (2016)</td>
</tr>
<tr>
<td></td>
<td>SEQ, ONS Energy</td>
<td>Dutch</td>
<td>55MW (2011)</td>
</tr>
<tr>
<td></td>
<td>CES</td>
<td>USA</td>
<td>400MW (2015)</td>
</tr>
</tbody>
</table>

[Stromberg et al., "CO₂ free power plant project: status oxy-fuel pilot plant", 2nd Workshop of International Oxy-Combustion Research Network, Windsor, USA (2007)]
Ongoing Projects: Power Plants

**Vattenfall (GER):** 30 MWth (Schwarze Pumpe, 2008)

**Jupiter Oxygen (USA):** 25MWe (Orrville, 2009)

**CS Energy (AUS), IHI (JPN):** 30MWe Retrofit (Callide, 2009)

**Total (FRA):** 35MWth (2008, Lacq)
Korean Project on Oxy-coal

First step of a long term project aiming 2020 and beyond
Finding solution in the CCS
- Design development of an oxy-coal power plant
- Coal power plant as highly visible point source (320 M tCO2/y @ 500MW)

Demonstration of Carbon Capture and Storage Readiness for coal fired power plants by 2018

Technical Significance
- Commercial-scale oxy-coal plant (~500MW)
- Cost of CCS <30€/tCO2
- Demonstration at 100 MWe Class by 2020
Phased Target

1st Step ’07.10~’10.9 (3yrs)
- Conceptual Design of Oxy-PC Boiler
- Development of key technology of Oxy-PC Combustor
- Development of SOx & Dust Removal with New Technology

2nd Step ’10.10~’12.9 (2yrs)
- Basic Design of Oxy-PC Combustor
- Basic Design of Oxy-PC Plant
- Pilot plant test operation
- Preparation of construction Plot
- Development of key technology

3rd Step ’12.10~’15.9 (3yrs)
- Detailed Design & Construction of 100MW Oxy-PC Power plant
- Detailed Design & Construction of Demo. Plant in the 100MW class
Ministry of Knowledge & Economy

KEPRI

Consultant Group

Review

Project 1

KEPRI
Sub: KAIST, Pusan Univ.
- Optimization & Integration of Oxy-PC Boiler

Project 2

KEPRI
Conceptual Design of Oxy-PC Boiler

Project 3

KITECH (Korea Institute of Industrial Technology)
Sub: Seoul Univ., Pohang Univ.
- Design of factors for Oxy-PC Combustor

Project 4

KIMM Sub: KAIST,KIER
- Development of SOx & Dust Removal with New Technology

Project 5

KIGMR (Korea Institute of Geoscience & Mineral Resources)
International collaboration of CSLF Project
Oxyfuel Development Strategy

To develop a competitive oxy-fuel firing technology suitable for full plant application post-2015

- A phased approach to the development and demonstration of oxyfuel technology.

**Phase 1:**
- Fundamentals Technologies and conceptual Design

**Phase 2:**
- Basic Design of Oxyfuel Combustion System

**Phase 3:**
- Detail Design and Repowering of 100MWe class power plant
Oxy Coal-KEPRI: Phase 1 – Conceptual Design of Furnace

Establishment of conceptual design procedure of conventional Air-PC Boiler

Additional design factors for Oxy-PC boiler

Basic spec. (should be discussed with other sub-projects)

Overall Comb. System
- Excess oxygen
- Geometry/Shape of the Furnace
- Combustion efficiency
- NOx emission

Related to Comb. Efficiency
- Wall or Corner firing
- Capacity/Positions/Numbers
- Portion of oxygen in oxidizer (Primary/Secondary/OFO)
- FGR ratio

NOx Reduction
LNB/OFO/SNCR

Other Factors

Heat and Mass Balance + Consideration of FGR

CFD Analysis w/ CMC Model
- Conditional Moment Closure
- Detailed chemistry
- NOx chemistry
- Tuning using Experimental Data
- Simulation of 100 MWe Boiler

Experiment
- Single burner test
- Multi-burner test
- Combustion & Radiative heat transfer characteristics
- Database by various coals

Fuel NOx formation mechanism in Oxyfuel conditions
NOx reduction in stage II

Conceptual Design of Furnaces for 100 MWe Boiler
Oxy Coal-KEPRI: Phase 1 – Combustion Fundamentals

Characterisation of coal ignition, devolatilisation, carbon burnout and nitrogen partitioning behaviour under oxyfuel firing conditions

- Test Furnace
  - Carbon burnout
  - Coal reactivity
  - Flue gas recycle rate
  - Oxygen purity
  - CO2 recovery

