Energy Conversion & Power Generation from Solid Fuel

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Main-text : Power Generation

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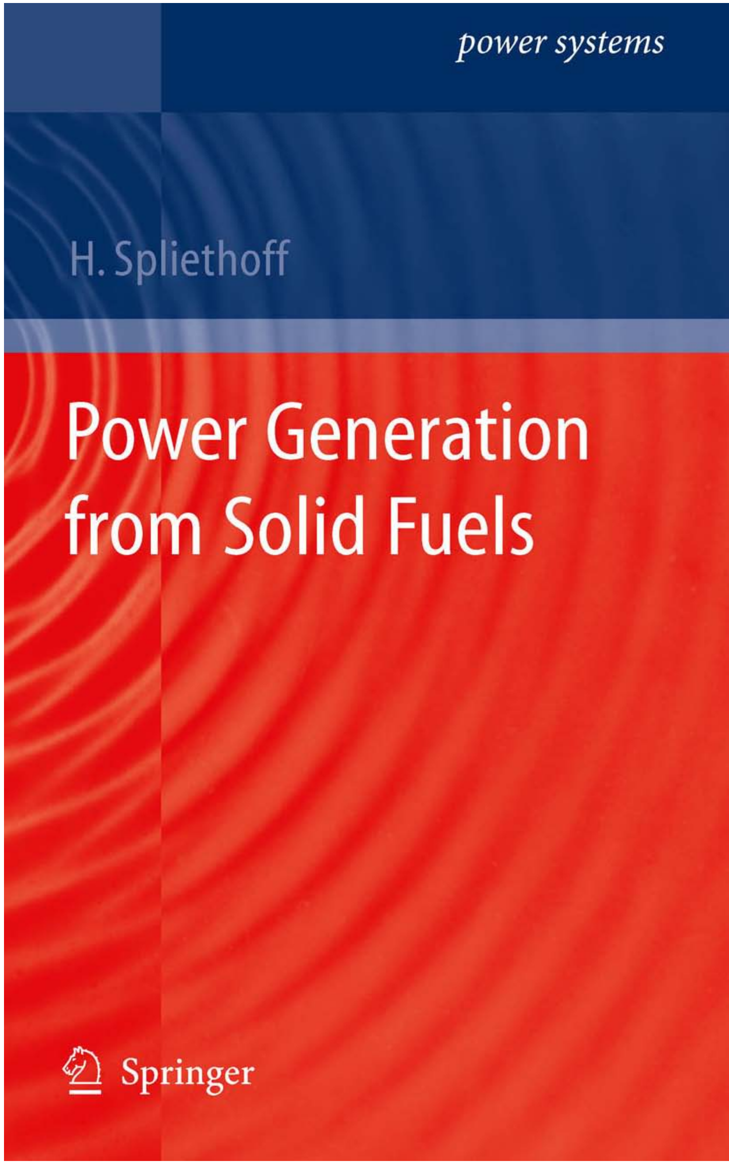
2. Solid Fuels
3. Thermodynamic Fundamentals
4. Steam Power Station for Electricity and Heat Generation
5. Combustion System for Solid Fuels
6. Power Gen. from Biomass &Waste
7. Combined Cycle Power Plants
8. Carbon Capture and Storage(CCS)



Sub-text : Power Generation

1. Power Plant System Design (Kam W. Li)
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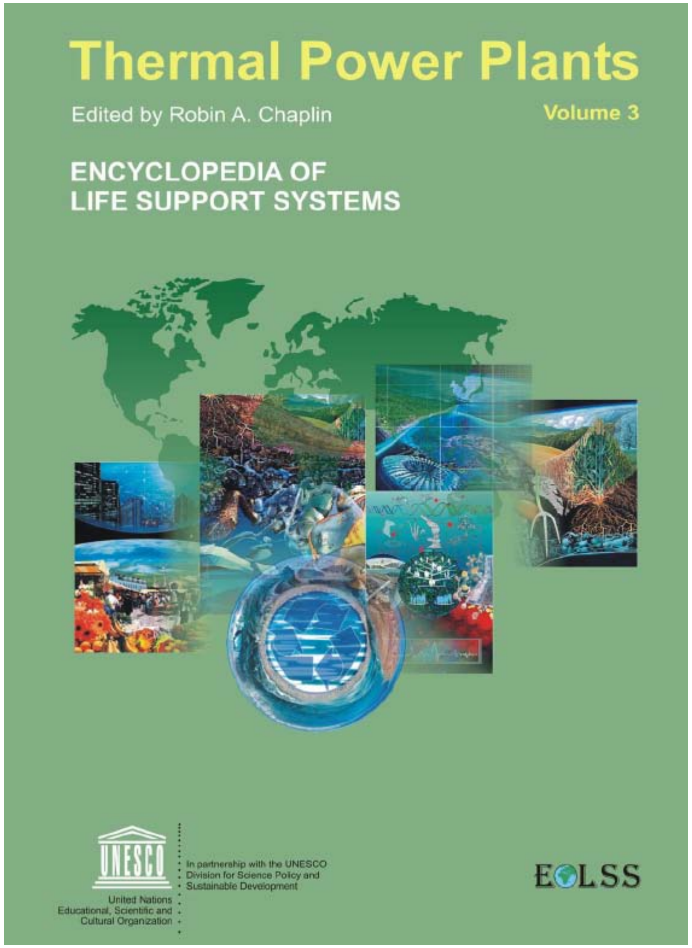

Class material information

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- 자료 내용 : 교재(pdf), 수업자료
- 과제 Upload (654321)

