Current CCS R&D Activities in Korea

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Contents

- Introduction
  - Energy Statistics
  - CO2 Emission
- Korean Government Policies
- CCS R&D Activities & International Cooperation
- Summary

Energy Statistics of Korea

	1th	2nd	3rd	4th	5th	6th	Korea
Energy Consumption (millionTOE)	U.S. 2,326.4	China 1697.8	Russia 704.9	Japan 520.3	India 423.2	Germany 328.5	**Korea(10) 225.8**
Oil Consumption (1,000 b/d)	U.S. 20,589	China 7,445	Japan 5,164	Russia 2,735	Germany 2,622	India 2,575	**Korea(7) 2,312**
GDP (billion $)	U.S. 13,202	Japan 4,340	Germany 2,907	China 2,668	U.K. 2,345	France 2,231	**Korea(13) 888**

*** BP Statistics 2007, World Bank 2007**

	Korea	Germany	U.K.	Japan	U.S.
Average Growth Rate of Energy Consumption(%) ('95-'05)	**4.22**	∆0.28	0.57	0.66	0.97

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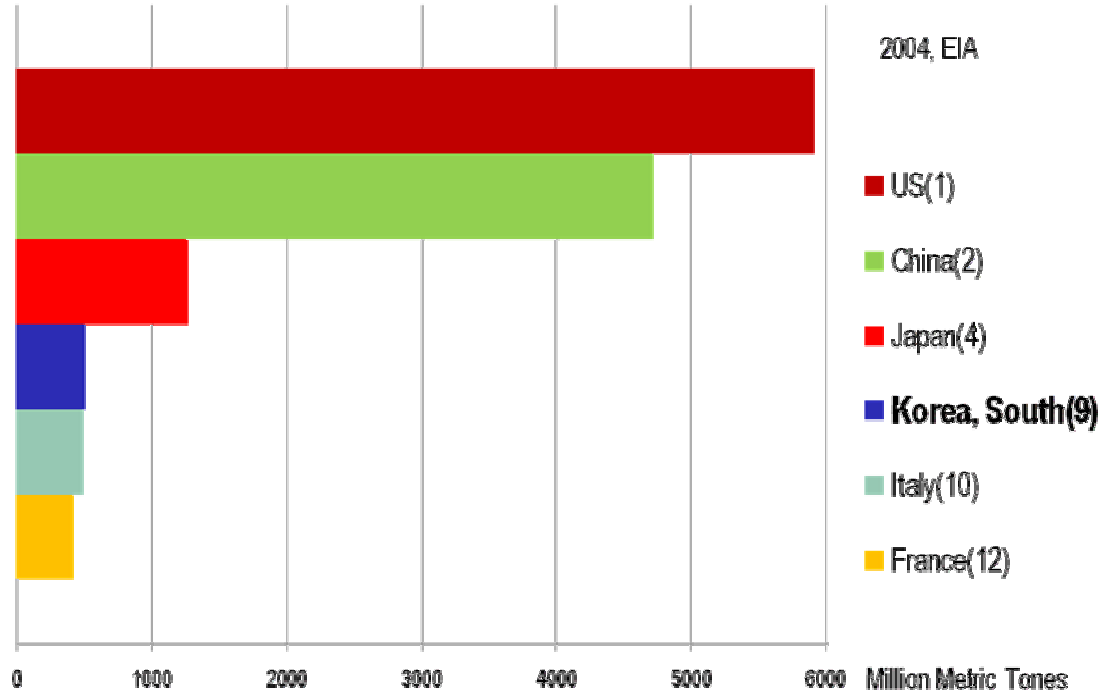
Energy Supply in Korea

- Energy Imports : US$ 85.6 billion (Oil : US$ 55.9 billion)
- Dependency on Imports of Energy : 97% (as of 2006)
- More than 82% of oil from Middle East (as of 2006)

