EA  является для нас важным
и поможет нам достичь наших целей.

Мы должны быть готовы к тому,
что это может быть трудным.

Важно помнить,
что мы должны стараться
и не сдаваться.

Мы можем быть
уверены в себе и
в своих возможностях.
1. Japanese Strategy for CO₂ Reduction
2. Oxy-firing Studies in Japan
3. Study of 1000MW Oxy-firing Super-Critical Unit
4. Japan-Australia Oxy-firing Project
5. Conclusion
1. Japanese Strategy for CO$_2$ Reduction
2. Oxy-firing Studies in Japan
3. Study of 1000MW Oxy-firing Super-Critical Unit
4. Japan-Australia Oxy-firing Project
5. Conclusion
CO₂ reduction is prime task for global warming and is not depend on the place to recover CO₂.

By IEA/World Energy Outlook 2000
As domestic coal lost its competitiveness, coal imports increased

Amount of domestically-produced and imported coal

Source: "Statistics of Energy Production, Supply and Demand"
Japan must reduce GHG at –6%
Use of Coal
Japan’s new coal policy towards 2030 called “Clean Coal Cycle (C3) Initiative” is presented and launched. To promote the development of innovative CCT towards the realization of zero-emission utilization is described in C3 Initiative.
Field Ⅱ: Promote the development/demonstration/dissemination of CCT

From METI Home Page
1. Promote the development of innovative CCT
   * F/S of Advanced Gasification
   * Oxy-fuel to existing boiler with Australia
   * IGCC, IGFC, HyPr-RING

2. Demonstrate diversified CCT models
   * F/S of co-production with gasification
   * F/S of CTL/H₂ from coal/biomass/plastics gasification
CCT Spreading Energy Sector in Japan (2030)

- Coal Gasification
- Power Station
- USC
- IGCC
- IGFC
- CO₂ Capture
- CO₂ Sequestration
- SCOPE21
- Steel
- Iron Works
- UBC (Upgrading Brown Coal)
- Biomass
- Waste
- HyPr-RING
- FC Vehicle
- Hydrogen Station
- Chemical, etc.

From METI Home Page
1. Japanese Strategy for CO₂ Reduction
2. Oxy-firing Studies in Japan
3. Study of 1000MW Oxy-firing Super-Critical Unit
4. Japan-Australia Oxy-firing Project
5. Conclusion
2. Oxy-firing Studies in Japan

- [List items]
- [List items]
- Newly-installed plant
  - High efficiency
    - IGCC
    - 700 class USC

- Existing plant
  - High efficiency
  - Switching fuel
  - Positive CO₂ recovery
    - Oxy-firing
    - Chemical absorption
Oxy-fuel Combustion System

- Air
- ASU
- P.C.
- Boiler
- Flue gas recycle

- IHI
# Coal Combustion under CO₂ Atmosphere

<table>
<thead>
<tr>
<th>Item</th>
<th>Combustion with air</th>
<th>Combustion with oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Windbox</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td>21%</td>
<td>21〜30%</td>
</tr>
<tr>
<td>N₂</td>
<td>79%</td>
<td>(0)〜10%</td>
</tr>
<tr>
<td>CO₂</td>
<td>0%</td>
<td>40〜50%</td>
</tr>
<tr>
<td>H₂O</td>
<td>Small</td>
<td>10〜20%</td>
</tr>
<tr>
<td>Others</td>
<td>-</td>
<td>NOₓ, SO₂ ･･･</td>
</tr>
<tr>
<td><strong>Flue gas</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td>3〜4%</td>
<td>3〜4%</td>
</tr>
<tr>
<td>N₂</td>
<td>70〜75%</td>
<td>(0)〜10%</td>
</tr>
<tr>
<td>CO₂</td>
<td>12〜14%</td>
<td>60〜70%</td>
</tr>
<tr>
<td>H₂O</td>
<td>10〜15%</td>
<td>20〜25%</td>
</tr>
<tr>
<td>Others</td>
<td>NOₓ, SO₂ ･･･</td>
<td>NOₓ, SO₂ ･･･</td>
</tr>
</tbody>
</table>

(Wet % base)
<table>
<thead>
<tr>
<th><strong>Calendar of Japanese Oxy-firing Study</strong></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Ignition and flame propagation under zero gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Combustion characteristics</td>
</tr>
<tr>
<td></td>
<td>In-furnace desulfurization test</td>
</tr>
<tr>
<td></td>
<td>Combustion simulation</td>
</tr>
<tr>
<td></td>
<td>Boiler system study</td>
</tr>
<tr>
<td></td>
<td>Operation characteristics</td>
</tr>
<tr>
<td></td>
<td>Dynamic simulation</td>
</tr>
<tr>
<td></td>
<td>Callide A project</td>
</tr>
</tbody>
</table>
**Ignition Characteristics**

