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
- CO$_2$ 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>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korea Electric Power Corp. (KEPCO)</td>
<td>Mother Company . Transmission &amp; Distribution . Oversea Business</td>
<td>Hydro (0.5GW) &amp; Nuclear (17.7GW)</td>
</tr>
<tr>
<td>Hydro &amp; Nuclear Power (KHNP)</td>
<td></td>
<td></td>
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<tr>
<td>Korea South-Eastern Power (KOSEP)</td>
<td></td>
<td>Thermal Power Generation</td>
</tr>
<tr>
<td>East-Western Power (EWP)</td>
<td></td>
<td>- Steam Power : Coal &amp; Oil</td>
</tr>
<tr>
<td>Western Power (WP)</td>
<td></td>
<td>- NGCC</td>
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<tr>
<td>Main Coal Power Stations</td>
<td></td>
<td>- 8 GWe for each company</td>
</tr>
<tr>
<td>6~10 units per one site</td>
<td></td>
<td></td>
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<tr>
<td>Korea Middle Power (KOMIPO)</td>
<td></td>
<td></td>
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<tr>
<td>Southern Power (KOSPO)</td>
<td></td>
<td></td>
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<td>Korea Power Engineering Co. (KOPEC)</td>
<td>Engineering Company</td>
<td></td>
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<tr>
<td>Korea Electric Power Research Institute</td>
<td>Research Wing</td>
<td></td>
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<tr>
<td>(KEPRI)</td>
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</tbody>
</table>
The State of Capacity & Power Generation

Power Plant (the end of 2006)

**Power Capacity**
- Nuclear: 4,790 MW (7.3%)
- Hydraulic: 5,485 MW (8.4%)
- Oil: 17,716 MW (27.0%)
- Gas: 17,436 MW (26.6%)
- Total: 65,514 MW

**Power Generation**
- Coal: 148,749 GWh (39.0%)
- Renewal Energy Capacity: 240MW
- Renewal Energy Power Generation: 511GWh
- 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>
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<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>
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<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>
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<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>
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<td>Canada</td>
<td>3,842,202</td>
<td>275,708</td>
<td>0</td>
<td>4,117,910</td>
<td>5.9</td>
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<td>U.S.A</td>
<td>795,442</td>
<td>0</td>
<td>0</td>
<td>795,442</td>
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<td>Switzerland</td>
<td>56,397</td>
<td>0</td>
<td>0</td>
<td>56,397</td>
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<td>Singapore</td>
<td>32,909</td>
<td>0</td>
<td>0</td>
<td>32,909</td>
<td>0</td>
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<tr>
<td>India</td>
<td>0</td>
<td>60,623</td>
<td>0</td>
<td>60,623</td>
<td>0.1</td>
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<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>
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<tr>
<td>Prop.(%)</td>
<td>24.5</td>
<td>65.8</td>
<td>9.7</td>
<td>-</td>
<td>-</td>
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</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 2nd commitment period; 2013-2018

Actual technology needed to correspond with the state of obligatory reduction

GHG Emission State of Korea

- GHG exhaustion: 10th in the world
  - 590mil-ton/yr (’04)

- CO2: 510 mil-tonCO2/yr

- Coal firing power plant: 115 Mil-tonCO2/yr
  - 23% of total CO2 emission
  - 75% of total power generation
  - In case of including Heavy oil, Max. 84

84% CO2 from Electric Power Generation

Fixed Source
3.2 Mil-tCO2/500MWe-unit

Ideal target for Apply CCS Technology
CO2 Capture & Storage
Power Generation Industry

- Major contributor to CO₂ emissions
- Pathway to zero emission for fossil fuels

CO₂ emissions from fossil fuel combustion (reference scenario)

An integrated approach to "zero emission"
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

Nitrogen Concentration [\%]

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>
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</thead>
<tbody>
<tr>
<td><strong>Pre-combustion</strong></td>
<td>BP, Chevron</td>
<td>USA</td>
<td>400MW (2014)</td>
</tr>
<tr>
<td></td>
<td>Alliiance, 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><strong>Post-combustion</strong></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>
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<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></td>
<td>RWEEn 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>
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<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
Target for Research and Development of Oxy-PC Combustion

Phased Target

1st Step '07.10~'10.9 (3yrs)
Development of conceptual Design
- Conceptual Design of Oxy-PC Boiler
- Optimization & Integration 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

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

Review
- Consultant Group
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
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
- CaCO₃ sorbent
- CO₂ pore
- SO₂
- O₂
- CaCO₃
- CaSO₄

**[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 furnace

reaction mechanism & sorbent particle’s behavior
Basic Characteristics of dry EP in Oxy-pc combustion
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

O2 : 1.5~6%
T : 350~370°C

Air Ingress: 1~3%

SOx: 50ppm
Nox: 70ppm
Dust: 1mg

Recovery CO2: 90%, 95%

CO2 Purity: 98%

FGR: 60~80%

FGR(FDF)
Air Inlet
PAF

GGH

GOH

ESP

FGD

BSTF

N2

Stack

O2

95%, 99%

ASU

N2

Coal Dryer

Coal

N2

Coal

In furnace
SOx/NOx

OFA

Furnace

H2O

CO2

Grp(FDF)

Air Inlet

H2O

PAF

GGH

CO2

FGR

FGR(FDF)
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><strong>Capacity</strong></td>
<td>125MW</td>
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<tr>
<td><strong>Fuel</strong></td>
<td>Anthracite, bituminous coal, heavy oil mixing</td>
</tr>
<tr>
<td><strong>Main Steam Pr/Temp</strong></td>
<td>131.9 kg/cm² / 541°C</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>36%</td>
</tr>
<tr>
<td><strong>Start up Year &amp; manufacturer</strong></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 !!