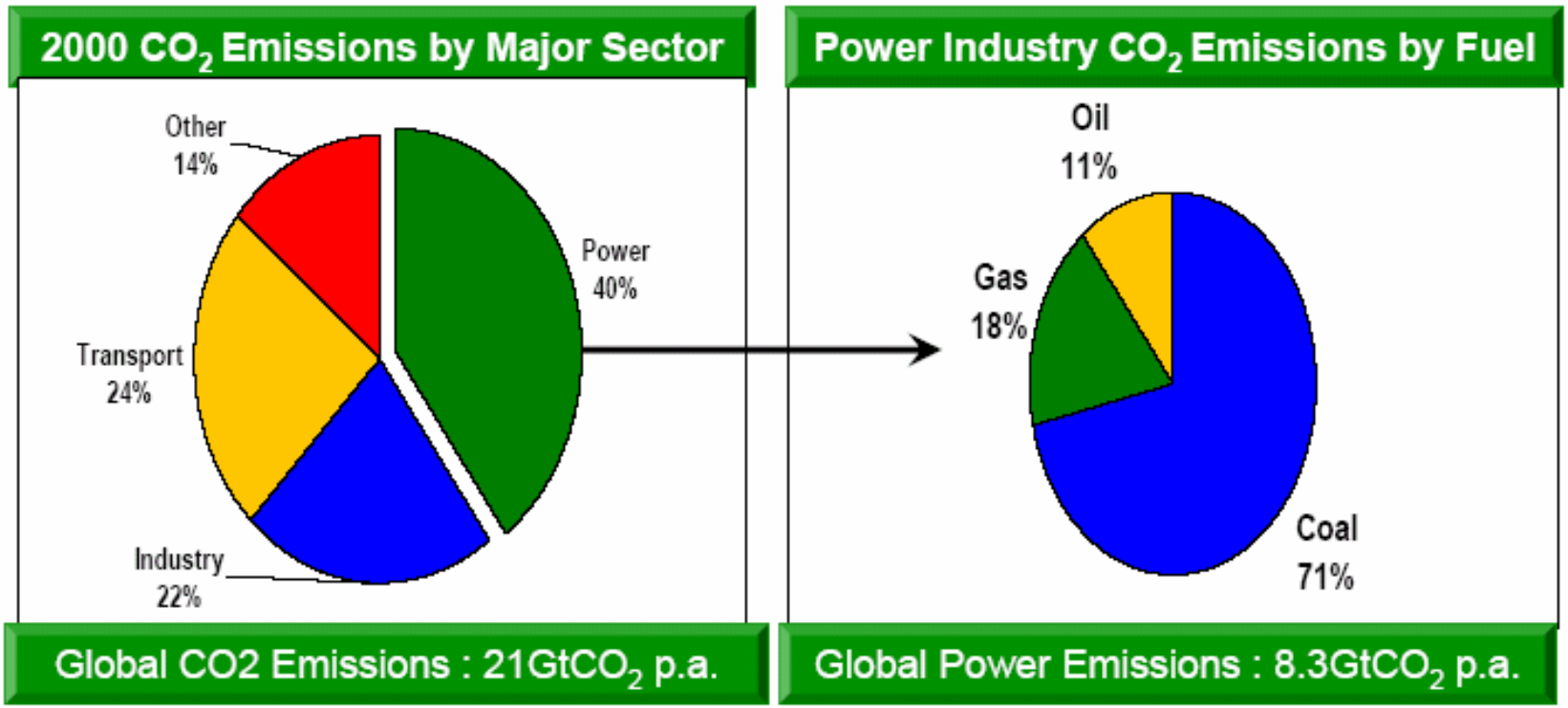
Carbon Dioxide Emission in Korea



	1990	2004	[2004/1990]
Japan	1,015	1,262	24 %
Korea	238	497	109 %

Ref.: EIA, "International Energy Outlook 2007"

Global CO_2 Emissions



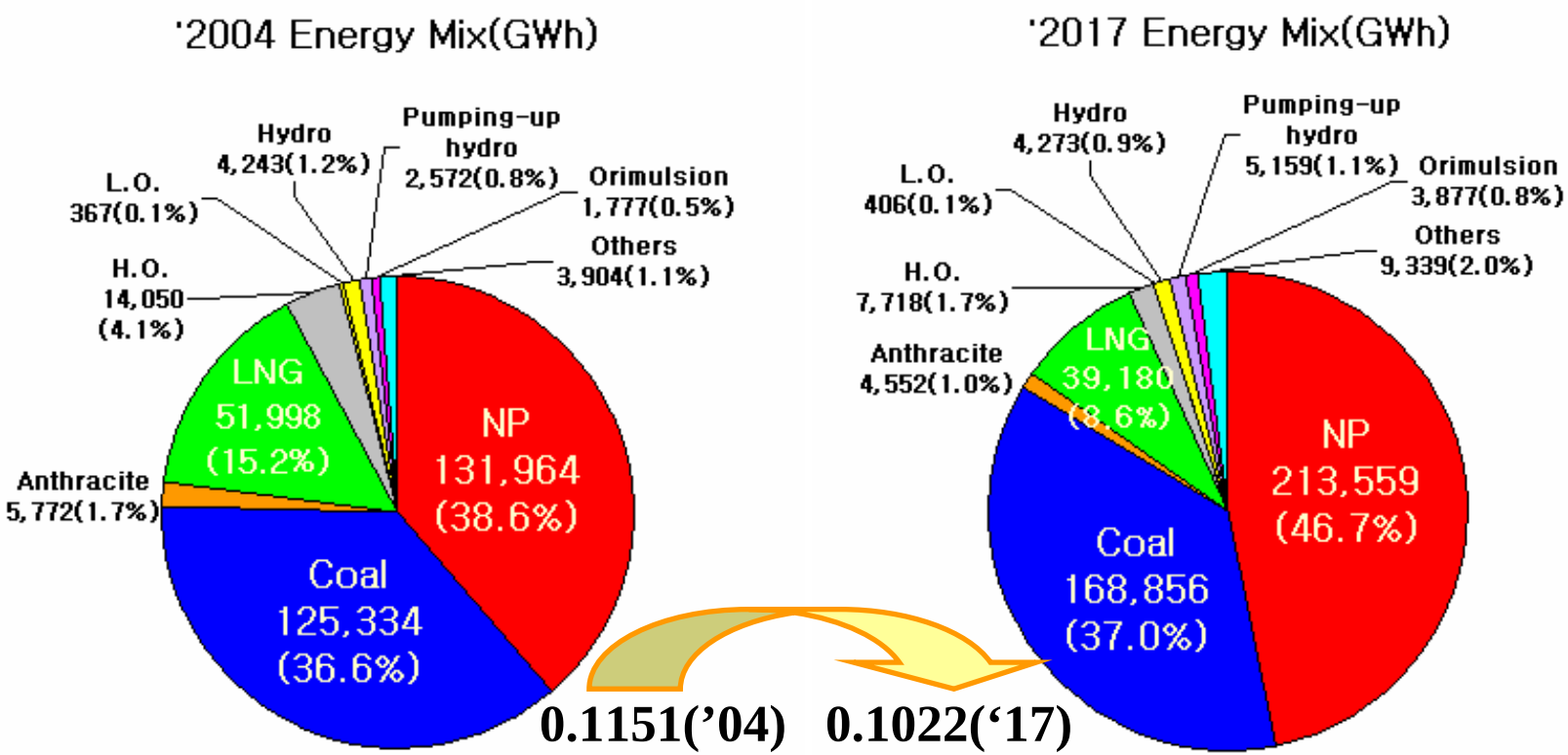
- ❑ **Power sector is responsible for ~41% of global emissions**
- ❑ **Coal represents ~70% of emissions from power plant**
- ❑ **Many large stationary point sources (500 MW PC) emits 2.5~3.5 $MtCO_2/y$**
- ❑ **Large opportunity for CO_2 capture and storage**

Ref.: Hill, BP, 2005, 4thCCS

C Emission Intensity from Korean Power Plant

550 ppm
(Atmospheric. [CO_2]at '50

0.0545 kgC/kWh
(C Emission Rate from Power Plant



0.1151('04) 0.1022('17)

Korea
PC: 0.2227 kgC/kWh
NGCC: 0.1162 kgC/kWh

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The Problems in Korea

- **Fossil fuels are needed**

  - IEA WEO 2006 show that fossil fuels will remain as major energy source in 2030 (53% increase from now to 2030)