**Small gravity test**

**Device**: Free drop chamber

**Gravity**: $1.0 \times 10^{-4} \text{g}$, 10 seconds

---

**Test procedure**

- **Capsule drop**
- **Ignition**
- **Observation**
- **+7 sec.**
- **+10 sec.**

**Device**:

- Gas sampling cylinder
- 8mm VTR
- Pressure transducer
- Band pass filter
- Combustion chamber
- Pulverized coal particle
- Timer Relay
- Battery
- Timer
- A/D converter
- Computer
- Coal dispersion gas
- Solenoid valve
- High speed camera (temperature observation)
Ignition Characteristics
Experimental system to simulate O2/CO2 coal combustion

School of Engineering
Tokyo Institute of Technology
**Drastic NOx Reduction**
(NOx: mainly due to Fuel-NOx)
(Drastic decrease of Conversion Ratio from Fuel-N to NOx)

Summary of $CR^*$ values for $O_2/CO_2$ coal combustion

<table>
<thead>
<tr>
<th>$\lambda$ (oxygen-fuel stoichiometric ratio)</th>
<th>0.7</th>
<th>1.0</th>
<th>1.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO concentration in exhaust gas</td>
<td>1130 ppm</td>
<td>1710 ppm</td>
<td>1490 ppm</td>
</tr>
<tr>
<td>$CR^*$</td>
<td>0.05</td>
<td>0.12</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Ratio of $CR^*$ to that of air combustion

<table>
<thead>
<tr>
<th></th>
<th>17 %</th>
<th>25 %</th>
<th>26 %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1/6)</td>
<td>(1/4)</td>
<td>(1/4)</td>
</tr>
</tbody>
</table>

$CR^*$: conversion ratio from fuel-N to exhausted NO

Ratio of $CR^*$ to that of air combustion

\[
\frac{CR^* \text{ in } O_2/CO_2 \text{ coal combustion}}{CR^* \text{ in conventional coal combustion in air}}
\]
Drastic Reduction of CR* (Fuel-N to NOx) by Oxy-firing

**Base case**
- Conventional
  - O2 : 21%
  - H.R.: 0%

**Oxy-fuel**
- O2 : 30%
  - H.R.: 0%
  - Decreased to one-seventh

**Oxy-fuel**
- O2 : 21%
  - H.R.: 0%

**Oxy-fuel**
- O2 : 15%
  - H.R.: 40%

Various cases for CR* estimation

<table>
<thead>
<tr>
<th>Cases</th>
<th>System</th>
<th>O2 concentration (%)</th>
<th>Gas recirculation ratio according to chemical stoichiometry $\alpha$</th>
<th>$\lambda$ in volatile matter combustion zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>Conventional pulverized coal combustion</td>
<td>21</td>
<td>0.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Case 2</td>
<td>O2/CO2 pulverized coal combustion</td>
<td>30</td>
<td>0.77</td>
<td>0.7</td>
</tr>
<tr>
<td>Case 3</td>
<td>O2/CO2 pulverized coal combustion</td>
<td>21</td>
<td>0.84</td>
<td>0.7</td>
</tr>
<tr>
<td>Case 4</td>
<td>O2/CO2 pulverized coal combustion with about 40% heat recirculation</td>
<td>15</td>
<td>0.89</td>
<td>0.7</td>
</tr>
</tbody>
</table>

From Prof. Okazaki
What is in-furnace desulfurization?

A very economical method of SO₂ removal through sorbent (CaCO₃) injection into the furnace

Desulfurization reaction:
- CaCO₃ → CaO + CO₂
- CaO + SO₂ + 1/2O₂ → CaSO₄

CaSO₄ decomposition:
- CaSO₄ → CaO + SO₂ + 1/2O₂

The cause of decrease in desulfurization efficiency at high temperature
Local desulfurization efficiency: 0.35
Gas recirculation ratio: 0.84

Fuel-S (SO₂): 1.0 (mol/s)
SO₂
2.2 (mol/s)
1.43 (mol/s)

Removed-S (CaSO₄): 0.77 (mol/s)
Exhausted-S: 0.23 (mol/s)
Recycled-S: 1.2 (mol/s)

System desulfurization efficiency: $h = 77\%$

Coal property (wt. %, dry)
C: 71.1  O: 8.86
H: 4.23  N: 1.76
S: 2.00

Calculation conditions
Oxygen-fuel ratio = 1.2, Temperature = 1400 K
one pass residence time = 8 s, Ca/S = 5, CaCO₃ (10 mm)
Enrichment of heat and mass in combustion field

- Recirculation of heat (enrichment of heat)
- Recirculation of mass (enrichment of mass)

- CO$_2$ separation and recovery
- Extremely low NOx emission
- High in-situ desulfurization efficiency

Combination of heat and mass recirculation

New combustion technology (PCC, AFBC, CFBC, PFBC, IGCC)