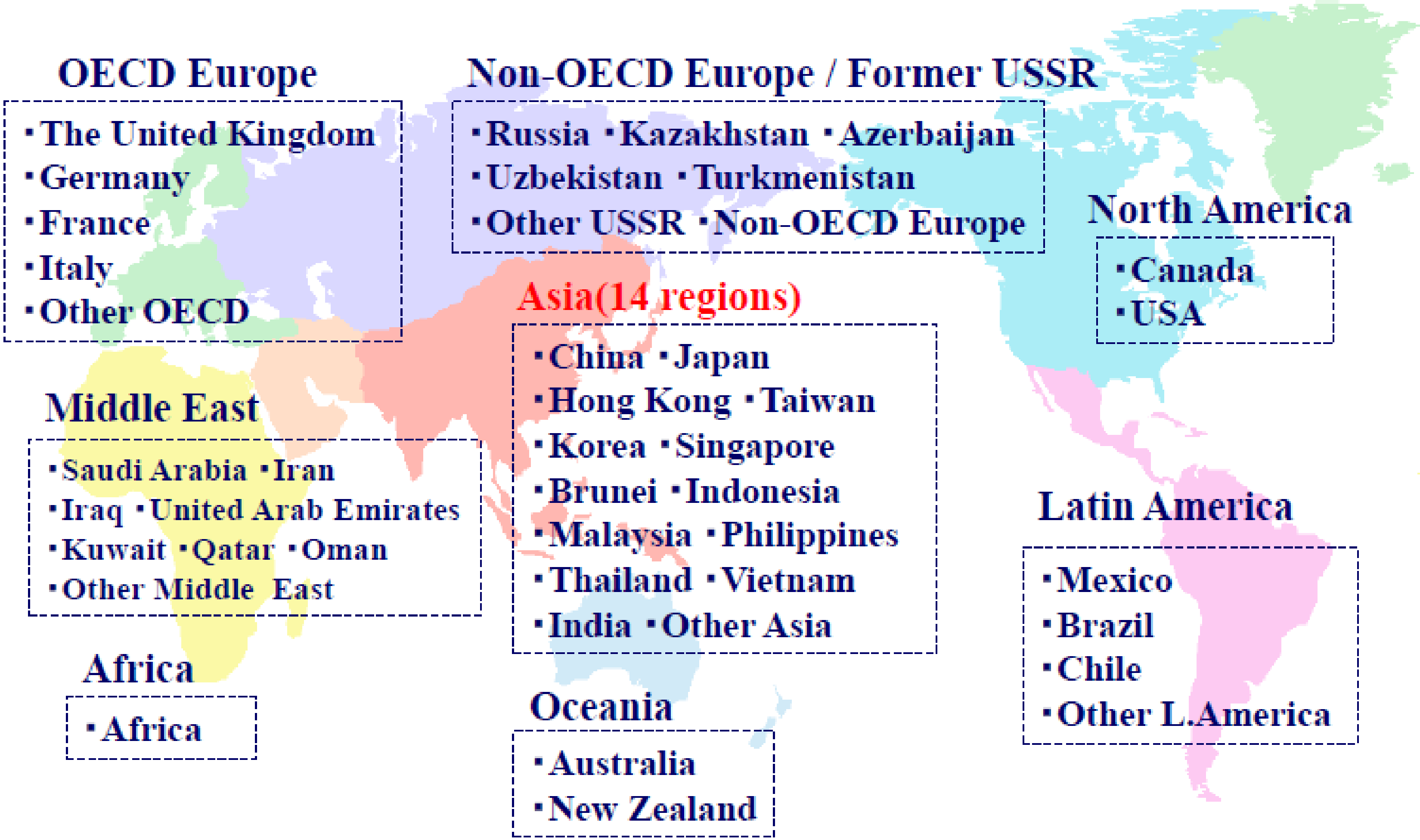
Motivation

1. **Primary Energy Consumption and CO_2 emission**
2. **Greenhouse Effect and Impacts on the Climate**
3. **Strategies of CO_2 Reduction**

1.1 Primary energy & CO2 emissions

Geographical Coverage

- The whole world is geographically divided into 43 regions, Asia into 14 regions.
- Geopolitically detailed analysis into Asian countries.



Basic Framework

MACRO Economic Model†

- GDP components
- Price/Labor etc.
- Industrial activities
- Transport activities

GDP, Crude oil price, Exchange rate, Population, Power generation outlook, World trade etc.

† Development of country-specific macro economic model in China, Korea and ASEAN countries (Indonesia, Malaysia, Philippines, Thailand)

Energy Demand-Supply Model

- Energy Demand
- Conversion Sector
- Energy Supply
- CO_2 emissions

World Trading Model of Crude Oil and Petroleum Products (LP Optimization)

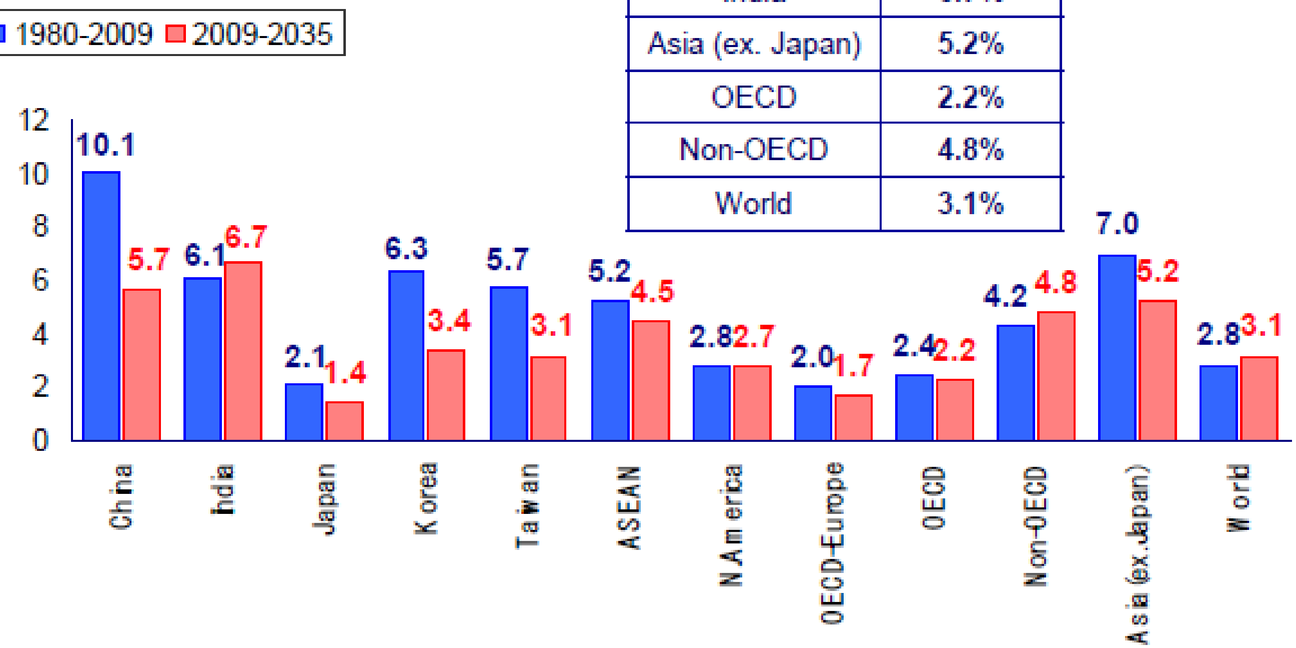
End-use Energy Technology Model (Automobile, Electric Appliances etc.)

These models allow us to fully understand the interaction among numerous parameters in a logical and consistent way.

Major Assumption： GDP

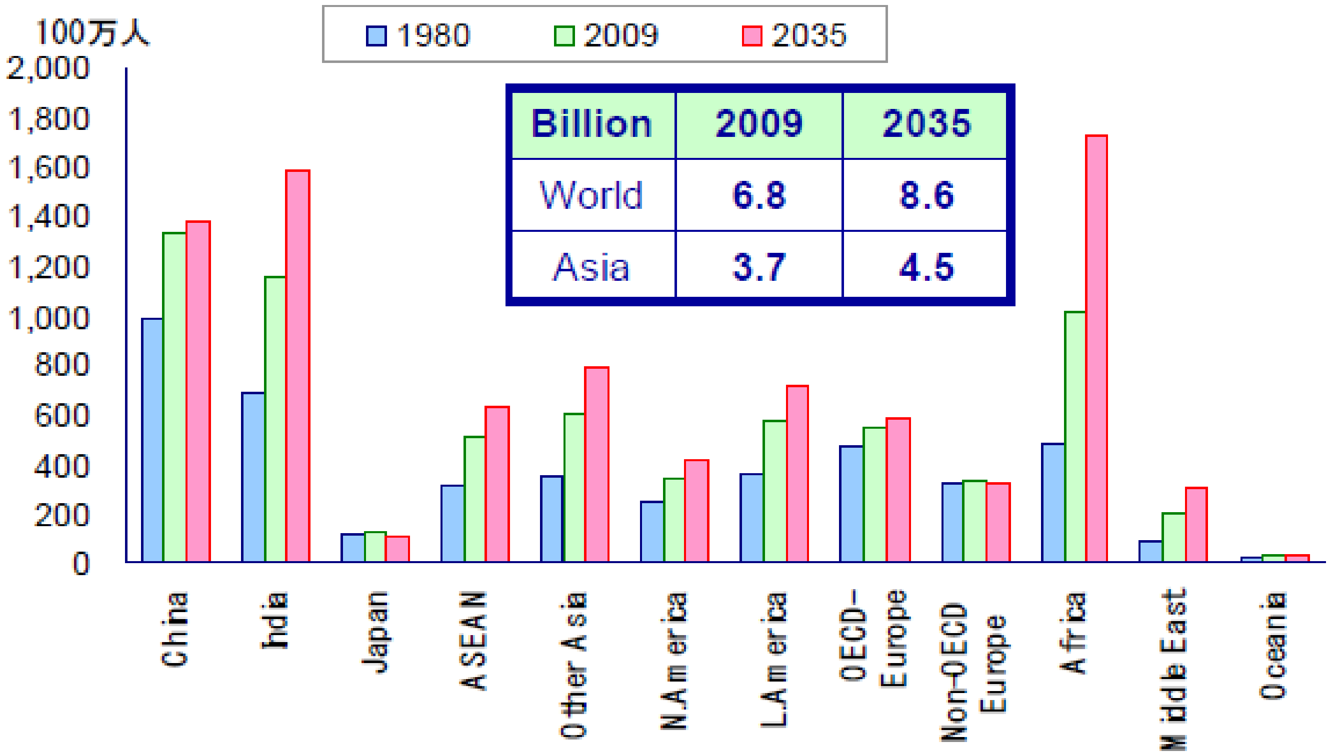
Average Annual Growth Rate (%)

	2009-2035
China	5.7%
India	6.7%
Asia (ex. Japan)	5.2%
OECD	2.2%
Non-OECD	4.8%
World	3.1%



- World economy will continue to grow steadily at 3.1% per annum through 2035. Repercussions from the recent financial crisis were globally felt to slow the economic growth, but with the economic stimulus measures by numerous countries will lead to early recovery.
- GDP in China will continue to achieve an annual growth rate of 5.7% per year shifting from the investment- and export-driven growth to the domestic demand-driven one.
- GDP in India will register a high growth rate at 6.7% per year, reflecting increases in improved labor quality, and liberalization and direct investment from foreign countries.
- ASEAN countries will achieve steady economic growth supported by industrialization and export increases.