- **Korea: The priority in the energy system is to expand nuclear in short-term and to introduce renewable energy sources in the long term**
  - **All analysis show that renewable energy source will play a large role, but not large enough and soon enough.**
  - **More nuclear Power in Korea will relax the C emission Intensity with limitation.**
- **No renewable energy source <u>not known</u> today can play a significant role in 25 years from now, i.e. 2030**

Emissions from fossil fuels must be reduced

The Power Sector

- **The power sector is the major single emitter of CO_2**
  - **KEPCO with her subsidies is one of the major Energy companies in Korea**
- **The Power industry must take responsibility and take the lead for introducing CO_2 free technology.**
- **To be able to make the deep cuts necessary, CCS is necessary**
- **Imminent needs of large scale-up & demonstration of CO_2 capture plant**
- **Primary target is to make technology available in 2020 at an avoidance cost of 25-30 $/ton of CO_2 but also to start development of second generation technology**

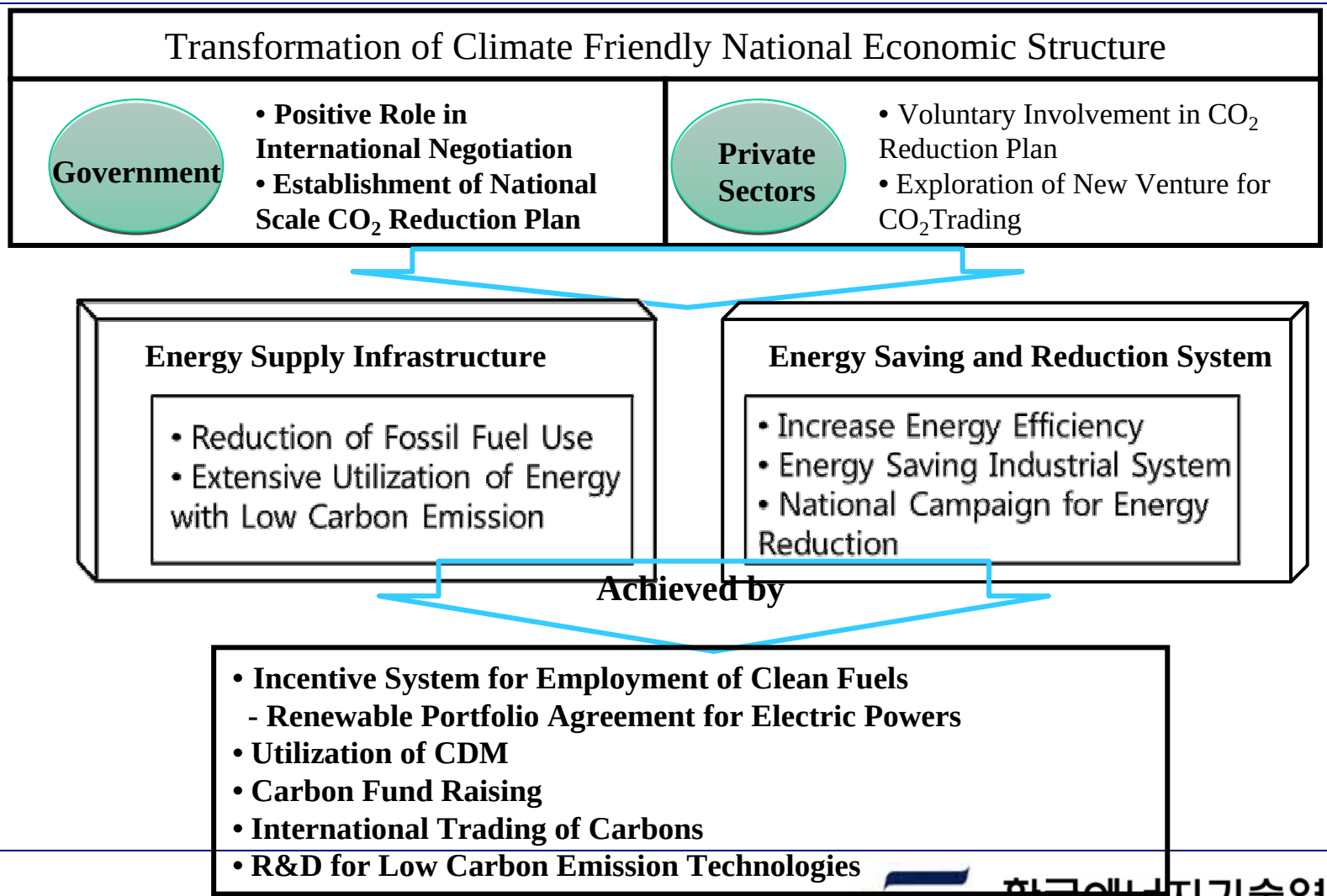
Korea Government Efforts

- **“Inter-ministerial Committee for Climate Change” (Apr. 1998)**
  - **» Prime Minister (Chair)/8 ministries/3 agencies/NGO**
- **“The 1st National Initiative for Addressing Climate Change” (Feb. 1999)**
- **“Special Congress Committee for Climate Change” (Mar. 2001)**
- **“The 2nd National Initiative for Addressing Climate Change” (Mar. 2002)**
- **“The 3rd National Initiative for Addressing Climate Change” (Mar. 2005)**
- **“The 4th National Initiative for Addressing Climate Change” (Dec. 2007)**