Protection of global environment

From Prof. Okazaki
Combustion Test Facility

Capacity: 1.2Mwt (Coal 150kg/h)

Furnace: Ø1.3m × 7.5m L
Flow diagram of industrial-scale combustion test facilities
Flue Gas (CO₂) Liquefied Test

Pressure vessel (7 MPa)

- Furnace
- GAH, G/C
- Bag filter
- Gas filter
- Transporting gas for P. C.
- Combustion gas
- Water spray
- Steam heater
- Gas cooler
- Flue gas compressor

Cooling unit
Compressor

Flue gas compressor unit
Pressure vessel
Results of Oxy-firing Test

Ignition/combustion characteristics

Flame of test facilities

Flame temperature (Radiation thermometer)
Combustion condition
Coal : Coal A
Coal feed rate : 100 kg/h
Flue gas oxygen : 3.5%
Wind box oxygen : 30% ($O_2$/RFG combustion)
Pure oxygen flow rate : 20 Nm$^3$/h ($O_2$/RFG combustion)

Burner type ($O_2$/RFG combustion)
TYPE-ᶗ : Pure oxygen supply from the center of the burner
TYPE-ᶘ : Pure oxygen swirly supply from the center of the burner

Result of Oxy-firing Test
**Result of Desulfurization Test**

**Combustion conditions**
- **Coal**: Coal A, B
- **Flue gas Oxygen**: 3.5%
- **Coal feed rate**: 100 kg/h
- **Wind box oxygen**: 30%
- **Pure oxygen flow rate**: 20Nm³/h
- **Desulfurizing agent**: CaCO₃

**Comparison of desulfurization rate**

**Sulfur captured in the system**

**Combustion conditions**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Coal A</th>
<th>Coal B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur captured in the system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air combustion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂/RFG combustion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Combustion conditions**
- **Coal**: Coal A, B
- **Flue gas Oxygen**: 3.5%
- **Coal feed rate**: 100 kg/h
- **Wind box oxygen**: 30%
- **Pure oxygen flow rate**: 20Nm³/h
- **Desulfurizing agent**: CaCO₃
Ignition/Combustion Characteristics
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5. Conclusion
Basic Design of 1,000MWe Class Power Plant
Boiler Configuration
Furnace Heat Absorption

< Air-case >
WB O₂ conc.: (21%)

< Oxy-case >
WB O₂ conc.: 25% 30% 35%
ASU and Compressors

< Image >

< Image >
Dynamic Plant Simulation
Dynamic Plant Simulation

(Note) □: Light off □: Combustion mode change
□: Turbine roll □: 30%L to 60%L
□: Synchronization □: Furnace draft control
□: Turbine master auto

1. Boiler demand
2. MW
3. Main steam flow
4. Reheat steam flow
5. Heat input
6. Furnace draft
7. Oil flow
8. Coal flow

Time (s)
(Note)  □: Light off  □: Combustion mode change
□: Turbine roll  □: 30%L to 60%L
□: Synchronization  □: Furnace draft control
□: Turbine master auto

1. Boiler demand
2. AH outlet gas flow
3. Chimney flow
4. O₂ flow
5. O₂ conc. at ECO outlet
6. O₂ conc. at W/B
7. CO₂ conc. at ECO outlet
Basic Design

CO₂回収型微粉炭酸素燃焼発電プラント

CO₂地中投入

CO₂タンク

CO₂海中投棄

酸素製造装置

ボイラー
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Japan/Australia Oxy-firing Project

Power plant site
Site : Queensland, Australia
Plant : CS Energy Callide-A No.4 unit
Output : 30MWe
# Japan/Australia Oxy-firing Project

## Overall Schedule

<table>
<thead>
<tr>
<th>Items</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS of Aus./Japan Project</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design, conversion, operation of demonstration plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1. Japanese Strategy for CO₂ Reduction
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5. Conclusion
1. Oxy-firing: one of the simplest ways to reduced CO₂

2. Many Oxy-firing projects in many places go together hand in hand

Acknowledgement:
All the tests except done in TIT were funded by NEDO.
Integration of Coal, Hydrogen and CO₂ Sequestration

From Prof. Okazaki

Fossil Fuel (Coal, Oil ..)

CO₂ + H₂

FutureGen

steam reforming

Fossil Fuel (Coal, Oil ..)

O₂/CO₂ Combustion

Air-blown Combustion

CO₂ Recovery

CO₂ Separation and Recovery (MEA, KS-1 ..)

CO₂ Sequestration (Ocean, Geological ..)

FutureGen

shift reaction

exergy enhancement of low quality waste heat

Renewable Energy (Wind, PV ..)

Electricity

H₂ + O₂

H₂O

Hydrogen Energy System with Exergy Regeneration (Fuel Cell ..)

Integration of Coal, Hydrogen and CO₂ Sequestration

School of Engineering

Tokyo Institute of Technology