# 地球環境科学（第5回）

# $CO_2$回収型燃焼とNOx, SOxの同時低減
# $CO_2$の隔離技術

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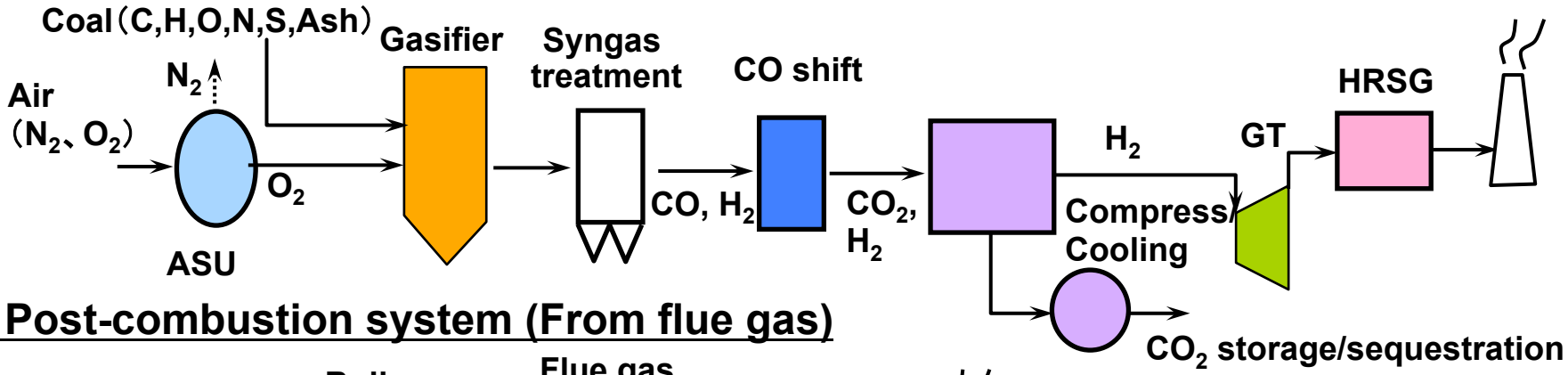
（機械科学科）

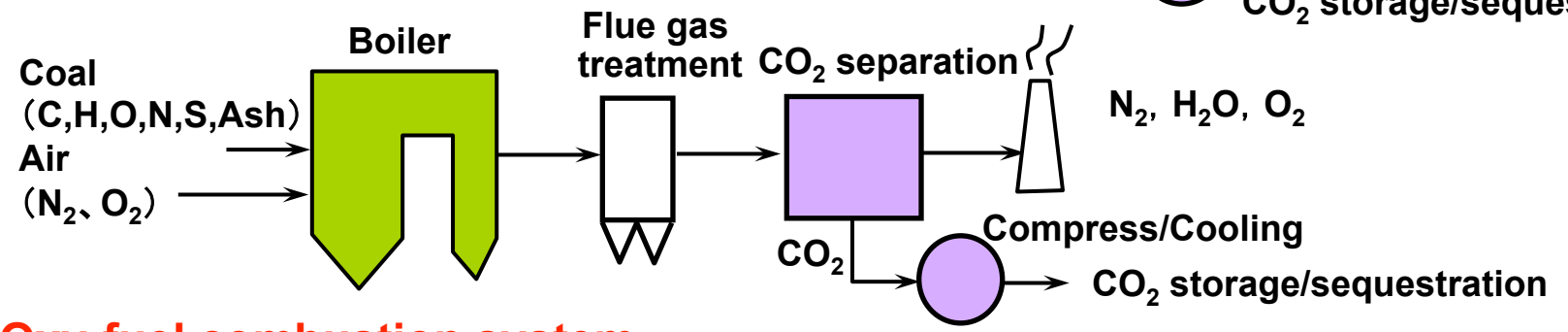
2010年11月25日（木）

# $CO_2$ recovery from coal-fired power station

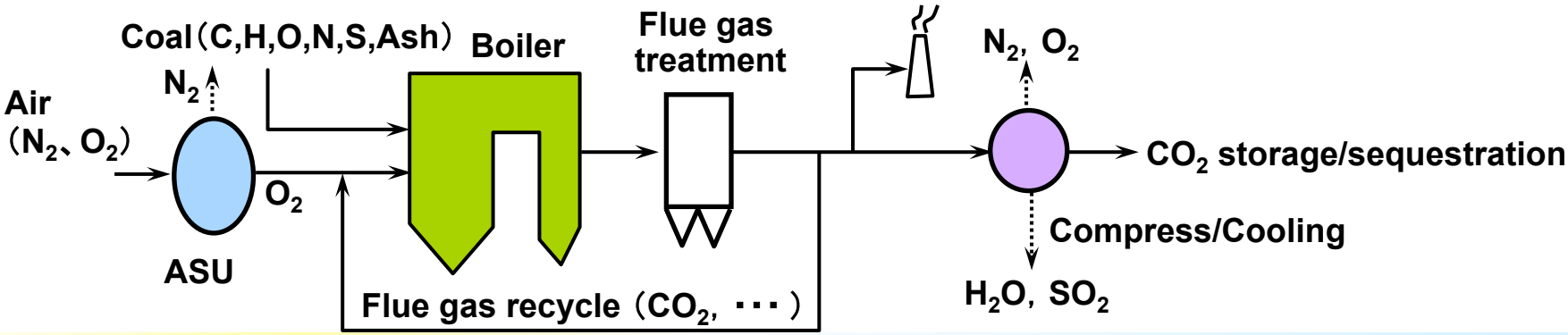
## 1. Pre-combustion system (Gasifier)



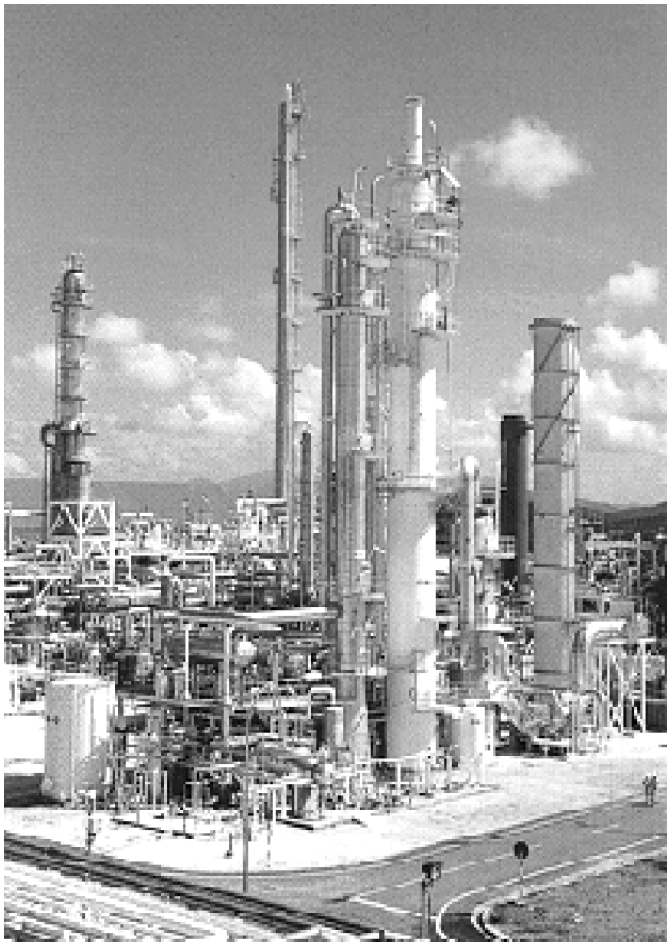

## 2. Post-combustion system (From flue gas)




## 3. Oxy-fuel combustion system



# $CO_2$ Recovery Plant by Chemical Absorption Method using MEA



*$CO_2$ Recovery Plant in Malaysia*
*(Mitsubishi Heavy Industries, Ltd.)*

## Main operation parameters

1) $CO_2$ Purity: More than 99.9 vol.% (Dry base) Impurities are nitrogen and oxygen.
2) $CO_2$ Recovery Ratio: 90% at normal operation, however more than 97% $CO_2$ recovery was attained by increasing steam consumption.
3) Steam Consumption: 1.5 ton L.P. Steam / ton $CO_2$ recovered.
4) Amine Loss: 0.35 kg/ton $CO_2$ recoverd.
5) Degradation: Degradation of KS-1 solvent is very slow. The plant has been operated for more than 5,700 hours, without the need to reprocess.

# $O_2/CO_2$ (Oxy-firing) Coal Combustion

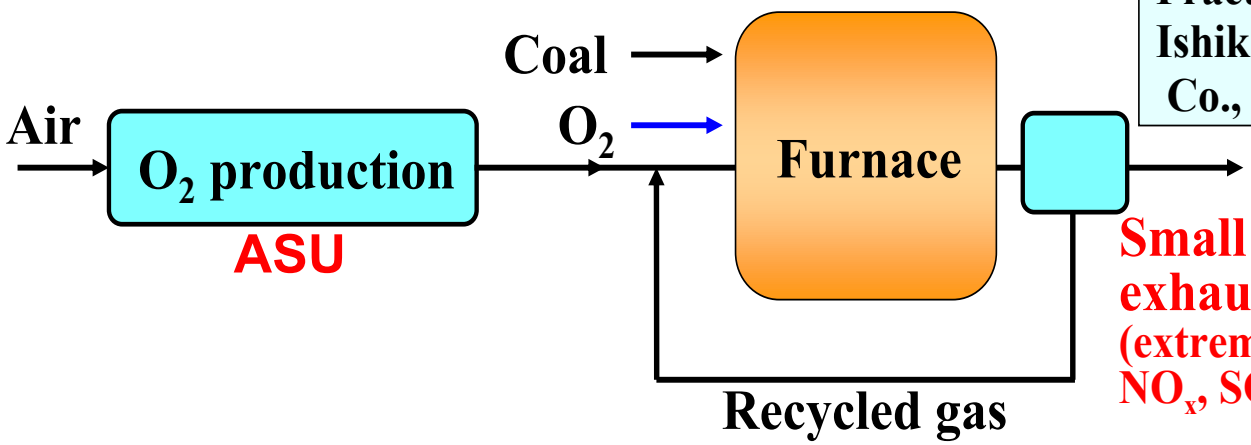
## Conventional pulverized coal combustion

$CO_2$ concentration in flue gas is about 13 % → Great energy consumption to separate $CO_2$