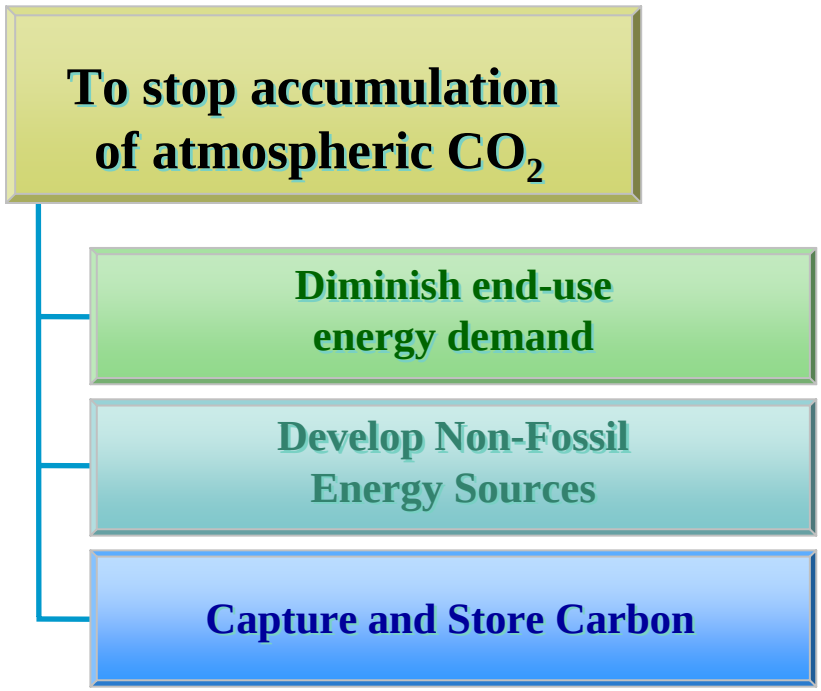
Korean Policies for Climate Change

Top Down Policy		Bottom Up Policy
Post Kyoto Protocol (EU leading)	Group	AP6+9 countries (US leading, High-Polluting Nations)
Prevention of Global Warming by Reduction of Greenhouse gases	Objective	Synthetic Consideration (Climate Change, Economic Growth, Energy Security)
Mandatory target	Reduction Target	Different responsibilities
Top Down, Active reduction	Target Setting up Method	Bottom Up, Voluntary reduction
Trading of Emission Credits	Execution Form	Clean Technology Development And International Cooperation
30% of Worldwide Emissions (Pressing that US and Developing Countries join in)	Emission Ratio of Member Nations	If all 15 nations take part in, 80% of Worldwide Emissions at Initial stage

Korean Strategies



CO_2 Mitigation Options



K. Caldeira, OECD Global Science Forum, 2006

R&D Portfolio in Korea

1. Energy Saving and Efficiency increase
   - Energy saving technology program
2. New and Renewable Energy
   - New and renewable energy development program
   - Hydrogen energy R&D center
3. Carbon Capture and Storage
   - CO_2 reduction & sequestration R&D Center
   - CO_2 ocean sequestration technology program

Seven Government Ministries

- 7 government ministries are involving climate change related S&T development
  - MOCIE (Ministry of Commerce, Industry & Energy)
  - MOST (Ministry of Science & Technology)
  - MOMAF (Ministry of Maritime Affairs & Fisheries)
  - MOE (Ministry of Environment)
  - RDA (Rural Development Administration)
  - KFS (Korea Forest Service)
  - KMA (Korea Meteorological Administration)

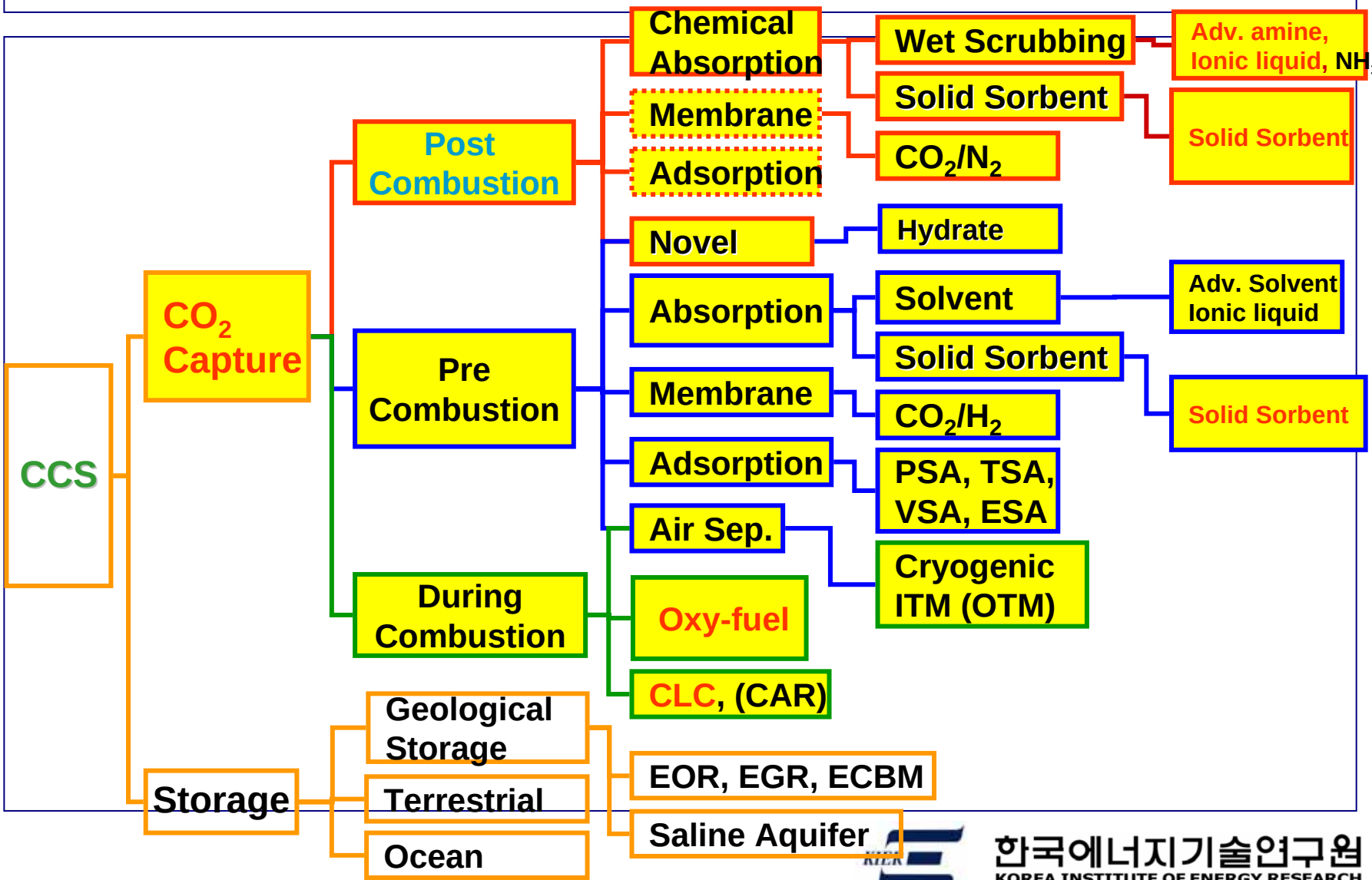
R&D Budget to address Climate Change in Korea