Major Assumption： Population



Billion	2009	2035
World	6.8	8.6
Asia	3.7	4.5

China

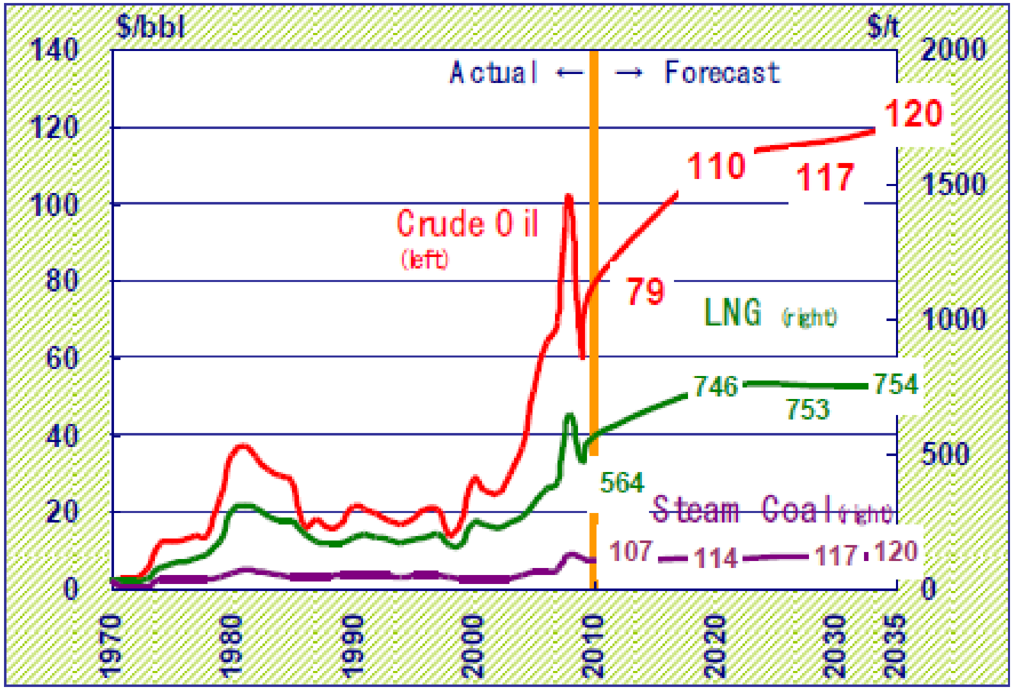
2009
1.33 bil
↓
2035
1.38 bil
(0.05 bil growth)

India

2009
1.16 bil
↓
2035
1.58 bil
(0.42 bil growth)

- Of the incremental increase in world population over the period 2008-2035, developing countries account for roughly 90%.
- Population in China and India together will reach about 3 billion and its share will increase to 35% by 2035.
- Chinese population will peak in 2030 as a result of declining birth rate. India's population will represent the biggest in the world by 2035.

Major Assumption: Energy Prices

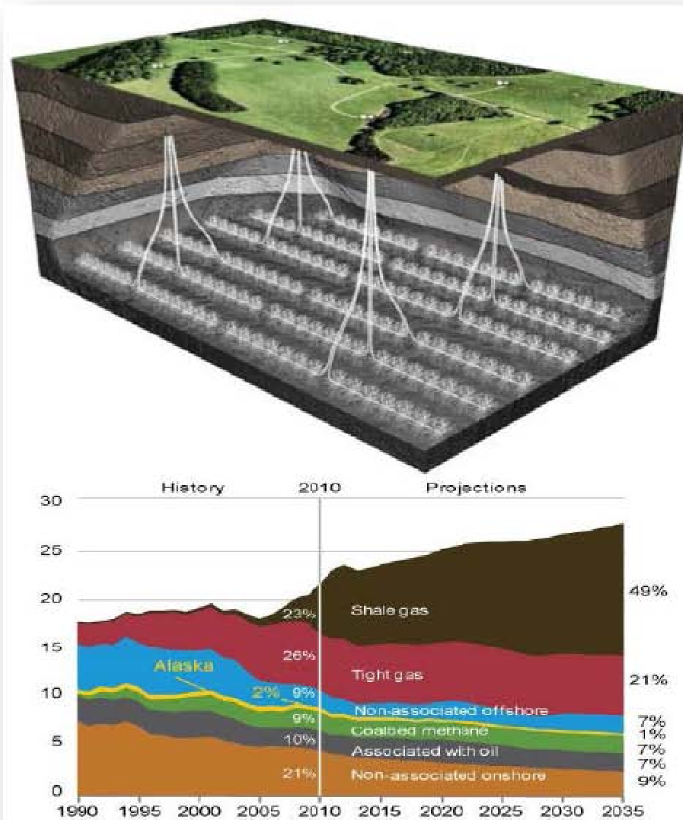


(*) 2010 real price (**) All the prices are calendar year data; In the graph, energy prices are explained by Japan's import energy price (on a CIF basis).

- After a decline in crude oil price from the recorded high level in 2008, crude oil price will continue to increase in the future resulting from the tight balance between demand and supply. Oil demand is projected to increase driven mainly by Asia, while upstream investment may not progress at a pace meeting the demand growth.
- LNG price is projected to increase in accordance with crude oil price.
- Coal price will show relatively moderate growth compared with the crude oil and LNG.

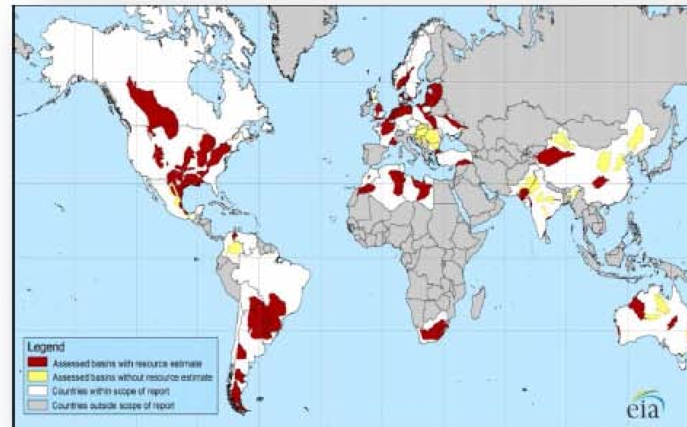
6. 세일가스의 부상

Shale Gas 개발로 가스 황금시대가 도래할 것으로 예상(IEA)



Source: U.S. Energy Information Administration, AEO2012 Early Release Overview, January 23, 2012.