## $O_2/CO_2$ pulverized coal combustion

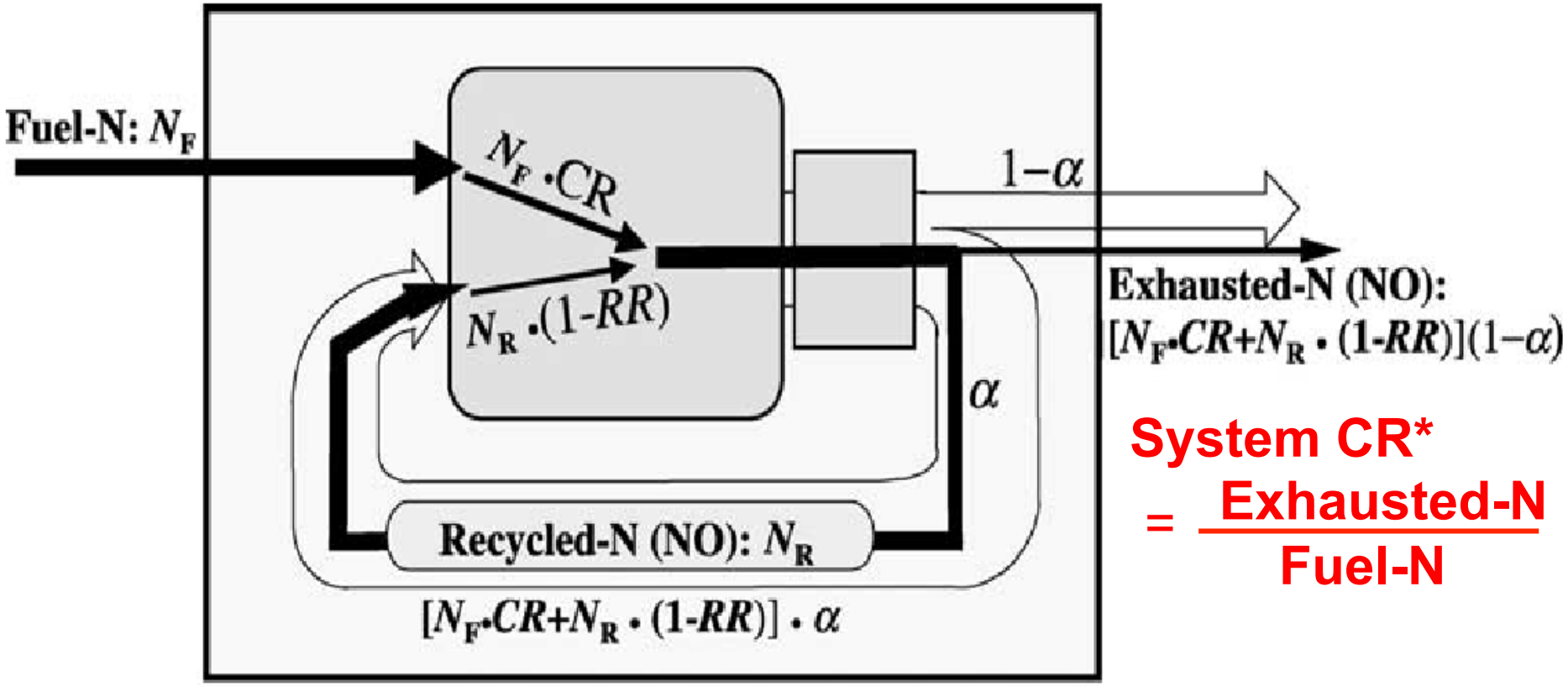
$CO_2$ concentration in flue gas is enriched up to 95 % → Easy and efficient $CO_2$ recovery

Practically realized by Ishikawajimaharima Co., Ltd.




Small amount of exhausted gas (extremely low amount of $NO_x$, $SO_x$)

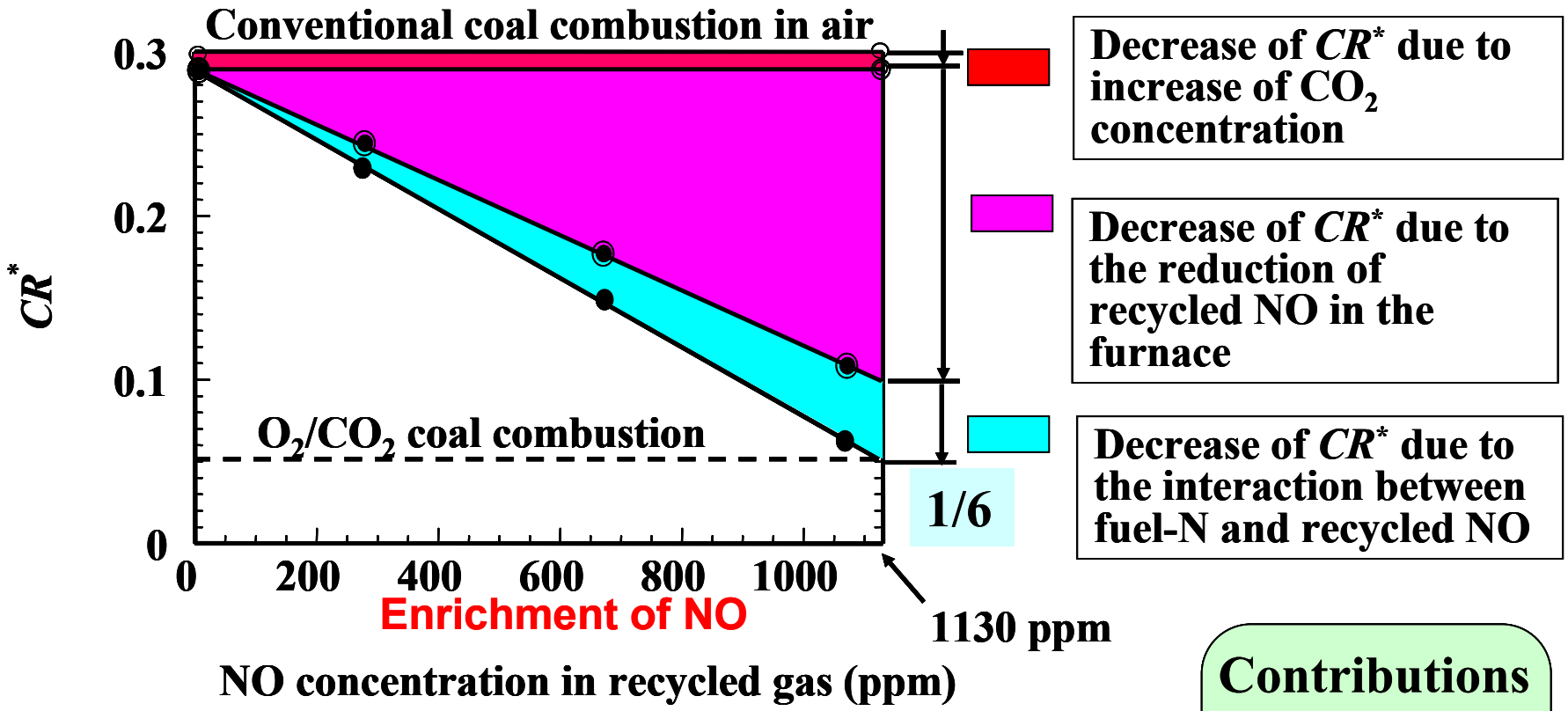
# Mass balance of N-atoms




**System CR*** $= \dfrac{\text{Exhausted-N}}{\text{Fuel-N}}$

$$N_R = \alpha \cdot N_F \cdot CR / [1 - \alpha (1\text{-}RR)]$$

**local CR and local RR were experimentally identified.**




$T_{max}$ = 1450 K  Fuel-N = 1.22 wt % (as N atom mass)
$\beta$ = 0.2  $CO_2/(CO_2+Ar)$ = 0.48 (vol.)  $\lambda$ = 0.7