Program	Budget (billion won= million dollar)	Period	Ministry
Energy Saving Technologies (large scale)	17.4	'05-'07	MOCIE
Energy Saving Technologies (general)	41	'02-'04	MOCIE
GHG Separation Technologies	6	'05-'07	MOCIE
Hydrogen Energy R&D Center	111	'03-'13	MOST
4^{th} Gen. Nuclear System Development	35.6	'05-'07	MOST
CO_2 Reduction & Sequestration R&D Center	139	'02-'12	MOST
CO_2 Ocean Sequestration Technologies	5.2	'05-'07	MOMAF
Next Generation Environmental Tech. for Climate Change	6	'05-'07	MOE

International Cooperation

- CSLF (Carbon Sequestration Leadership Forum)
  - Framework for international cooperation in research and development for the separation, capture, transportation and storage of carbon dioxide.
- IEA GHG (International Energy Agency Greenhouse Gas)
- APP (Asia Pacific Partnership on Clean Development & Climate)
  - In APP, Korea is actively involved in Cleaner Fossil Energy, that is CCS area.
  - Korea has been appointed chairs of
    - » Renewable Energy area
    - » Buildings & Appliances area
- FutureGen
  - Korea joined in Government steering committee

CCS Technology



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CO_2 Capture Researches in Korea

1. Wet Scrubbing by absorbent
2. CO_2 Capture by Dry Sorbent
3. Chemical Looping Combustor
4. Membranes
5. Oxy-fuel Combustion
6. Adsorption – PSA

CO_2 Wet Scrubbing

Target: Capture Cost: 55 \$/tCO_2 → <30 \$/tCO_2

Application: PC

50 tCO2/d DEMO (’08 – ’14)

Test Bed of CO_2 Capture
at Seoul LNG Cogeneration Plant, 2tCO_2/d

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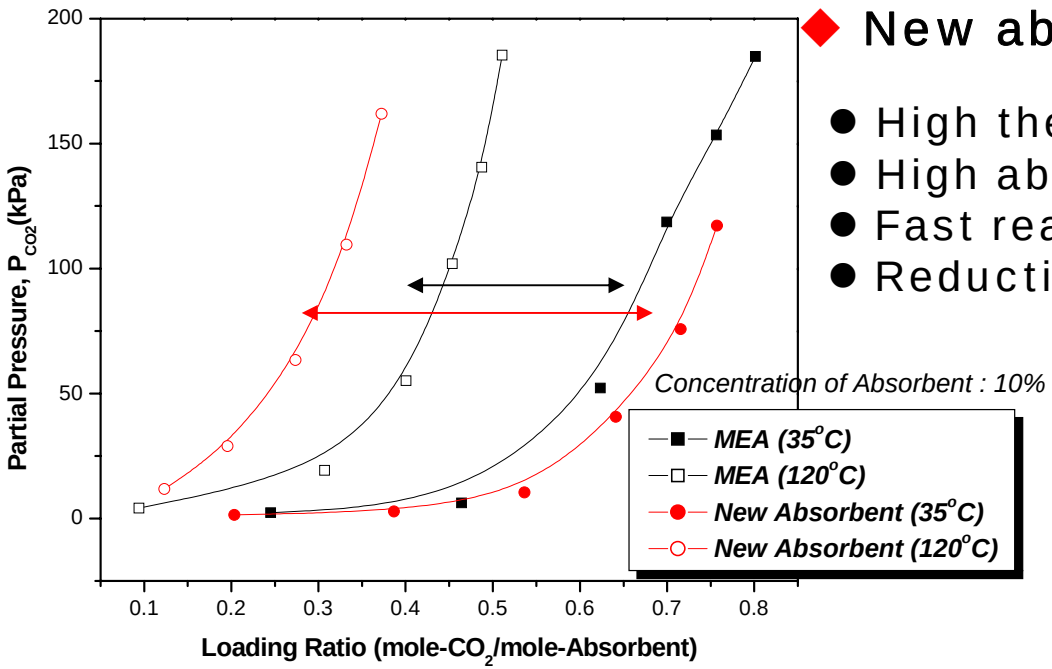
Chemical Absorbent



- New absorbent: KoSol 1 & 2
  - High thermal stability
  - High absorption capacity
  - Fast reaction rate
  - Reduction of regeneration energy

About 30% improvement of Performance vs. MEA

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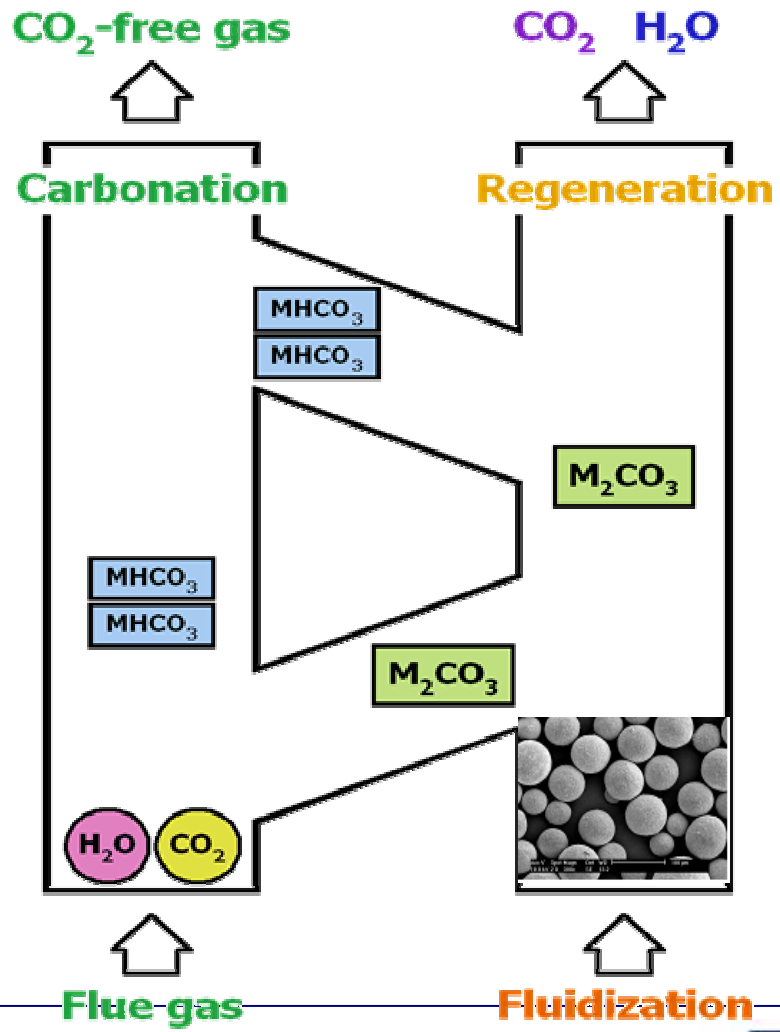
Roadmap to realization: absorption Process