<세일가스 시추방법 및 사용예상량>



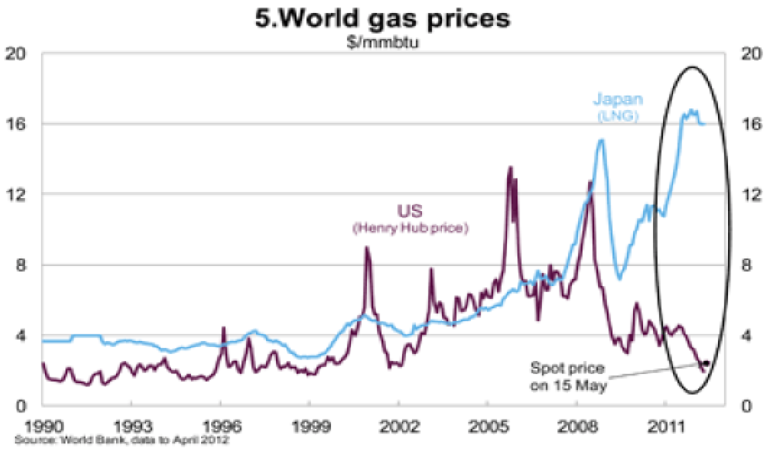
<전세계 세일가스 분포도>

국가명	세일가스	
	매장량(조 m^3)	비중(%)
미국/캐나다	35.4	19
중국	36.1	19
유럽	17.7	9
전 세계	187.4*	100

* 전세계가 60년 동안 사용할 수 있는 양

<전세계 세일가스 매장량>

6. 세일가스의 부상

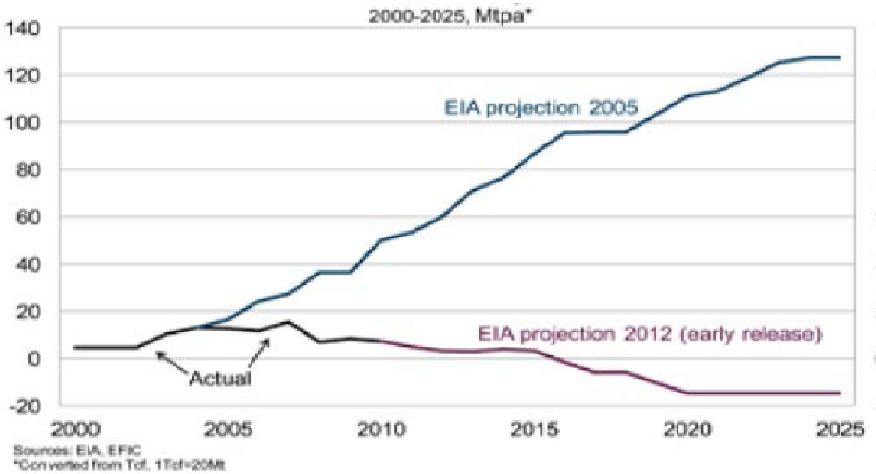


Shale Gas 등장에 따른 천연가스 가격 변동

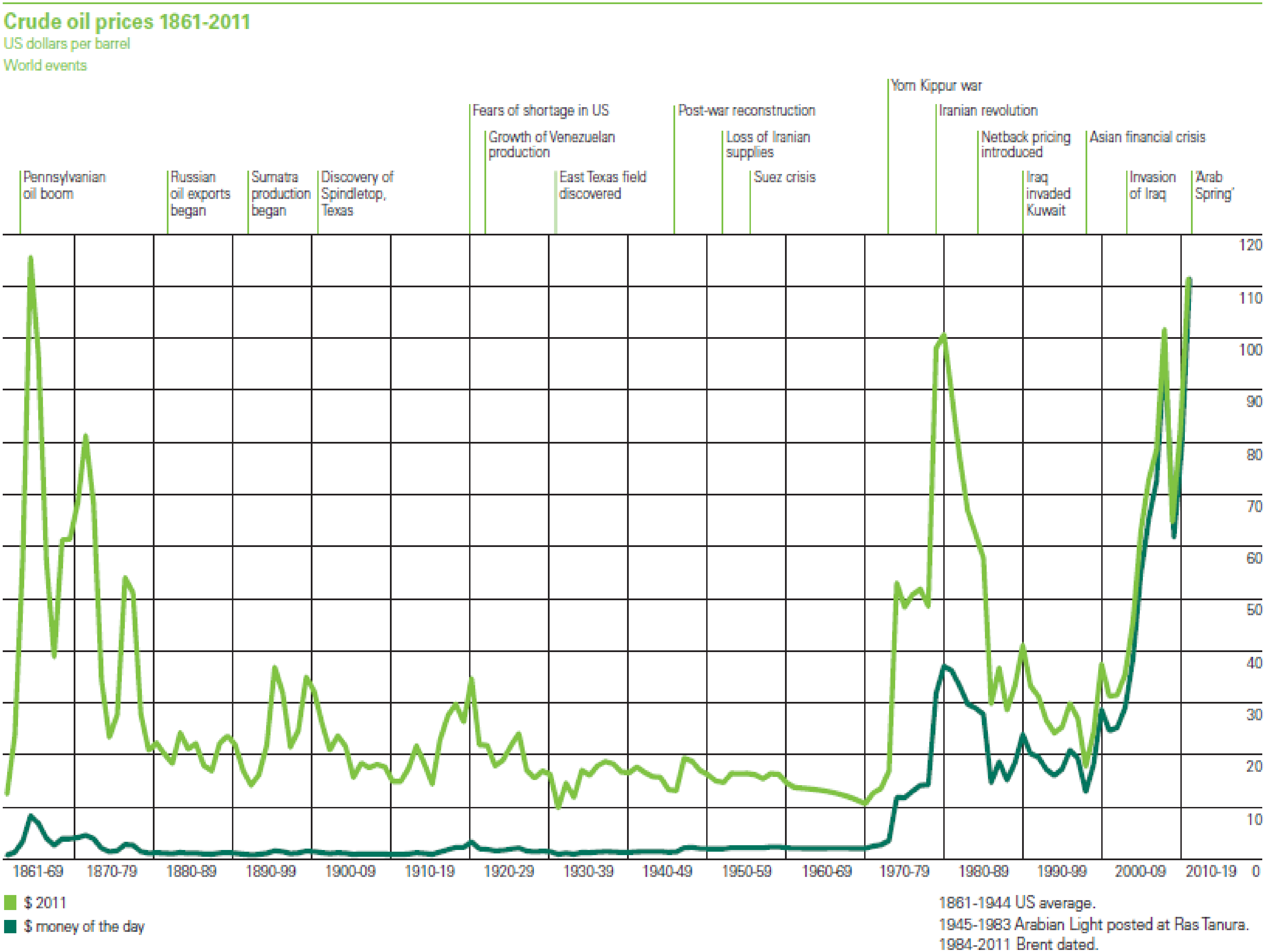
- 미국내 천연가스 가격이 2$/MMBtu 아래로 급락('12. 4)
- 안정적인 '저가격 가스시대'의 도래 예고

美, 천연가스 수입국에서 수출국으로

- 2020년까지 연간 4~5천만톤의 천연가스 수출국가가 될 전망
- 국내 셰일가스 도입가격은 11$/MMBtu 전망
  - 중동에 대한 이해관계에 상대적으로 덜 개입, 국내 에너지 security문제 부각 가능