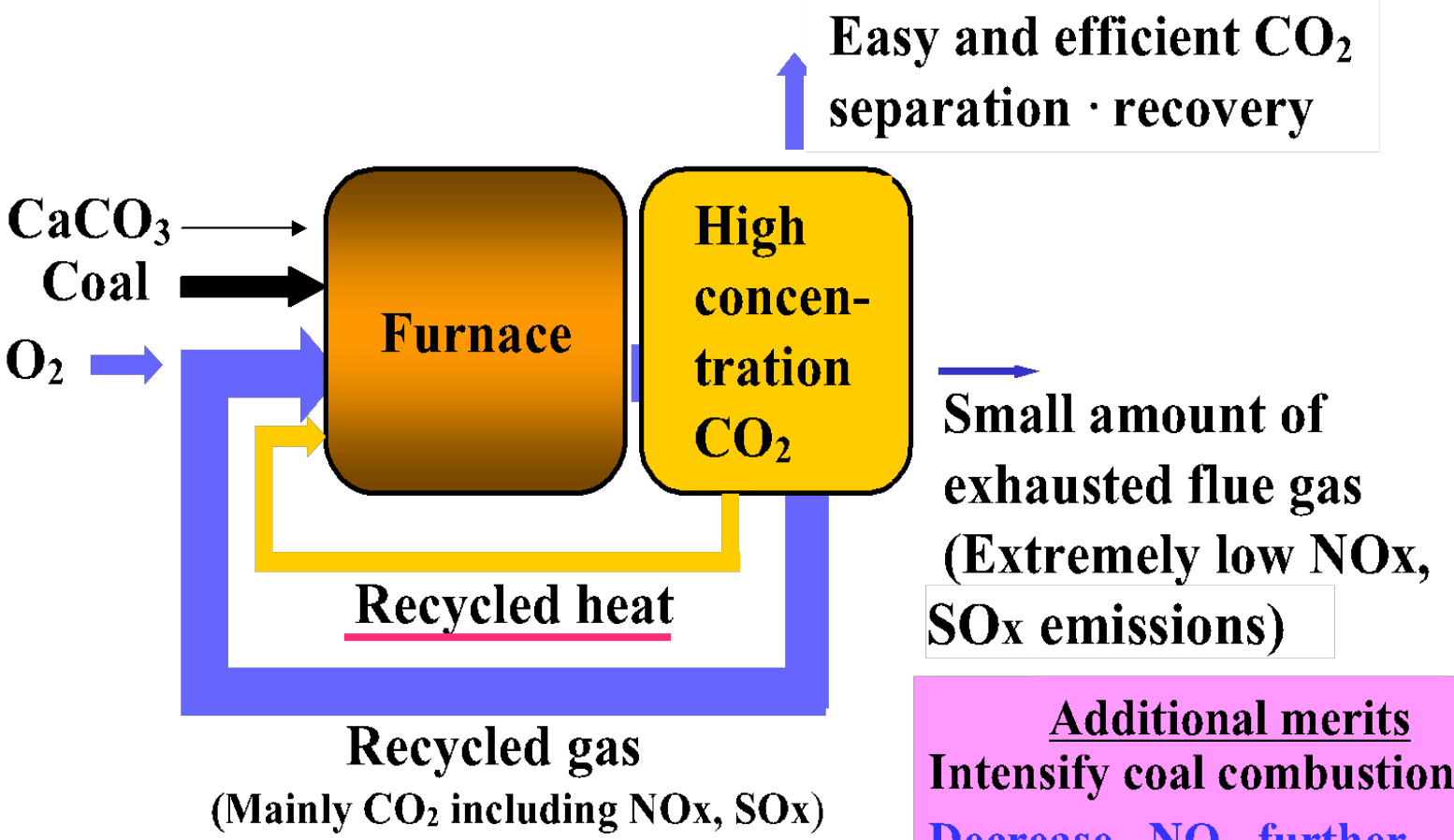
**Contributions**

- 4 %
- 78 %
- 18 %

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

## Discrimination of Various Mechanisms for NOx Reduction ($\lambda$ = 0.7)

# Further NOx Reduction by Heat Recirculation




Schematic of $O_2/CO_2$ Coal Combustion with both mass and heat recirculation

**Additional merits**

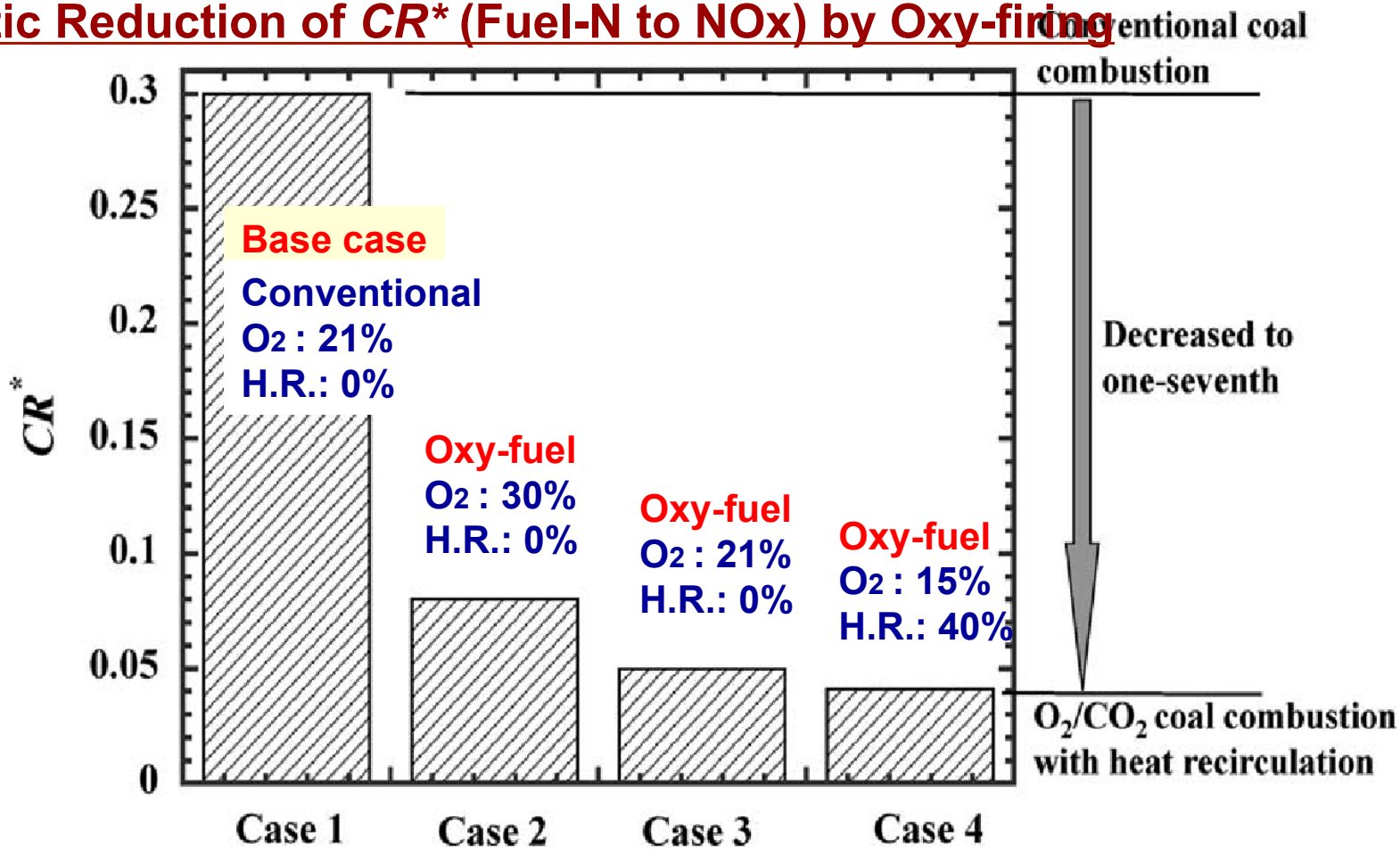
Intensify coal combustion

Decrease NO further through combustion with low $O_2$ concentration

Improve fuel flexibility

Broaden load change range of a boiler

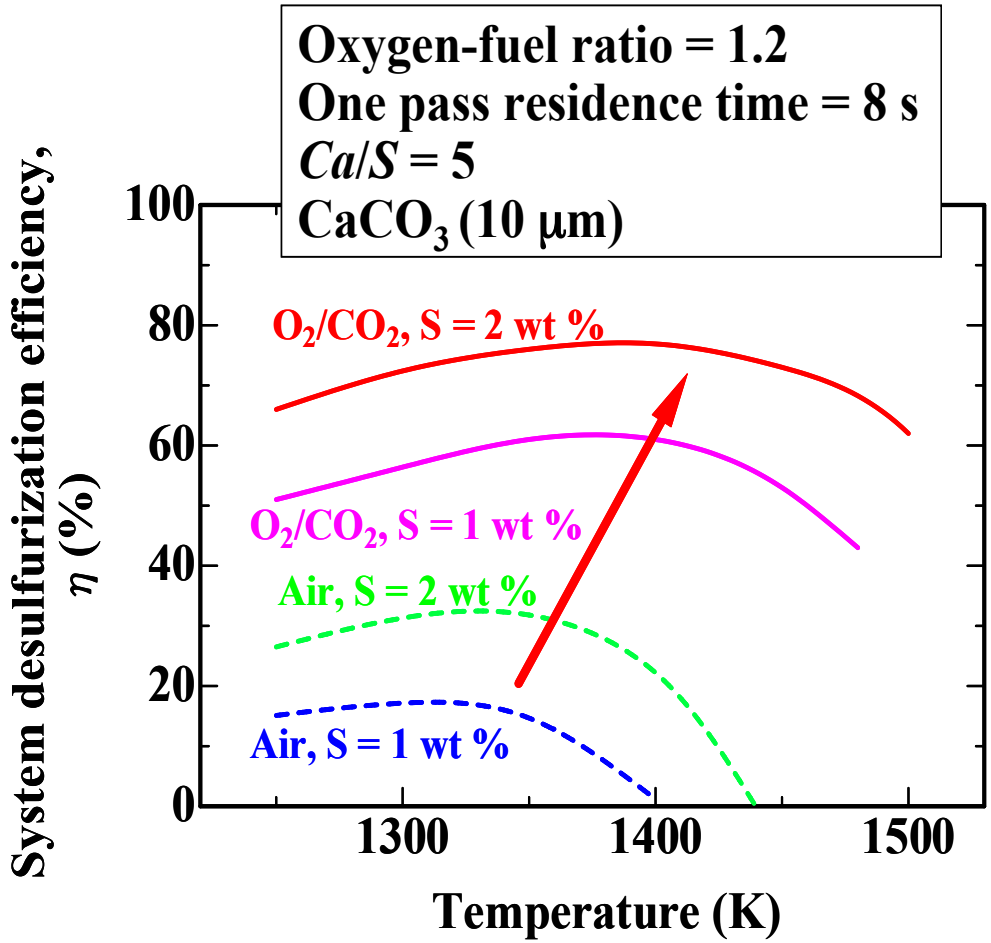
# Drastic Reduction of *CR** (Fuel-N to NOx) by Oxy-firing




Various cases for $CR^*$ estimation

| Cases | System | $O_2$ concentration (%) | Gas recirculation ratio according to chemical stoichiometry $\alpha$ | $\lambda$ in volatile matter combustion zone |
|---|---|---|---|---|
| Case 1 | Conventional pulverized coal combustion | 21 | 0.0 | 0.7 |
| Case 2 | $O_2/CO_2$ pulverized coal combustion | 30 | 0.77 | 0.7 |
| Case 3 | $O_2/CO_2$ pulverized coal combustion | 21 | 0.84 | 0.7 |
| Case 4 | $O_2/CO_2$ pulverized coal combustion with about 40% heat recirculation | 15 | 0.89 | 0.7 |