~ 2007	2008 ~ 2015	2016 ~ 2020
Test bed	**Small scale Demonstration**	**Demonstration Plant**	**Commercial Plant**
~2 tCO2/d	**~ 5 MW**	**~50 MW**	**500 MW**
● Absorbent screening ● Basic principles ● Flue gas characteristics ● wet & solid sorbent	● Development of a new type of absorbent ● Validation of basic principles and scale-up factors ● Long term operation characteristics	● Verification and optimization of the process ● ~ 30 US$/tCO$_2$	● large scale reduction of CO$_2$ to meet global guideline ● < 20 US$/tCO$_2$

Concept of Dry Sorbent Technology



$$M_2CO_3(S) + CO_2 + H_2O \Leftrightarrow 2MHCO_3(S)$$

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Dry sorbent Process: overview

- Background
  - Need for development of cost-effective and energy-efficient CO_2 capture process
- Objectives
  - Development of commercial-grade dry sorbent for CO_2 capture
  - Development of CO_2 capture process with two fluidized bed reactors

    - Improving CO_2 removal (>80%) ant the extent of regeneration (>90%)
    - Continuous operation of two-fluidized bed reactor system (>50h)
    - Installation and operation of a 100 Nm^3/h process

Dry Sorbent Technology in Korea

100 Nm^3/h test facility at KIER(2006)

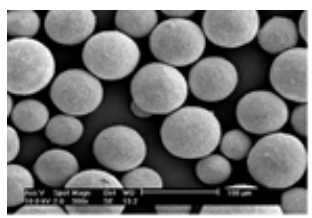
Completing Pilot scale test, 2000 Nm^3/h ('12: < 17 US$/$tCO_2$)

'08

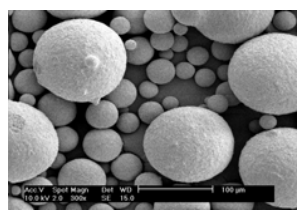
100 Nm^3/h process development
Development of Commercial level sorbent

'05

2 Nm^3/h process test facility
Met the target performances of sorbent in the Lab



Sorb KX 40



Sorb TKX 35

Chemical Looping Combustor (CLC)

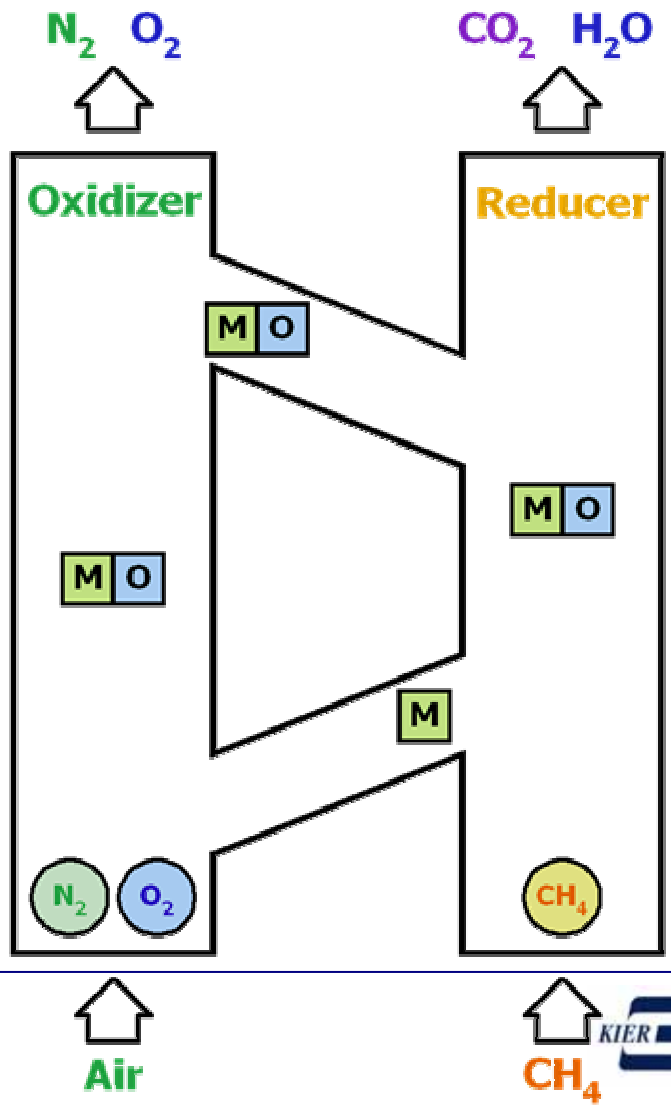
AIR Reactor / Metal Combustion

$4M + 2O_2 \rightarrow 4MO$

700-1200 ºC

Less Thermal NOx (w/o SCR <50ppm)

Exothermic Gas Turbine, Steam Turbine



Fuel reactor / Fuel Combustion

$CH_4 + 4MO \rightarrow CO_2 + H_2O + 4M$

600-1200 ºC

High CO_2 Concentration (>98%)

Endothermic Steam Turbine

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CLC: Overview

- **Development of Chemical-Looping Combustion Technology**

  (for Low emission and High efficiency LNG-fired Power Generation System)

  - **Process scale : 0.1 MW (100kW)**
  - **Performance : Inherent CO2 separation (>98%), Low NOx emission (<50ppm)**
  - **Application : Small scale LNG fueled co-generation system**
  - **Research Level : World best !**
- **Research Period : Mar. 2000 ~ August 31, 2011**