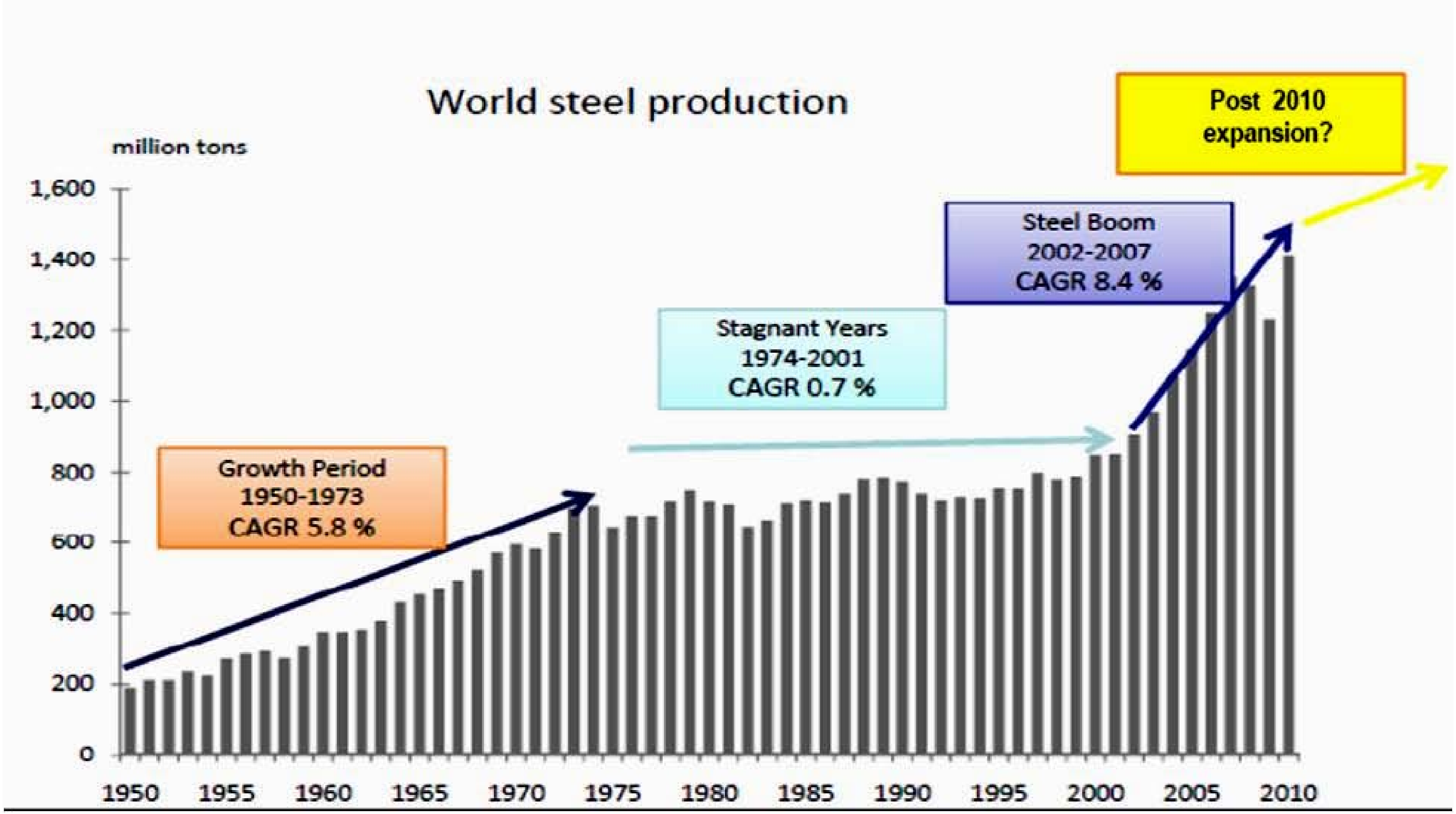


美, US 스틸 (가스용 제철), 듀크에너지(가스발전), 석유화학(Pvc), 자동차, 전자 부문 경쟁력 제고


Crude oil prices 1861-2011
US dollars per barrel
World events
Pennsylvanian oil boom
Russian oil exports began
Sumatra production began
Discovery of Spindletop, Texas
Fears of shortage in US
Growth of Venezuelan production
East Texas field discovered
Post-war reconstruction
Loss of Iranian supplies
Suez crisis
Yom Kippur war
Iranian revolution
Netback pricing introduced
Iraq invaded Kuwait
Asian financial crisis
Invasion of Iraq
'Arab Spring'
120
110
100
90
80
70
60
50
40
30
20
10
0
1861-69
1870-79
1880-89
1890-99
1900-09
1910-19
1920-29
1930-39
1940-49
1950-59
1960-69
1970-79
1980-89
1990-99
2000-09
2010-19
$ 2011
$ money of the day
1861-1944 US average.
1945-1983 Arabian Light posted at Ras Tanura.
1984-2011 Brent dated.

전세계 철강 생산량 현황

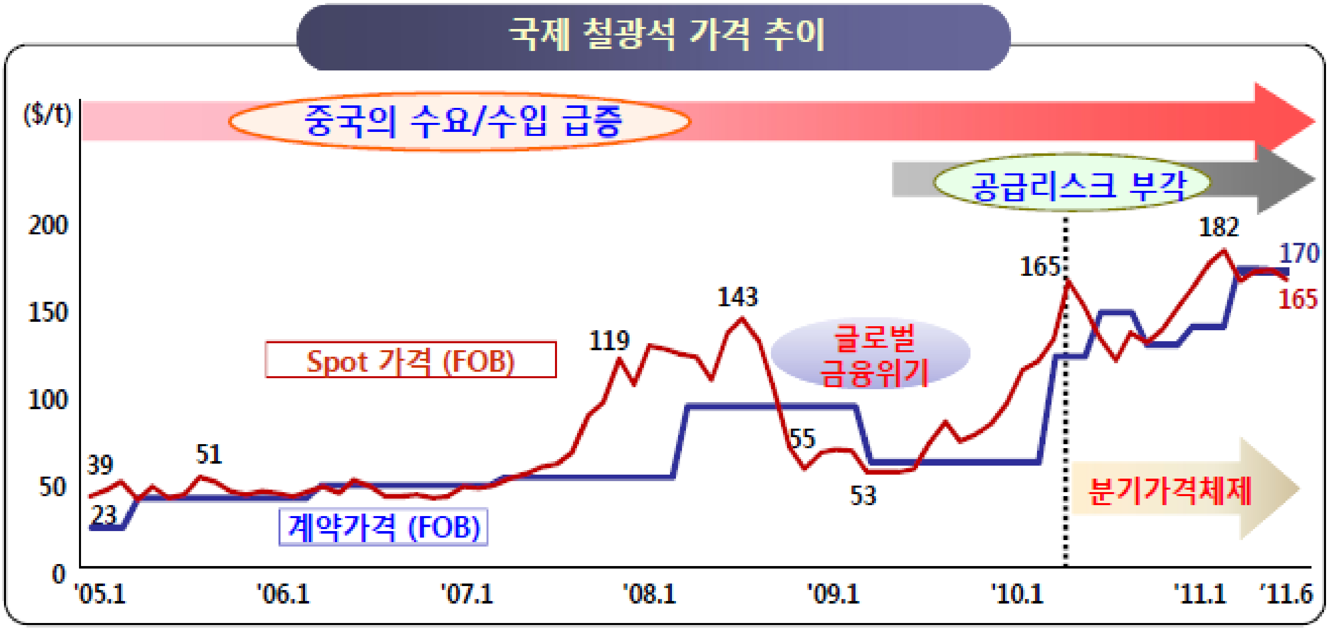
○ 세계 조강생산량은 1975년부터 2000년도까지 25년 동안 6~7억톤 수준을 유지
○ 2000년 이후 부터 중국의 급격한 조강생산량 증가에 따라 과거 6~7억톤 수준의 2배로 증가
○ 이러한 조강량의 증가로 철광석과 Coking Coal의 수요부족으로 가격 급등