# Drastic Enhancement of In-furnace Desulfurization Efficiency




η at S = 1 wt %

six times higher

In-furnace desulfurizatioin at high temperature

Air: impossible

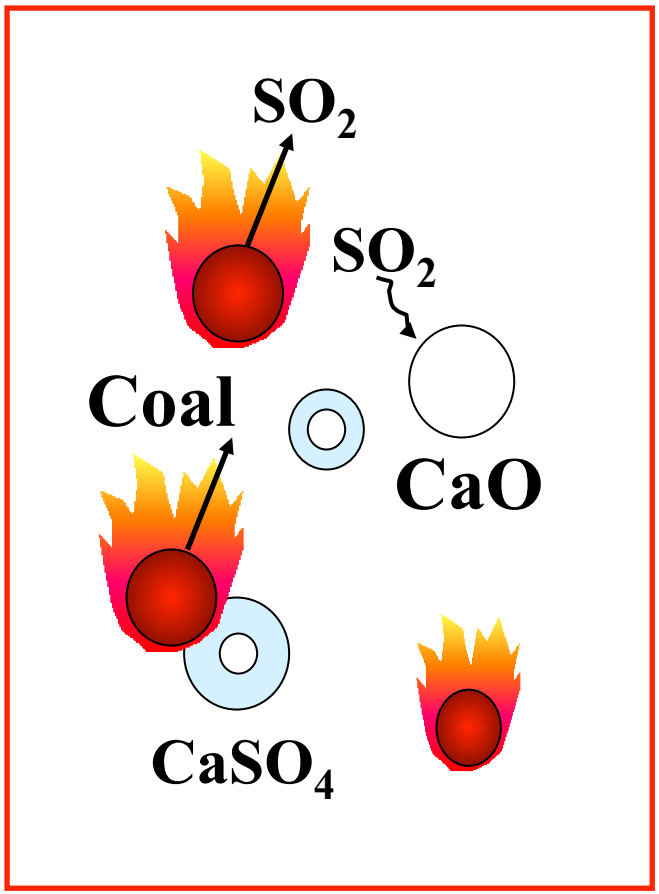
$O_2/CO_2$: can be realized

η in $O_2/CO_2$ → about four times higher
→ high in a wide temperature range

**Effect of temperature on system desulfurization efficiency**

**What is in-furnace desulfurization?**

**A very economical method of $SO_2$ removal through sorbent (脱硫剤, $CaCO_3$) injection into the furnace**




## Desulfurization reaction:

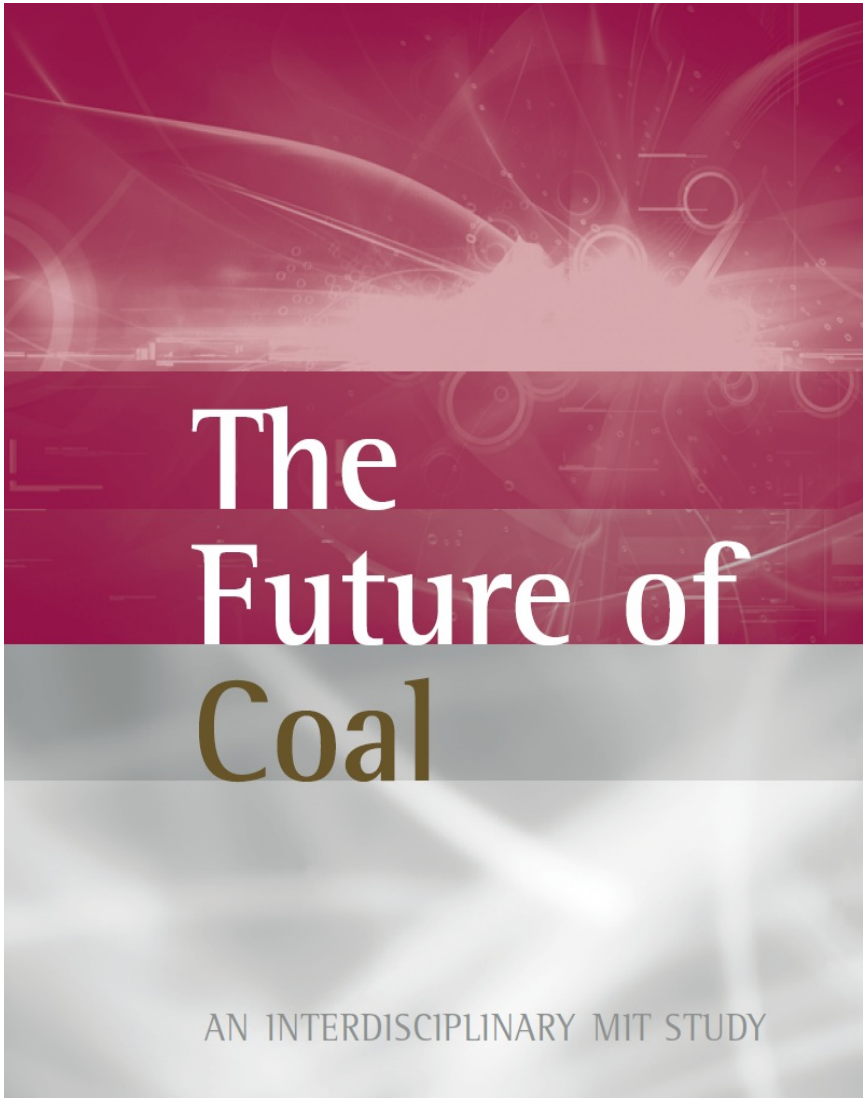
$$CaCO_3 \rightarrow CaO + CO_2$$

$$CaO + SO_2 + 1/2O_2 \rightarrow CaSO_4$$

## $CaSO_4$ decomposition:

$$CaSO_4 \rightarrow CaO + SO_2 + 1/2O_2$$

**The cause of decrease in desulfurization efficiency at high temperature**




OPTIONS FOR A
CARBON-CONSTRAINED WORLD

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**BOX 1 ILLUSTRATING THE CHALLENGE OF SCALE FOR CARBON CAPTURE**

- Today fossil sources account for 80% of energy demand: Coal (25%), natural gas (21%), petroleum (34%), nuclear (6.5%), hydro (2.2%), and biomass and waste (11%). Only 0.4% of global energy demand is met by geothermal, solar and wind.[1]
- 50% of the electricity generated in the U.S. is from coal.[2]
- There are the equivalent of more than five hundred, 500 megawatt, coal-fired power plants in the United States with an average age of 35 years.[2]
- China is currently constructing the equivalent of two, 500 megawatt, coal-fired power plants per week and a capacity comparable to the entire UK power grid each year.[3]
- One 500 megawatt coal-fired power plant produces approximately 3 million tons/year of carbon dioxide ($CO_2$).[3]
- The United States produces about 1.5 billion tons per year of $CO_2$ from coal-burning power plants.
- If all of this $CO_2$ is transported for sequestration, the quantity is equivalent to three times the weight and, under typical operating conditions, one-third of the annual volume of natural gas transported by the U.S. gas pipeline system.
- If 60% of the $CO_2$ produced from U.S. coal-based power generation were to be captured and compressed to a liquid for geologic sequestration, its volume would about equal the total U.S. oil consumption of 20 million barrels per day.
- At present the largest sequestration project is injecting one million tons/year of carbon dioxide ($CO_2$) from the Sleipner gas field into a saline aquifer under the North Sea.[3]

**Notes**

1. IEA Key World Energy Statistics (2006)
2. EIA 2005 annual statistics (www.eia.doe.gov)
3. Derived from the MIT Coal Study

(from FOREWARD)

Our audience is government, industry and academic leaders and decision makers interested in the management of the interrelated set of technical, economic, environmental, and political issues that must be addressed in seeking to limit and to reduce greenhouse gas emissions to mitigate the effects of climate change. Coal is likely to remain an important source of energy in any conceivable future energy scenario. Accordingly, our study focuses on identifying the priority actions needed to reduce the $CO_2$ emissions that coal use produces. We trust that our integrated analysis will stimulate constructive dialogue both in the United States and throughout the world.

This study reflects our conviction that the MIT community is well equipped to carry out interdisciplinary studies of this nature to shed light on complex socio-technical issues that will have major impact on our economy and society.

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(from EXECUTIVE SUMMARY)

We conclude that $CO_2$ capture and sequestration (CCS) is the critical enabling technology that would reduce $CO_2$ emissions significantly while also allowing coal to meet the world's pressing energy needs.

# The Power of Coal

Proceedings of
The 32nd International Technical Conference on
Coal Utilization & Fuel Systems
June 10 – 15, 2007
Sheraton Sand Key Clearwater, Florida, USA

The Clearwater Coal Conference

**Panel: Oxy-Fuel Technology**

**Oxy-Fuel I: Overview & New Developments**

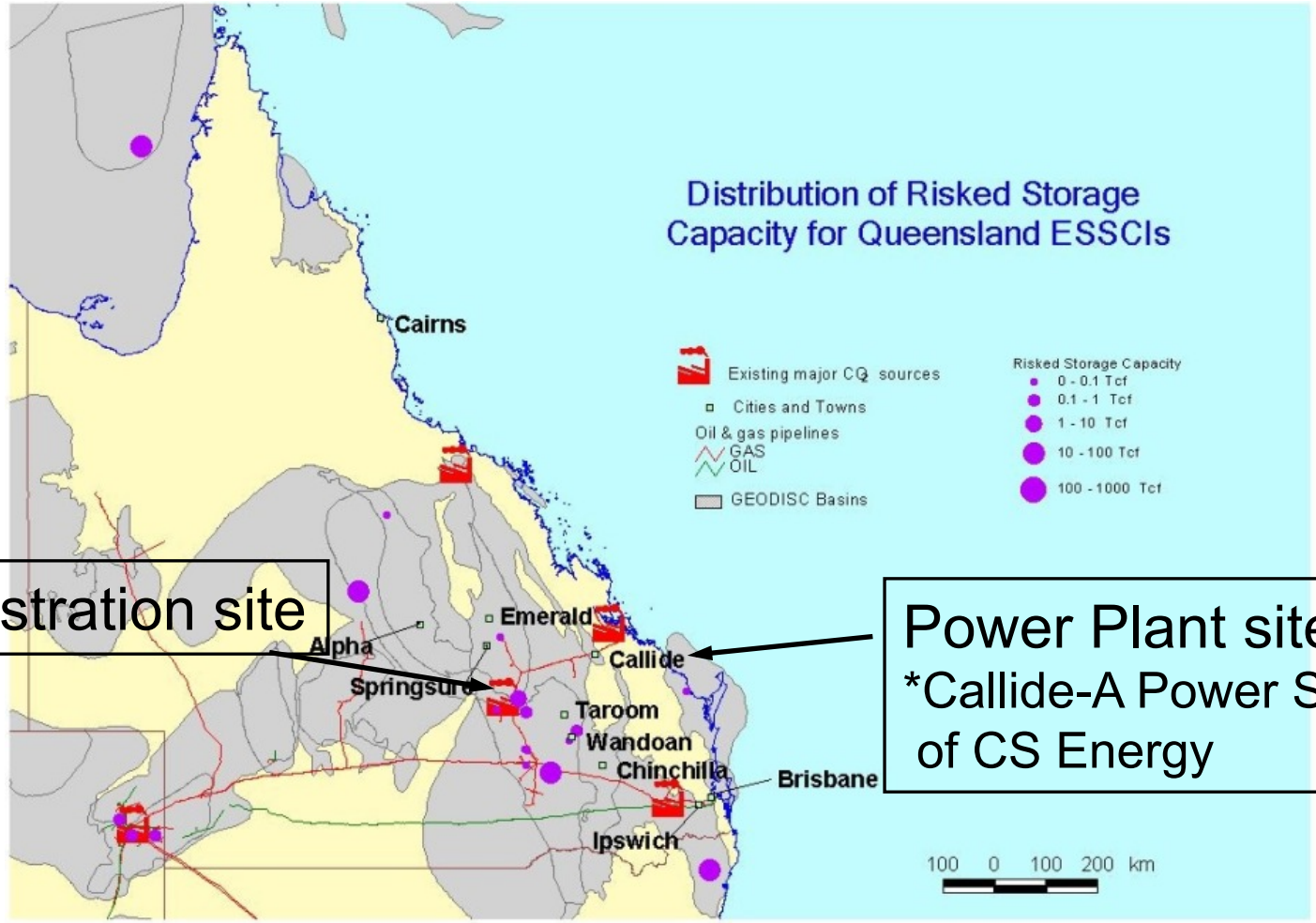
**Oxy-Fuel II: Oxy-Fuel vs. Air Combustion**