CLC in Korea

TGA

Fixed bed

Circulating Fluidized Bed

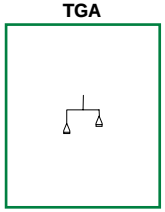
Batch Pressurized Fluidized Bed

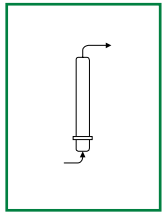
Two-Interconnected Fluidized Bed

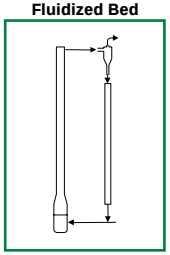
ASTM Attrition Tester D5757-95

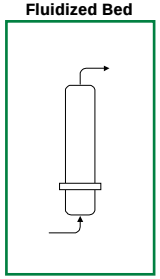
Automated Small-scale Fluidized Bed

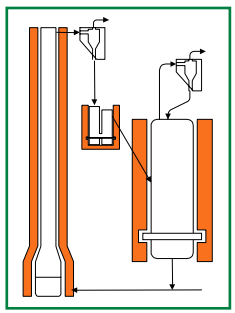
Two-Interconnected Pressurized Fluidized Bed

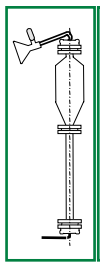


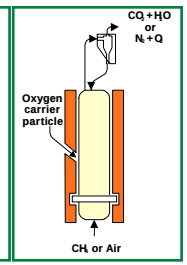


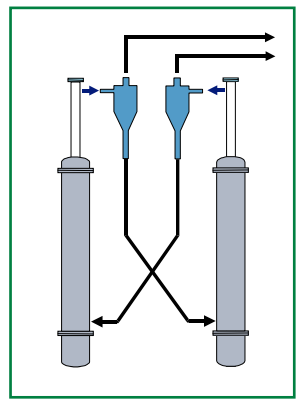












'00-'01 '02 '03-'05 '06-'11

Purpose	Reaction Solid conversion	Reaction Gas converstion	Hydrodynamics Design & operating values	Reaction Effect of T & P	Reaction Continuous & Long-Term operation	Reaction Attrition resistance, Cyclic test & LNG combustion	Reaction Continuous & Long-Term operation (New concept)
Press.	1 atm	1 atm	1 atm	1-3 atm	1-3 atm	1-3 atm	1-6 atm
Temp.	650-1000 °C	500-1000 °C	25-600 °C	700, 900 °C	700-900 °C	700-1000 °C	700-900 °C
Power	0.024 W	95 W	Hydrodynamics	1,310 W	50,000 W (50kW)	Complementary test	50 & 100kW

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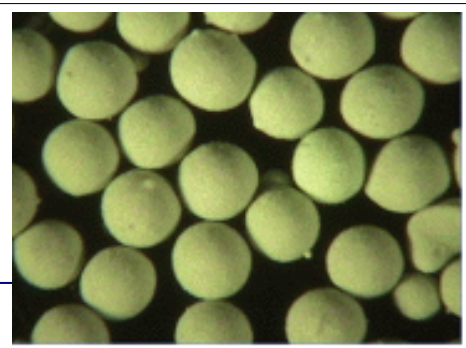
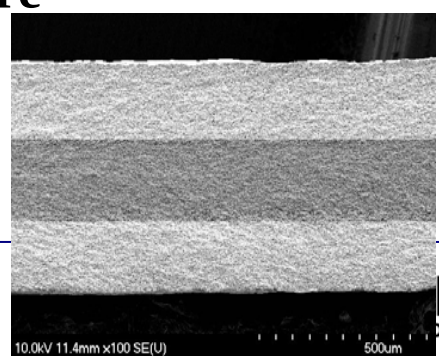
CLC - carrier

Item		Calcination temperature	
		650 ºC	800 ºC
Oxygen carrier		OCN-60	OCN-60
Shape		Spherical	Spherical
Average particle size [μm]		115	107
Bulk density [g/cm^3]		1.02	1.05
Attrition resistance	AI	17.0	38.3
	CAI	14.0	34.4
Photo			

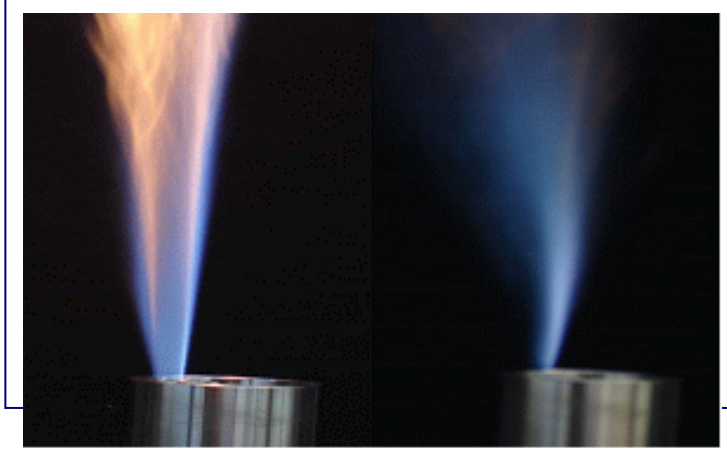
Membrane

- **Development of Separation Process for CO_2 Recovery in Real Emission Sources**
- **Development of Membrane Materials for CO_2 Recovery**
- **Projects ;**
  - **Development of Combined Separation Process for CO_2**
  - **Application of Membrane CO_2 Separation Technology to Commercial Plant**
  - **Development of membrane and Hybrid Process for CO_2 Recovery**
  - **Faujasite zeolite membrane for mid- and low temperature gases**
  - **Inorganic membrane for high temperature**



Oxy-fuel combustion

- **Development of elemental technology for oxy-fuel combustion**
- **Development of oxy-fuel pulverized combustor by CO_2 Recycle**
- **Projects ;**
  - **Development of Low NOx oxy-fuel burner**
  - **Development of ITM membrane for oxygen separation**
  - **Pulverized coal combustor with CO_2 recycle**