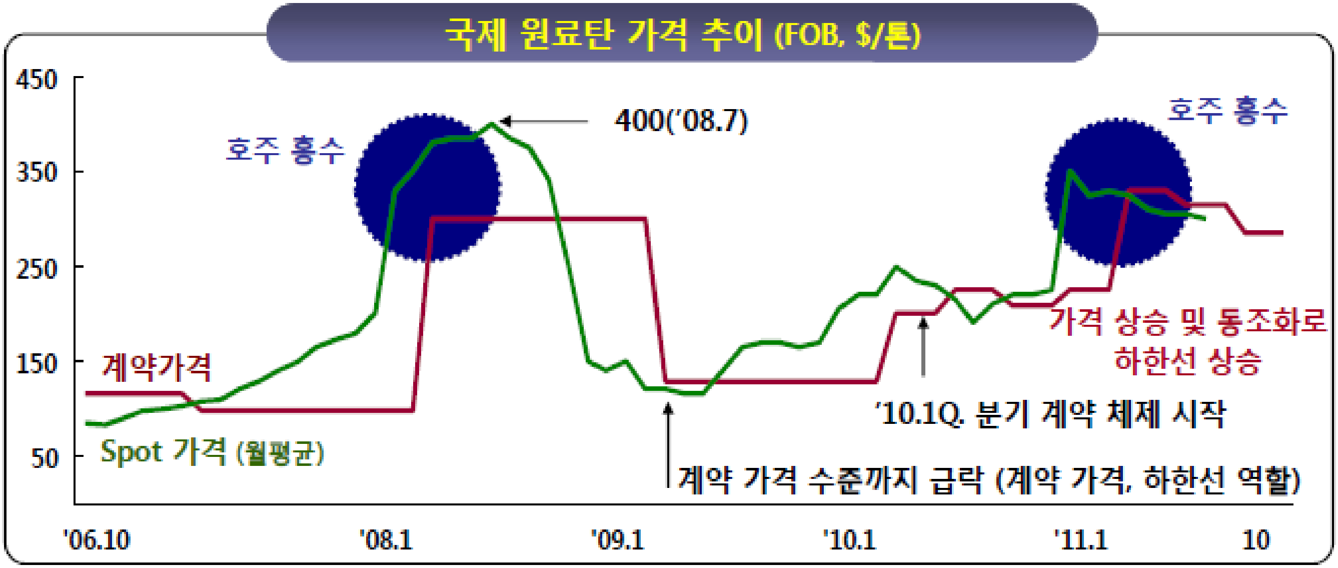
○ 조강량 증가 추이 (단위: 백만톤)

1970	1975	1980	1985	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
595	644	717	719	770	752	848	850	904	970	1069	1147	1251	1351	1329	1223	1413

최근 연원료 가격 현황



국제 철광석 가격 추이
($/t)
중국의 수요/수입 급증
공급리스크 부각
200
150
100
50
0
182
170
165
165
143
119
글로벌 금융위기
Spot 가격 (FOB)
55
53
39
51
23
계약가격 (FOB)
분기가격체제
'05.1
'06.1
'07.1
'08.1
'09.1
'10.1
'11.1
'11.6



국제 원료탄 가격 추이 (FOB, $/톤)
450
350
250
150
50
400('08.7)
호주 홍수
호주 홍수
계약가격
Spot 가격 (월평균)
가격 상승 및 동조화로
하한선 상승
'10.1Q. 분기 계약 체제 시작
계약 가격 수준까지 급락 (계약 가격, 하한선 역할)
'06.10
'08.1
'09.1
'10.1
'11.1
10

당사 현황

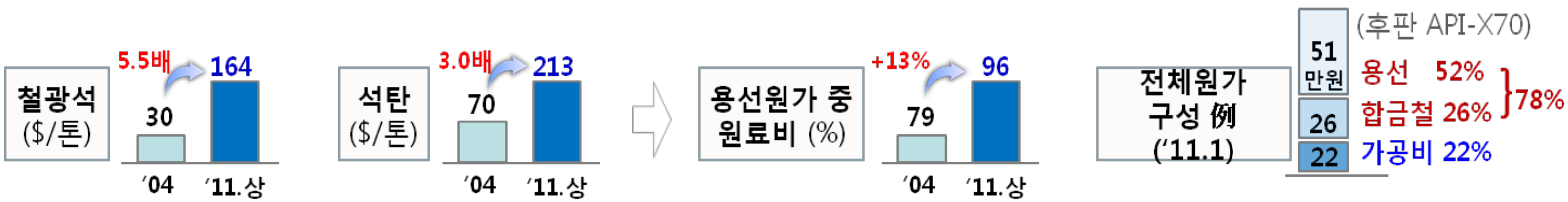
posco

○ 대외 환경 변화

① 지구 온난화 대책으로 CO_2 발생 규제 강화
② 고품위 철광석/점결탄 고갈로 안정확보 어려움
③ 연·원료의 급격한 수요증가/공급사 과점화: 가격 급등

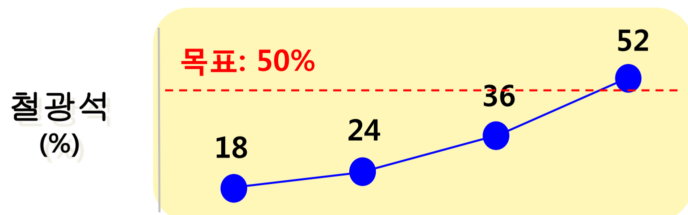
○ 당사 현황

① 용선/탄소강 제조 원가 중 연·원료비 비중 증가
② 고가 강점탄 사용 억제 & 미비점탄 사용비 증가
③ 극미분 원료 및 고Al_2O_3 철광석 증사용 불가피
④ 고로 대형화에 따라 고강도 소결광/코크스 필요
⑤ 종합 소재 메이커로서 다양한 광물자원 소요



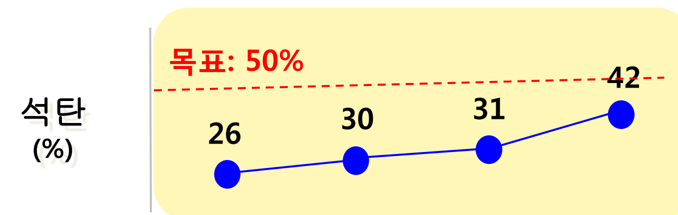
☞ **고품위 연·원료의 고갈과 가격급등으로 수급 불안정/원가중 연·원료비 비중 증가**
→ 연·원료 안정수급/고품질화 및 원가 경쟁력 확보 필요

○ Captive 연·원료 확보 목표 및 전망



(단위: Mt)	'10	'12	'14	'16
신규 저품위광	-	1.2	8.4	18.6
Namisa	-	1.2	3.1	3.3
API	-	-	1.5	6.0
Royhills	-	-	3.8	8.3

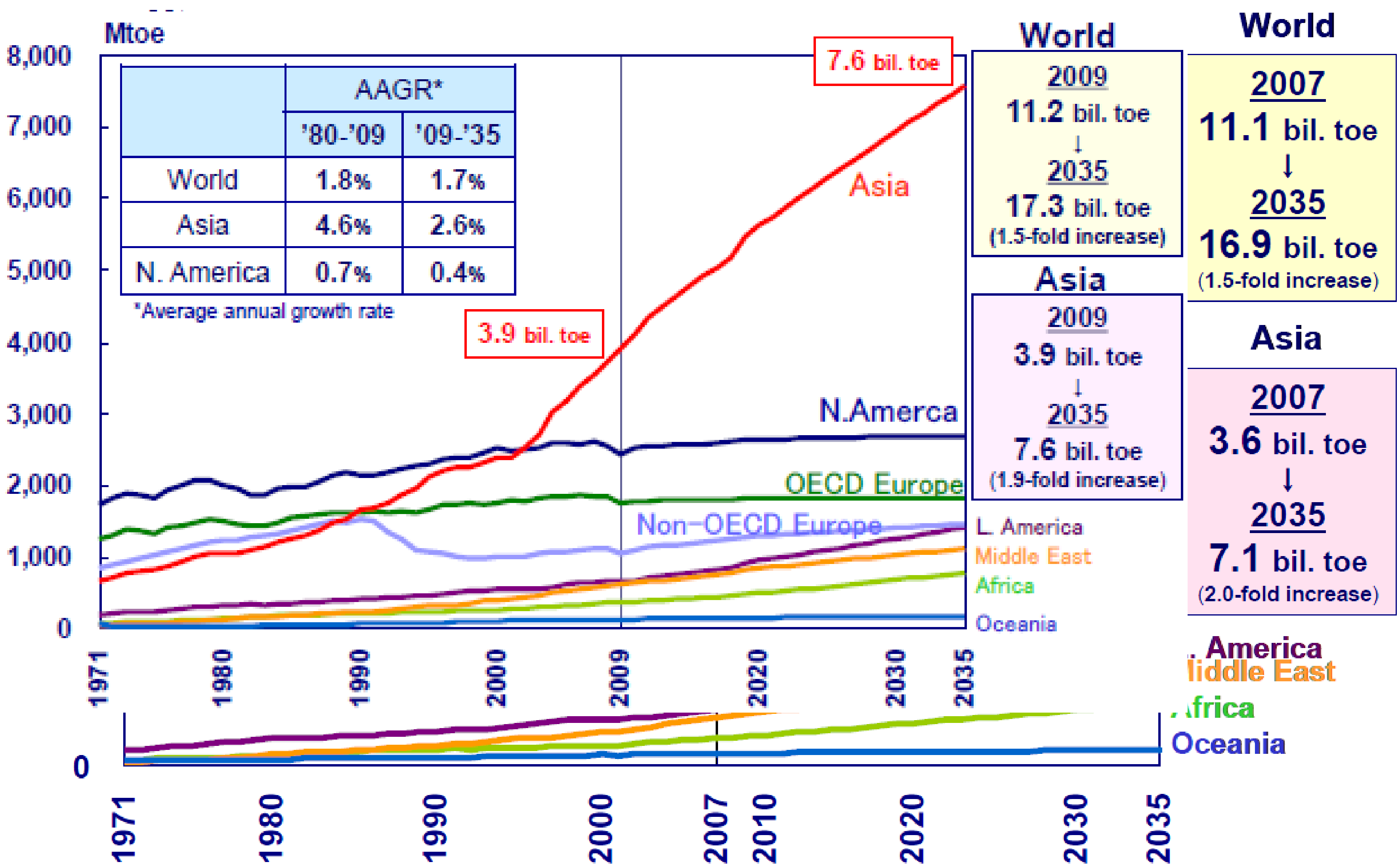
* 신규 미분광 사업 : Serpentina(6.9Mt), AHMSA(10.0Mt)