**Oxy-Fuel III: Pressurized Oxy-Fuel Combustion System**

**Oxy-Fuel IV: CFB Oxy-Fuel Combustion and Oxy-Fuel Burner**

# Australia/Japan Oxy-firing Project

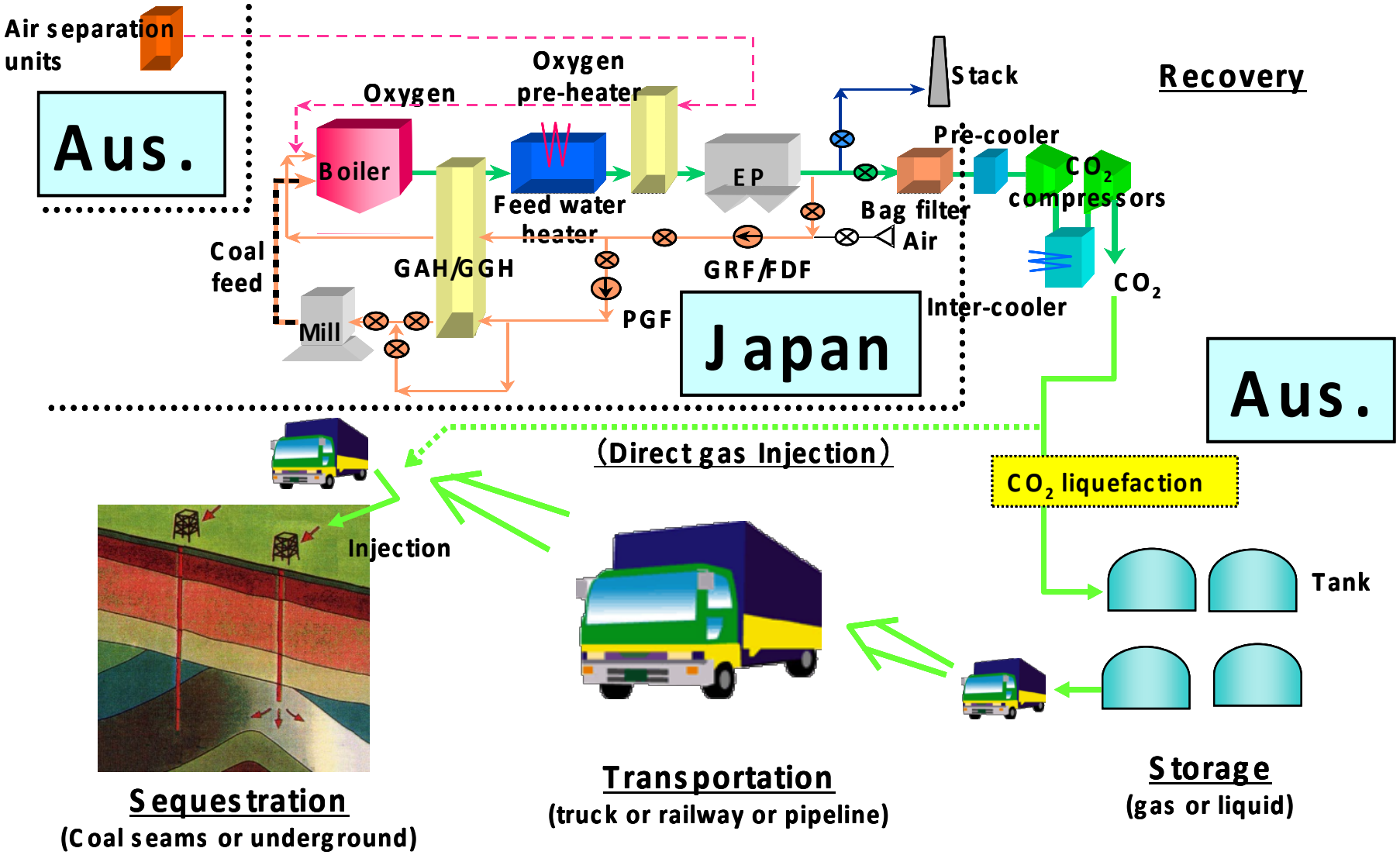
## Site map




Sequestration site

Power Plant site
*Callide-A Power Station of CS Energy

# Australia/Japan Oxy-firing Project



| | Conventional combustion | | $O_2/CO_2$ |
|---|---|---|---|
| | Without $CO_2$ recovery | MEA* | |
| $CO_2$ recovery rate | - | 90 % | 90 % |
| Gross capacity | 1000 MW | 840 MW | 1000 MW |
| Net capacity | 946 MW | 672 MW | 720 MW |
| Gross efficiency | 41.4 % | 34.7 % | 42.9 % |
| Net efficiency | 39.1 % | 27.8 % | 30.9 % |
| $O_2$ production / $CO_2$ liquefaction | - | - | 147 / 108 MW |
| $CO_2$ adsorption / $CO_2$ liquefaction | - | 38 / 72 MW | - |
| Other utilities | 54 MW | 58 MW | 25 MW |

•MEA: Monoethanolamine, a typical absorbent used for $CO_2$ recovery in conventional coal combustion

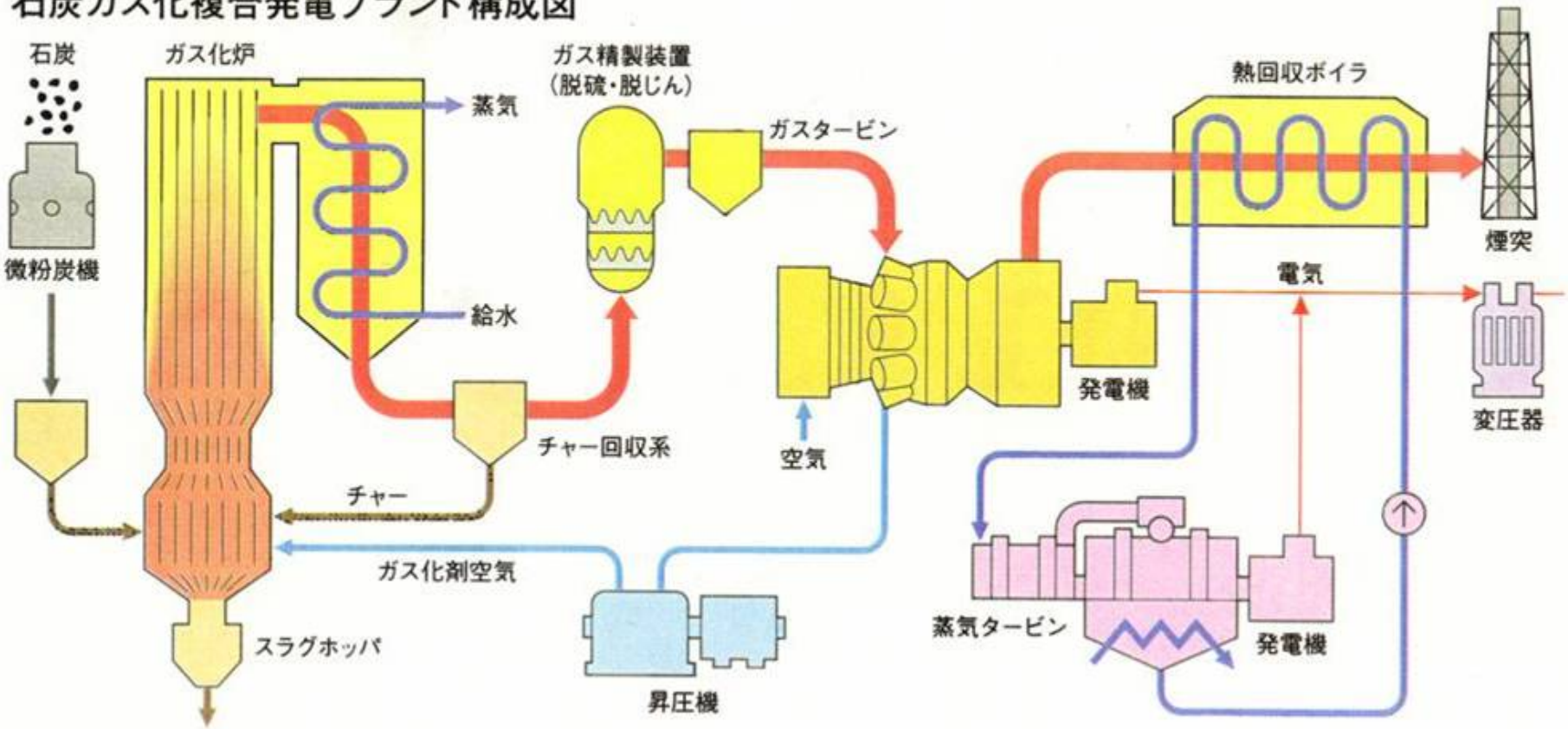
# Energy efficiency of $O_2/CO_2$ pulverized coal combustion

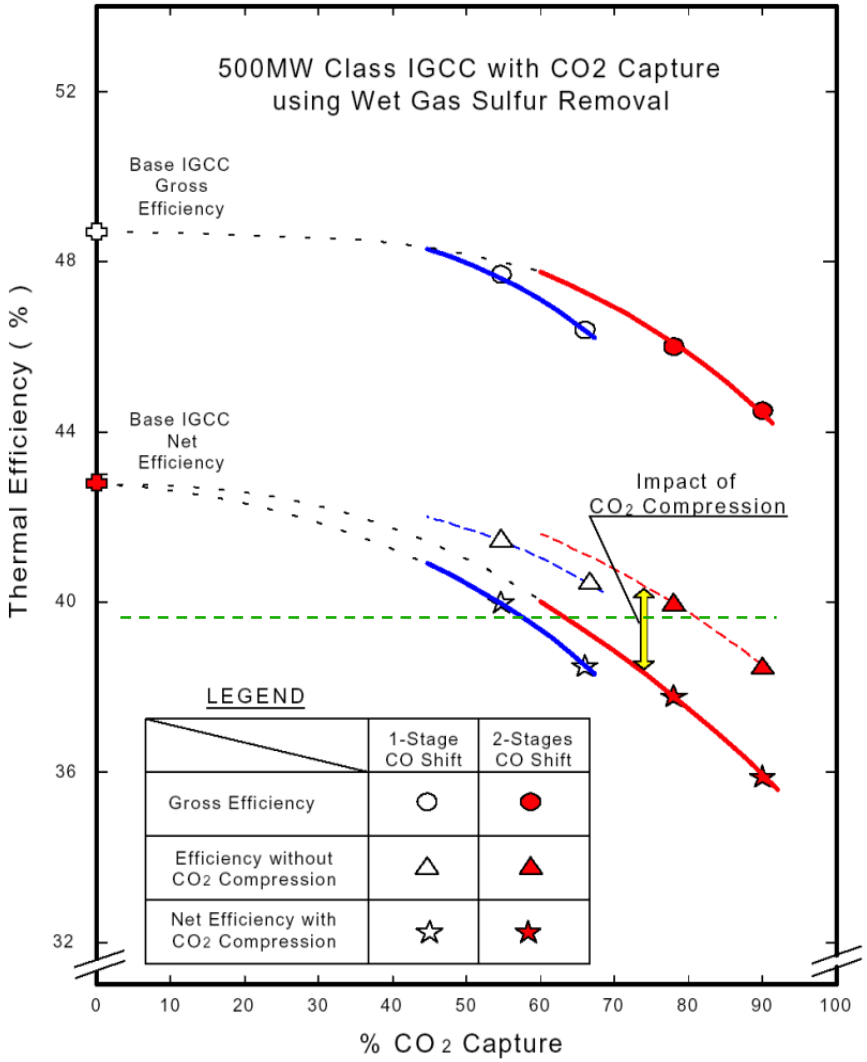
(the largest energy loss: oxygen production) ← (electrolysis for hydrogen)

# IGCC

## 石炭ガス化ガスタービン発電システム

### 石炭ガス化複合発電プラント構成図






# $CO_2$回収型IGCCの正味効率

発生する$CO_2$の70%を回収して、従来の微粉炭火力並みの効率を維持

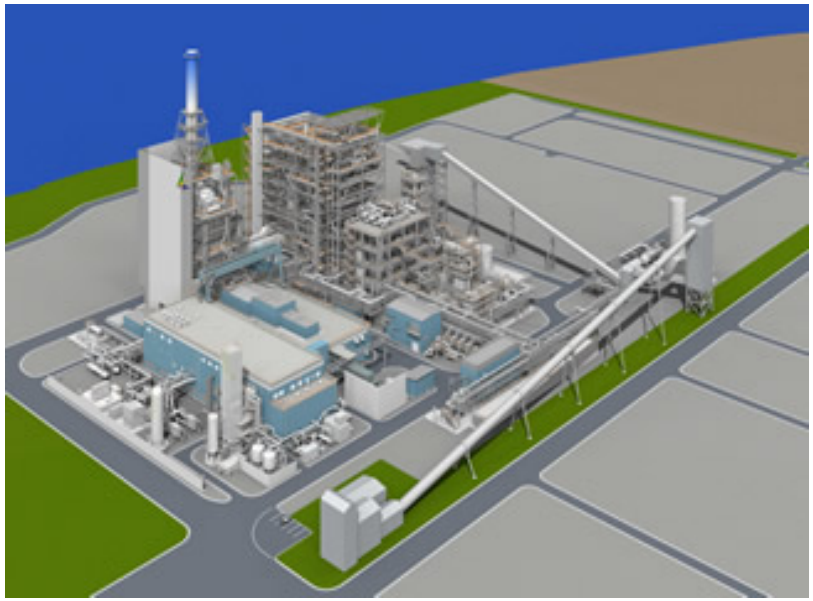
# *Integrated Coal Gasification Combined Cycle*