- Measurements
  - Gas compositions (O₂, CO₂, NOₓ, CO, SO₂)
  - Combustion efficiency
  - Furnace axial heat flux
  - Boiler performance parameters

*Photograph of KEPRI’S 1.5MW Test Furnace*
Oxy-PC Facility Schematic Diagram

Gas + P.C

Pulverized Coal Firing
SOx and Dust Removal Objectives

[The ultimate goal]

Development of practical environmental system’s design technique

• System protection from pollutant materials
• Economical efficiency
• Plant’s operation stability

[quantitative target values]

• deSOx efficiency : 90% or more
• particle concentration : under 1mg/Nm³
Approach Techniques

[Desulfurization]
In furnace deSOx

Oxy-PC combustion

sorbent

CaCO$_3$

SO$_2$

O$_2$

CaCO$_3$

CaSO$_4$

CO$_2$ pore

[Dust collection]
Hybrid EP

Dry EP + Wet EP

Water spray

Water film

Discharge electrode

Dust cake

failure

Return to FGD & EP
Test facilities for deSOx

Lab-scale oxy-coal combustion system

Behavior of S and SO₂

reaction mechanism
&
sorbent particle’s behavior
Test facilities for dry EP

Basic Characteristics of dry EP in Oxy-vc combustion
Bench scale EP of 600CMH

- Heater & thermal insulator
- Dry clean-air supply (Diffusion dryer, HEPA filter)
- 600CMH- Dry ESP
- Hopper
- HEPA Filter
- MFC
- ID Fan
- Inverter
- APS
- Data acquisition system
- H.V Power supply
- Clean air
- Pressurized air
- High purity CO₂ Bomb
- Fly Ash Feeder
- H₂O steam generator
- Fly Ash Feeder
- Diffusion dryer
- HEPA filter
Behavior of sulfur

[condition] CaCO3 spray : [Ca]/[S]=2.1

SO₂ conc. in supply gas
1790ppm

SO₂ conc. of exhaust gas (non-CaCO₃)
1410ppm

SO₂ conc. of exhaust gas (CaCO₃ spray)
530ppm

• effect of basic material (Ca or Mg)
• conversion to H₂S or SO₃

• desulfurization by sorbent spray

[Sulfur content] Fly ash 28.48g/1000g
Bottom ash   20.45g/1000g

In-furnace deSOx is efficient in oxy-pc combustion
Conceptual Design of Oxy-PC System

Capacity: 100MW, 125MW

Oxy, Oxy + Air

Coal Dry: O, X

Sub-bituminous

OFA

In furnace

SOx/NOx

O2: 1.5~6%

T: 350~370°C

Air Ingress: 1~3%

FGR: 60~80%

CO2 Purity: 98%

O2: 95%, 99%

Recovery CO2: 90%, 95%

SOx 50ppm

Nox 70ppm

Dust 1mg

CO2

H2O

PAF

Air Inlet

GRF(FDF)

COND

CO2

FGR

FGS

Stack

BSFT

Cooler

ESP

GOH

GGH

N2

ASU

Stack

Coal Dryer

Coal

Mill

Coal

N2

N2
Proposed Demonstration Project

- Replacing the Young-dong unit #1
  - Current: 125MWe. Domestic Anthracite
  - Decommission by 2013
  - Repowering to Oxy-Fuel Boiler
    - Coal: Imported Sub-Bituminous or Bituminous

- 100MWe Class Demonstration
  - Design by 2013
  - Construction by 2015
  - Demonstration: 2016~2018
## Overview of design standard conditions

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Yung dong PP(# 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>125MW</td>
</tr>
<tr>
<td>Fuel</td>
<td>Anthracite, bituminous coal, heavy oil mixing</td>
</tr>
<tr>
<td>Main Steam Pr/Temp</td>
<td>131.9 kg/cm² / 541C</td>
</tr>
<tr>
<td>Efficiency</td>
<td>36%</td>
</tr>
<tr>
<td>Start up Year &amp; manufacturer</td>
<td>1973, HITACHI</td>
</tr>
</tbody>
</table>
Assessment of Storage Potential in the continental shelf in Korea

- To establish the storage potential
- Target basin
  - Stage 1: Ulleung basin
  - Stage 2: West Sea & Cheju basin
Closing Remarks

- Pilot-scale test will be started at KEPRI’s 1,500kWt test facility from early 2009. Preliminary results of DTF impact of oxy-fuel firing on SO\(_2\) has been to be effective.

- KEPCO are taking a proactive role in the development and implementation of carbon capture technologies in electric industry in Korea.
Thank You !!