(단위: Mt)	'10	'12	'14	'16
신규탄	-	-	0.6	2.8
모잠비크	-	-	0.4	0.6
N.Century	-	-	0.2	0.6
S.Forest	-	-	-	1.0

* 신규 석탄 사업 : Klappan(0.6Mt), H.coal(1.0Mt), Cockatoo(1.0Mt)

Primary Energy Demand by Region ; World



	AAGR*	
	'80-'09	'09-'35
World	1.8%	1.7%
Asia	4.6%	2.6%
N. America	0.7%	0.4%

*Average annual growth rate

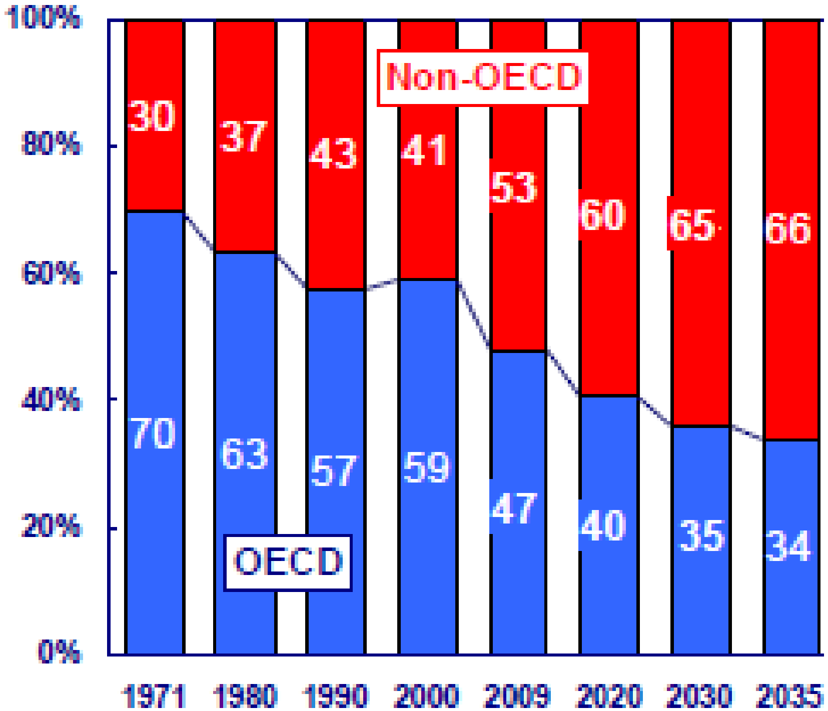
- By 2035, primary energy demand of Asia achieves twice as much as current level, reflecting high economic growth; 3.6 billion toe(2007) → 7.1 billion toe(2035).
- Non-OECD will represent 90% of incremental growth of global energy demand toward 2035.

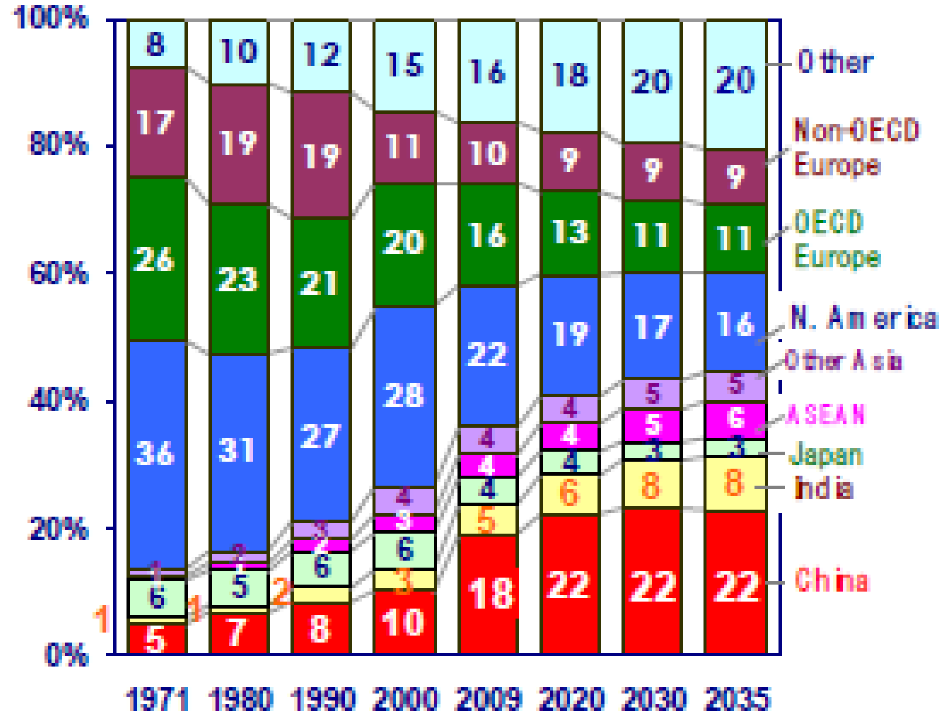
Incremental Increase in Primary Energy Demand by Region, 2007-2035

Share in increase (2009-2035)

China	India	Japan	ASEAN	Other Asia	N. America	OECD Europe
31%	15%	0%	10%	6%	4%	1%

Asia occupies more than 60% of total growth.