### *IGCC (Integrated Coal Gasification Combined Cycle)*

- Clean Coal Power R&D Co., Ltd.
- Air blown, entrained-flow gasifier
- 250MW demonstration, 2007-2009
- High efficiency (20% CO2 reduction)

### *IGFC (Integrated Coal Gasification Fuel Cell Combined Cycle)*

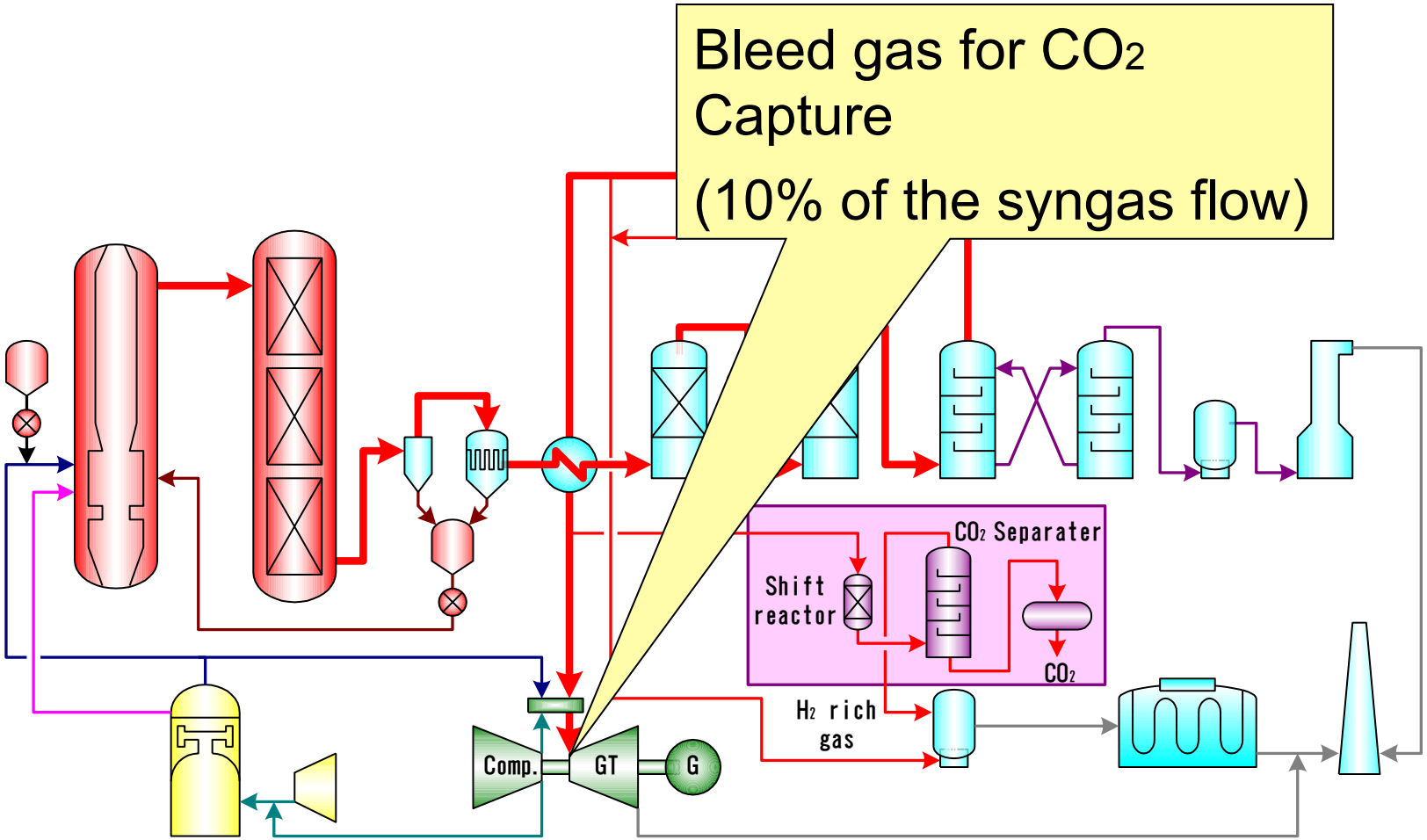
- EAGLE Project
- Oxygen blown, entrained-flow gasifier
- 150t/d pilot test, 2001-2009
- High efficiency (30% CO2 reduction)
- CO2 capture test, 2007-