Adsorption - PSA

Historical review

- Started from early 1990s
- Applied to small scale power plant in 1996 and 2001
  - Scale : 0.6 ~ 2 ton-CO_2 / day (Pilot Scale)
  - Operating mode : PSA, 3 towers (adsorbent ; Zeolite)
  - Location : Samsung Fine Chemicals, Po-hang Iron and Steel Co.
- 2 projects are going on or 5 projects were completed

Major research areas

- Enhancement of performance of adsorbents
- Reducing the energy consumption and process optimization
- Developing new adsorption technology ; Electric Swing Adsorption

R&D Topics of Adsorption Technology

R&D Topics

- **Development of Carbon Molecular Sieve for GHG and Application to PSA Process**
- **Development of CO_2 Recovery and Purification Process from Landfill Gas Using ESA Method**
- **Completed Projects ;**
  - **Development of Adsorption Process for CO_2 Separation Technology**
  - **Application of PSA to Commercial Plant CO_2 Separation**
  - **Development of CO_2 Capture Process with Chemical Materials etc.**

Participants

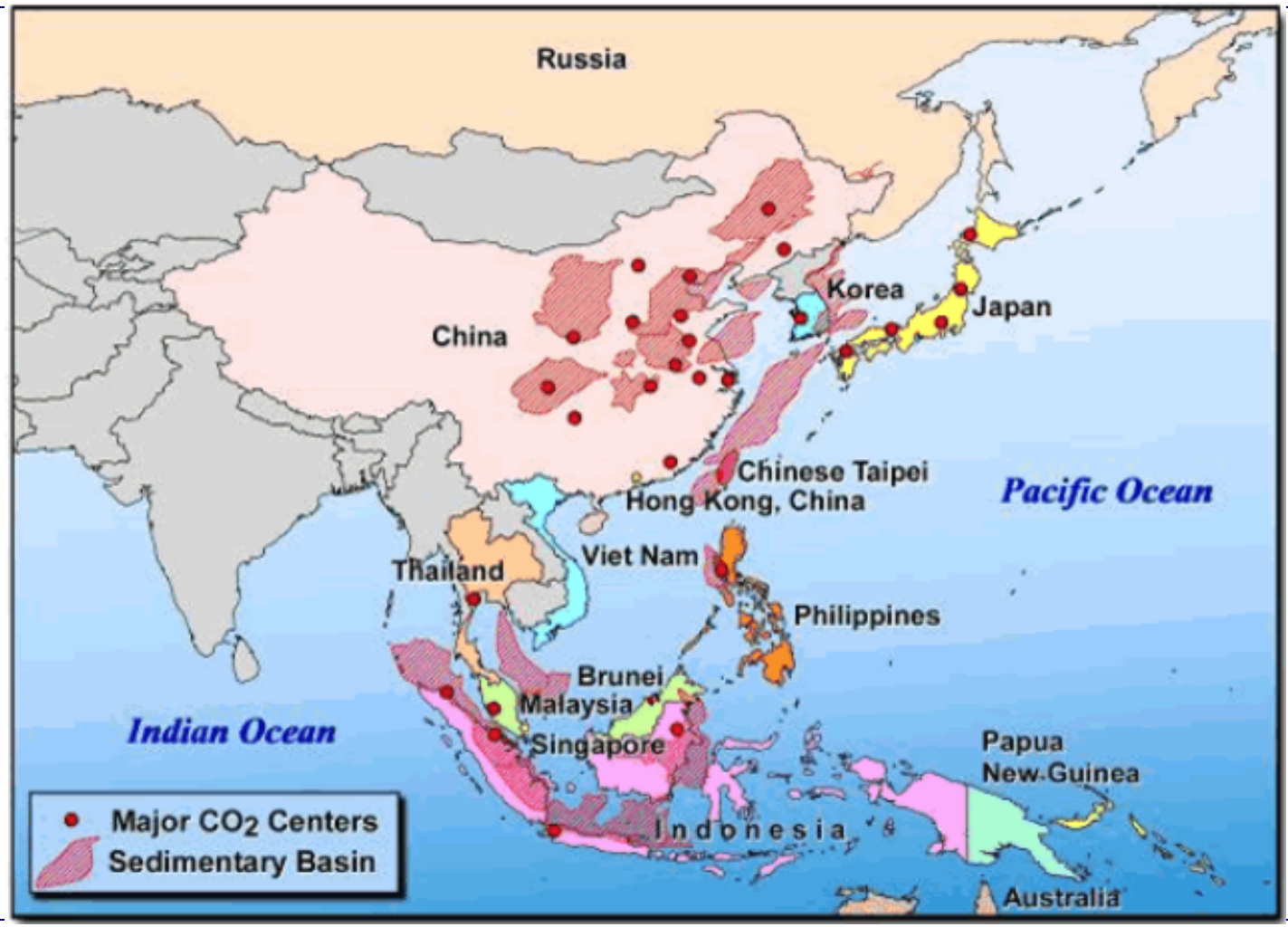
- **Institute/Company ; KIER, KIST, RIST / POSCO, Hyundai**
- **Universities ; Yonsei, Kyoungbuk National University**

Global CO_2 Storage Capacity

- **Japan and Korea's ability to continue using fossil fuels likely constrained by relatively small domestic storage reservoir capacity**

Ref.: Edmonds et al. "Global Energy Technology Strategy addressing Climate Change"GTSP (2007)

Sedimentary Basins near CO_2 Sources



Ref. S. Bachu, 2007, Capacity Building Workshop, Pittsburgh

Summary

- **Korean government is actively involved in international cooperation and development of technologies.**
- **CCS is one of a portfolio of CO_2 mitigation options**
- **Needs to drive capture cost down from 55 \$/tCO_2 to <30 \$/tCO_2**
- **Represents 75% of cost of CCS**
  - **'05~'20: ½ Reduction possible**
  - **'20~'30: IEA GHG work indicates 20~40% cost reduction from 30 \$/tCO_2**

Summary

- **Need significant reduction of CO_2 capture cost from new improved methods**
  - **Korea: 1) wet scrubbing: 25~30 \$/tCO_2 (1996-)**
    2) Dry sorbent technology: 20 \$/tCO_2 (2002-)
    3) Chemical looping combustion: <20 \$/tCO_2 (2002-)
    4) Oxy-Fuel Combustion (2002-)
- **Need R&D for a zero emission coal power generation**
- **Need to confirm the capacity of storage and to overcome the shortage of storage sites**