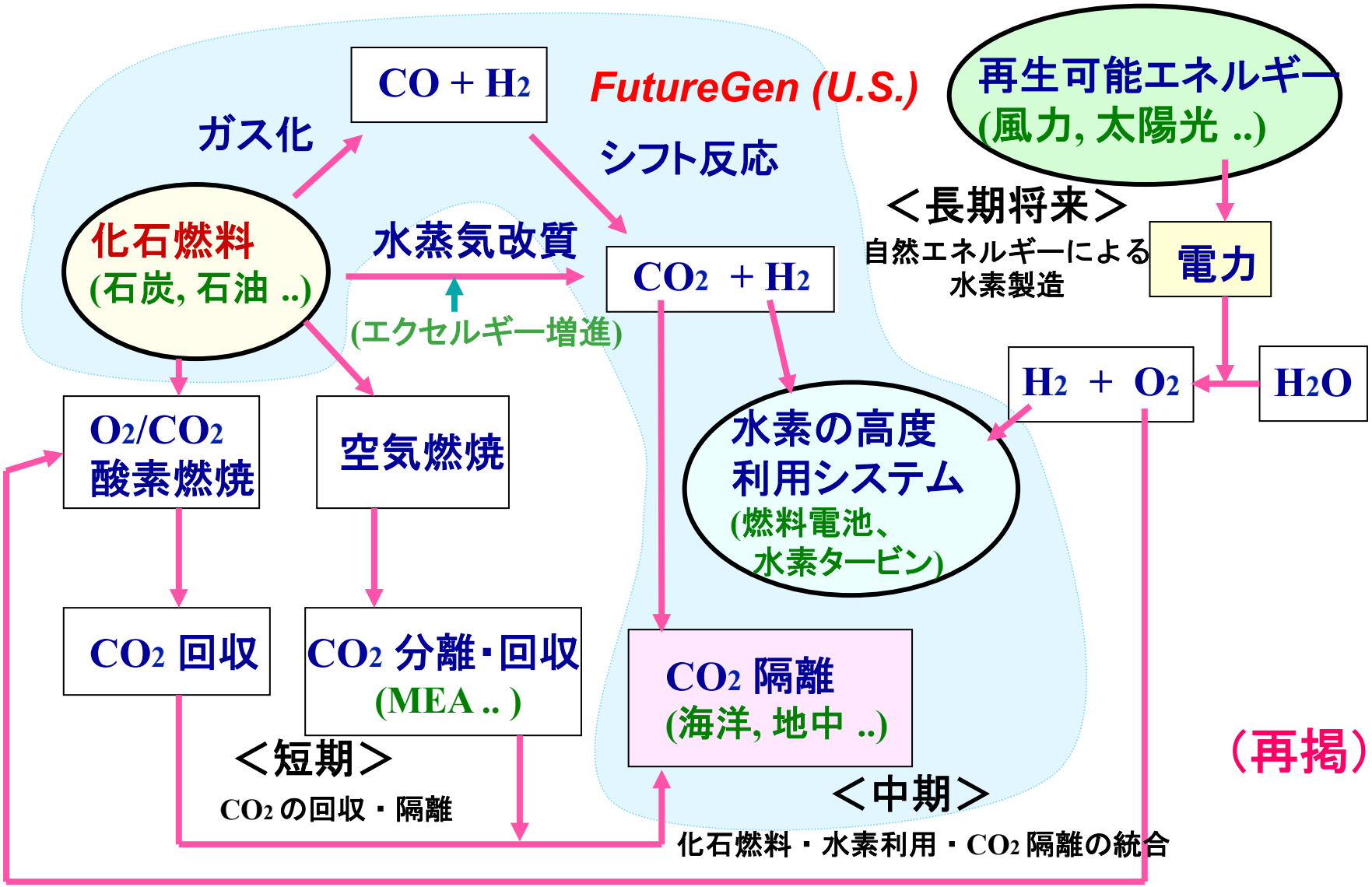


**Bird eye's view of the demonstration plant**

**Pilot plant at Wakamatsu Res. Inst., JPower**

# CO2 Capturing Test (without storage)

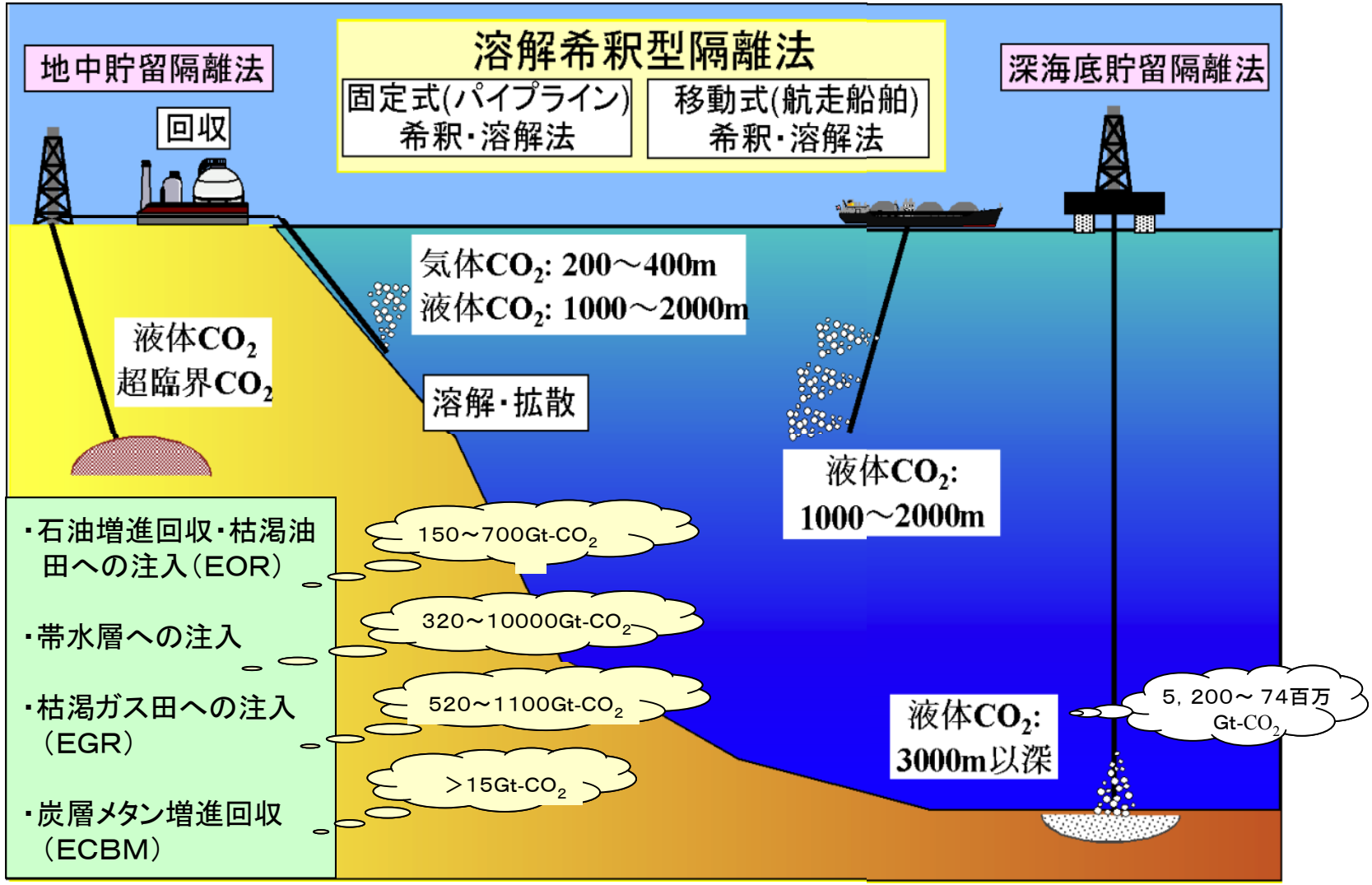





化石燃料・水素・再生可能エネルギー・$CO_2$ 隔離の統合　エネルギー・地球環境戦略

「再生可能エネルギー ＋ 水素」時代へのソフトランディングシナリオ

# 二酸化炭素隔離技術の概要




全世界の$CO_2$排出量：23．9Gt-$CO_2$／年　※Gt（ギガトン）＝10億t
日本の$CO_2$排出量　：1．2Gt-$CO_2$／年

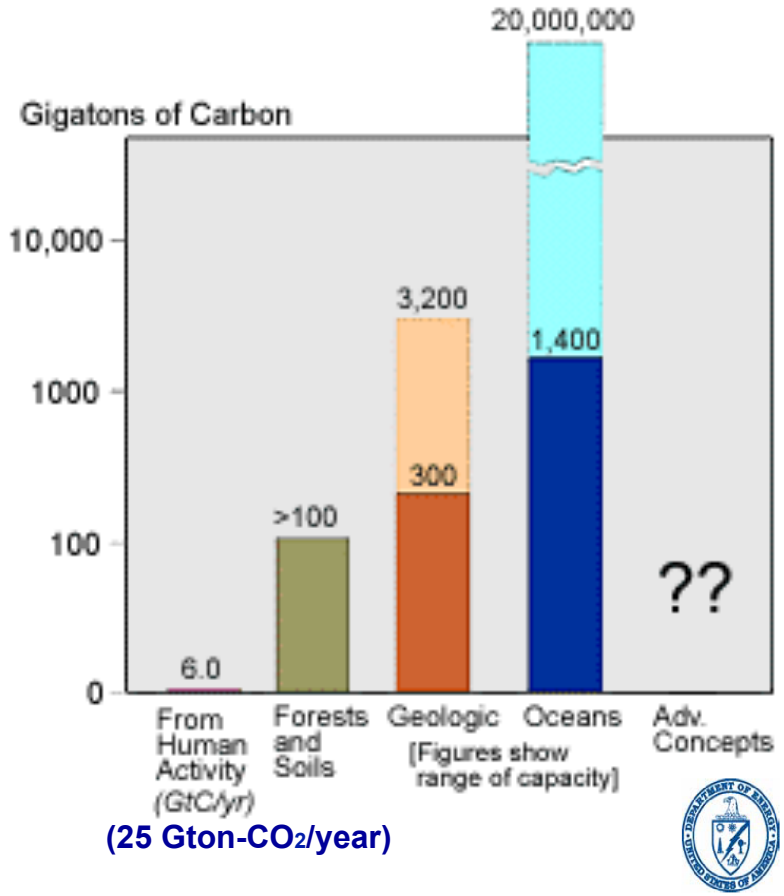
※数値は世界の隔離ポテンシャル（出典：IEAGHG）

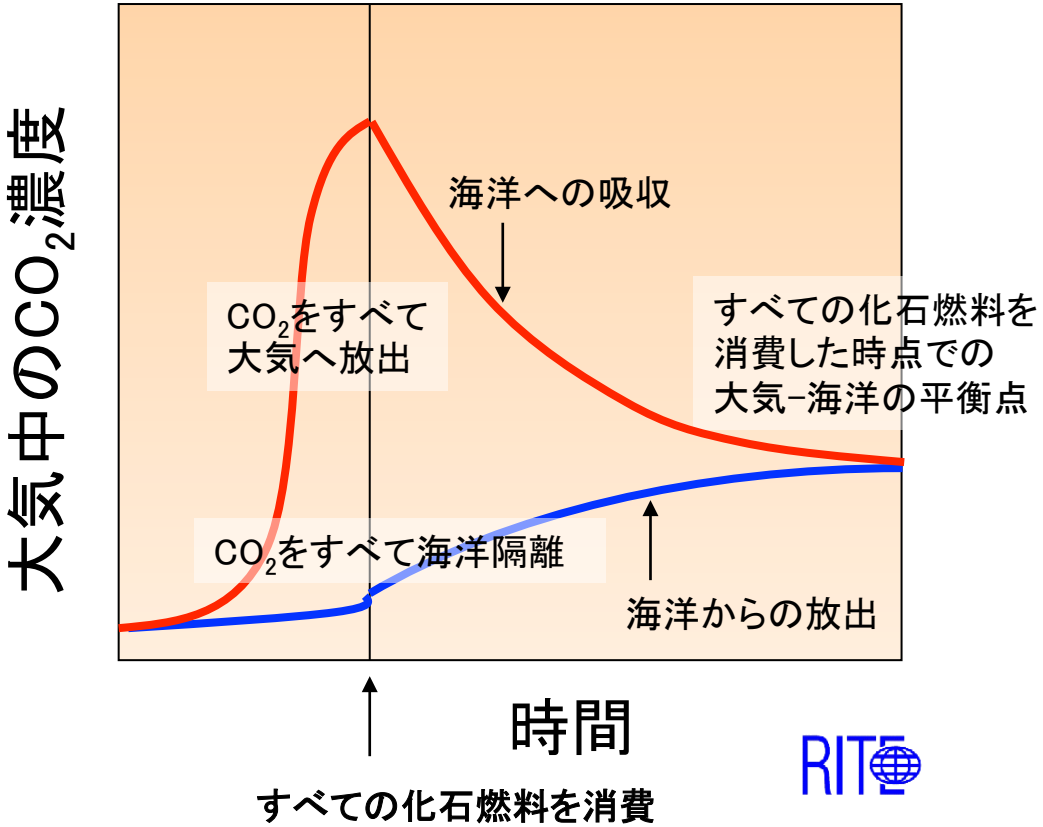
METI，RITE 作成による

# Ocean Sequestration of $CO_2$

**SEA-COSMIC : Study of Environmental Assessment for $CO_2$ Ocean Sequestration for Mitigation of Climate Change**

RITE

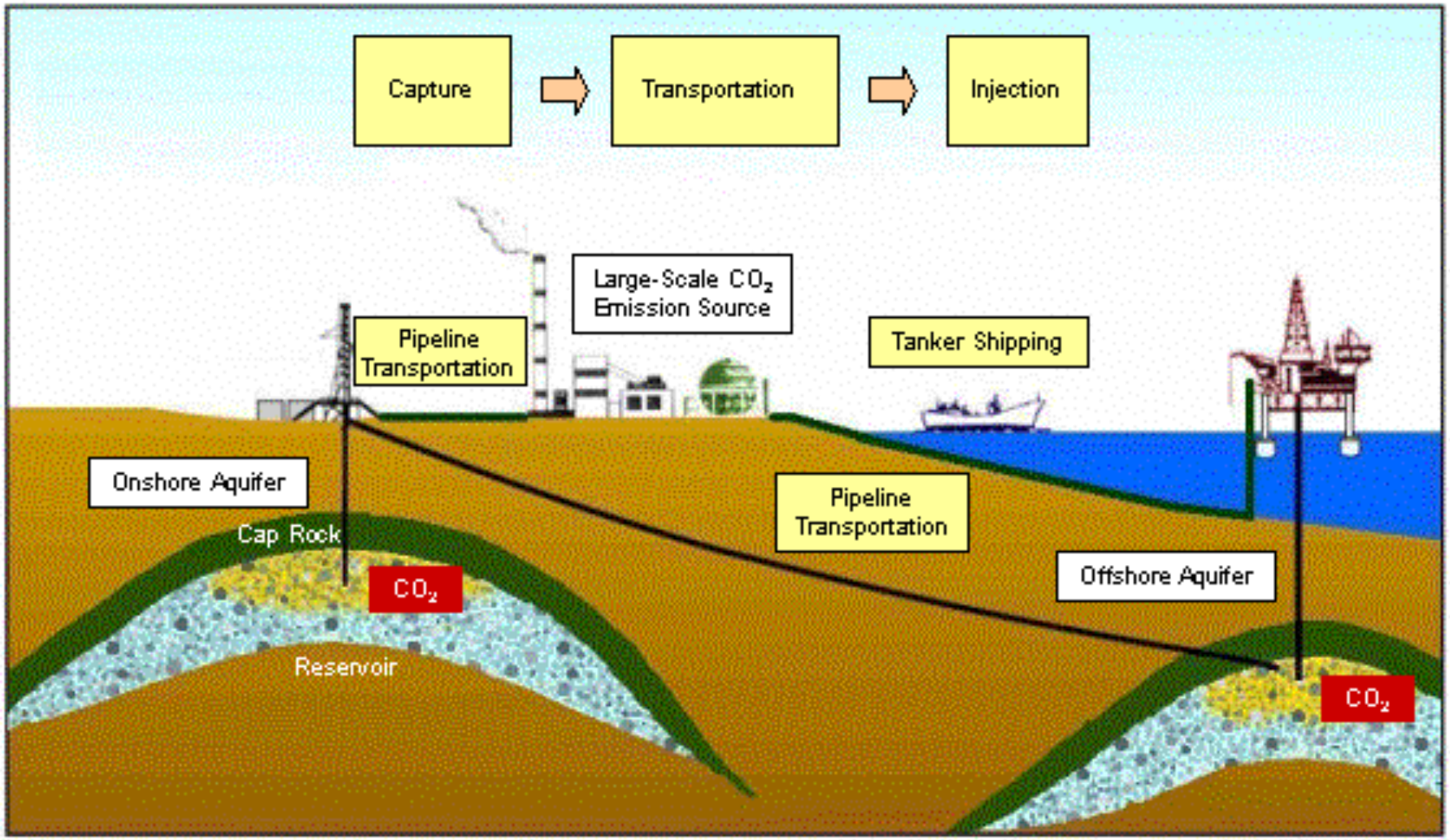



**Huge Capacity of Ocean for $CO_2$ Sequestration**

**The Essential Meaning of Ocean Sequestration of $CO_2$**

# Geological Sequestration of $CO_2$

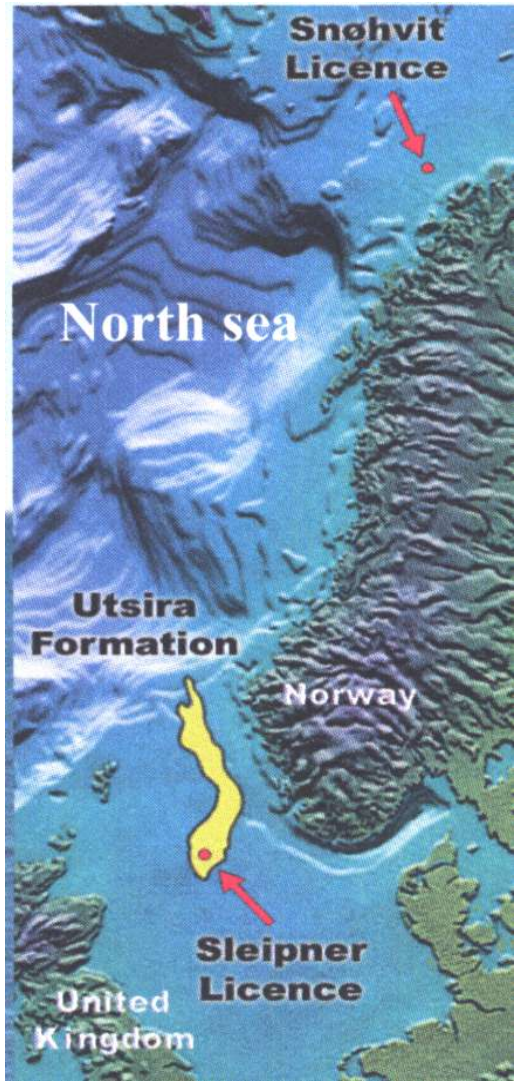


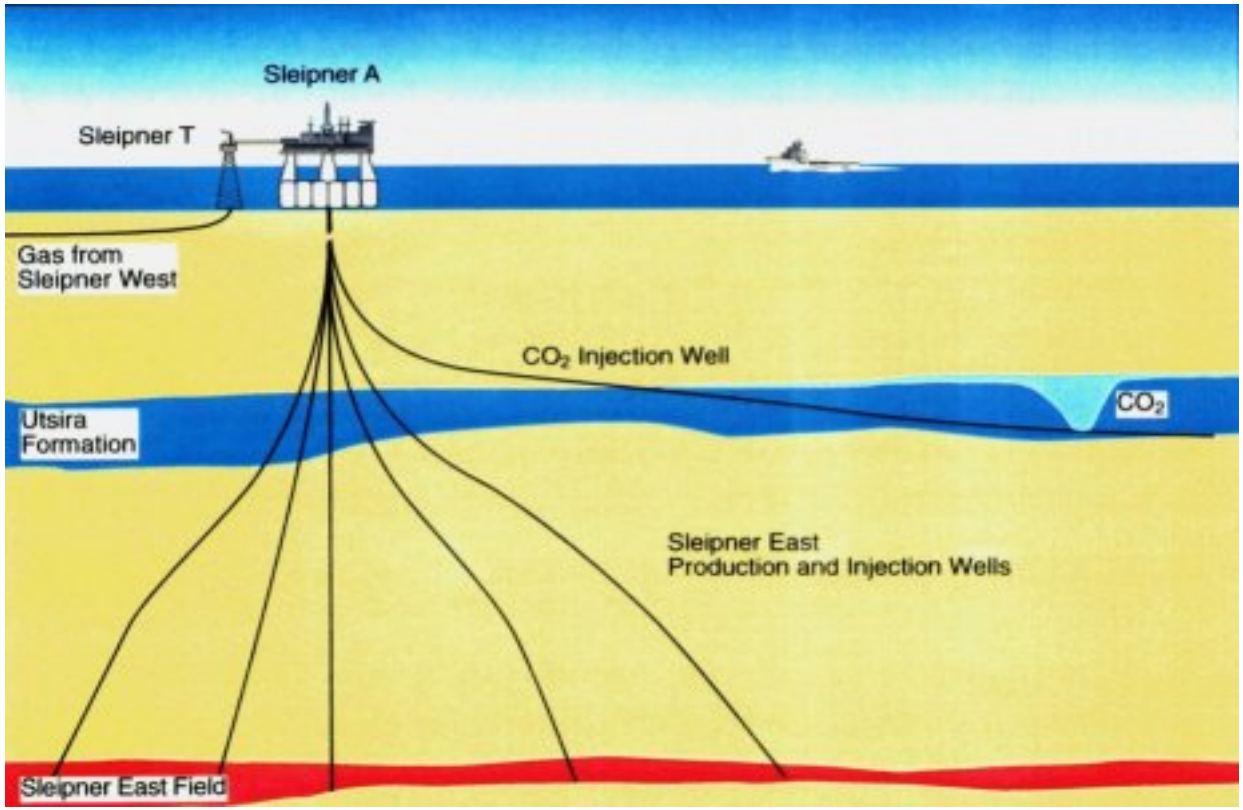

RITE

# Sleipner Project - aquifer

Statoil – Norway

1Mt$CO_2$/year




From Statoil leaflet

# Location of sites where activities relevant to $CO_2$ storage are planned or under way.

From IPCC special report, Carbon Dioxide Capture and Storage (2006)

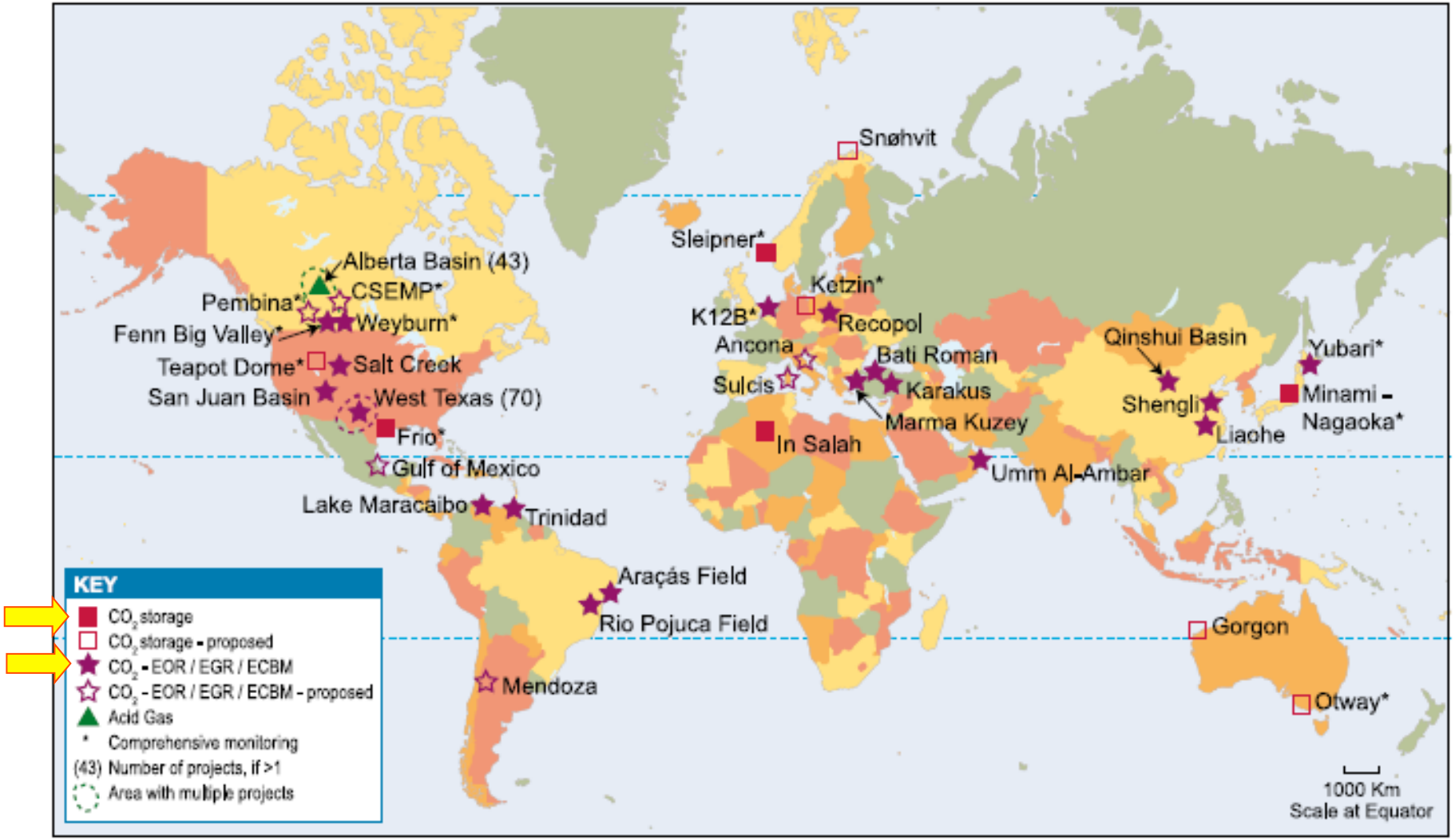
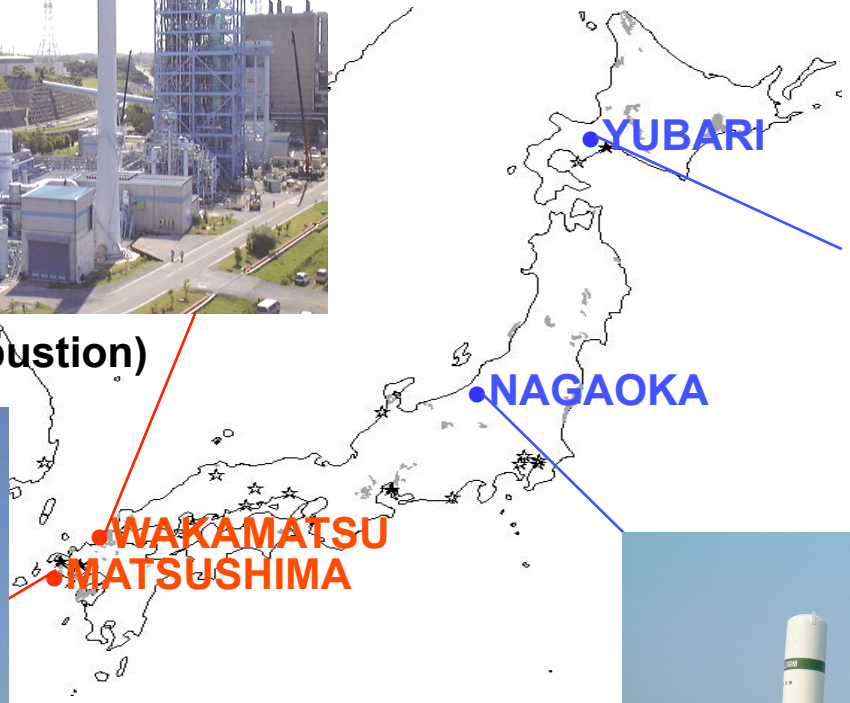



**Figure 5.1** Location of sites where activities relevant to $CO_2$ storage are planned or under way.

# CCS field test sites in Japan

Source: NEDO Home page, RITE Home page, JCOAL Home page

Capture (pre-combustion)



Geosequestration (coal seam)

Capture (post-combustion)

Geosequestration (aquifer)