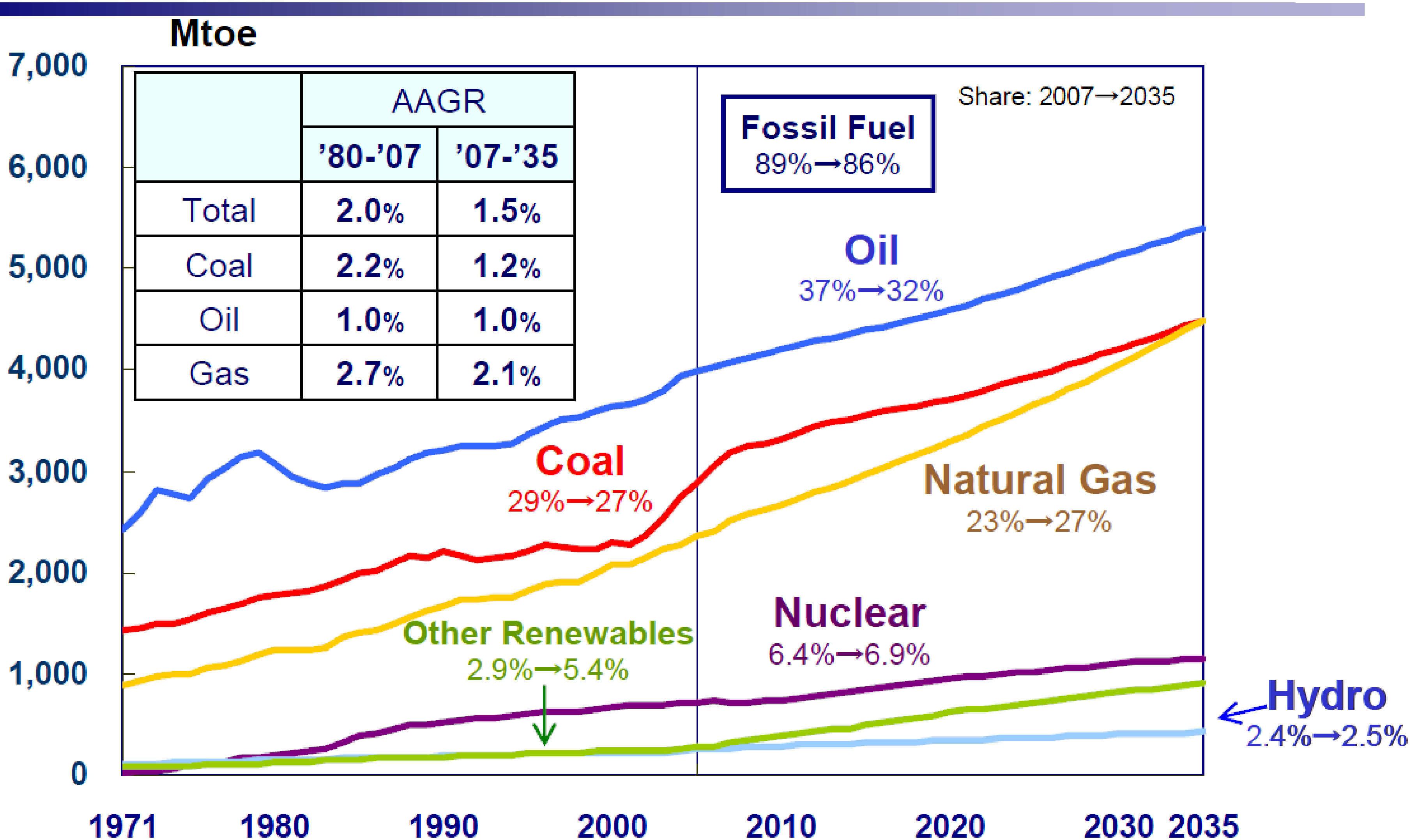




- Reflecting steady economic growth, energy demand in Non-OECD will exceed that of OECD.
- Energy demand in Asia will exhibit a rapid growth, with the share of Asia in the world energy demand expanding to 44% by 2035 from 35% in 2009.

61% of global energy demand increase to 2035 is due to Asia. In particular, approximately 40% of both China and India dominates the world increase. OECD is responsible for 12%, and Non-OECD, 88%.

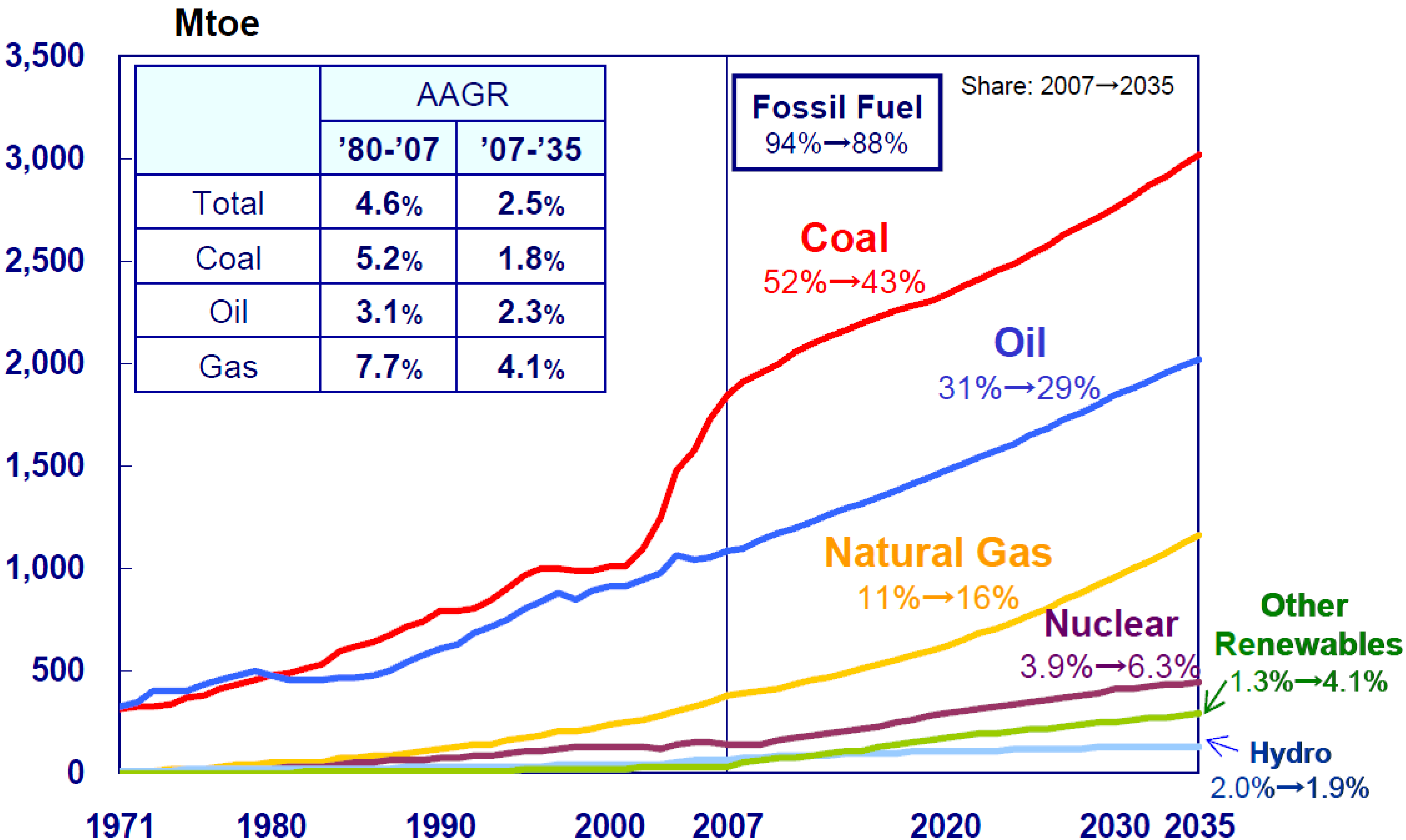
Primary Energy Demand by Fuel ; World



	AAGR	
	'80-'07	'07-'35
Total	2.0%	1.5%
Coal	2.2%	1.2%
Oil	1.0%	1.0%
Gas	2.7%	2.1%

- Oil will remain the largest energy source in primary energy mix by 2035. Around 2035, natural gas demand will grow with its future extensive use in various sectors, eventually catching up with coal around 2035.
- Fossil fuel continues to be the most important fuel by 2035, though its share will slightly decrease from 89% in 2007 to 86% in 2035.

Primary Energy Demand by Fuel ; Asia



	AAGR	
	'80-'07	'07-'35
Total	4.6%	2.5%
Coal	5.2%	1.8%
Oil	3.1%	2.3%
Gas	7.7%	4.1%

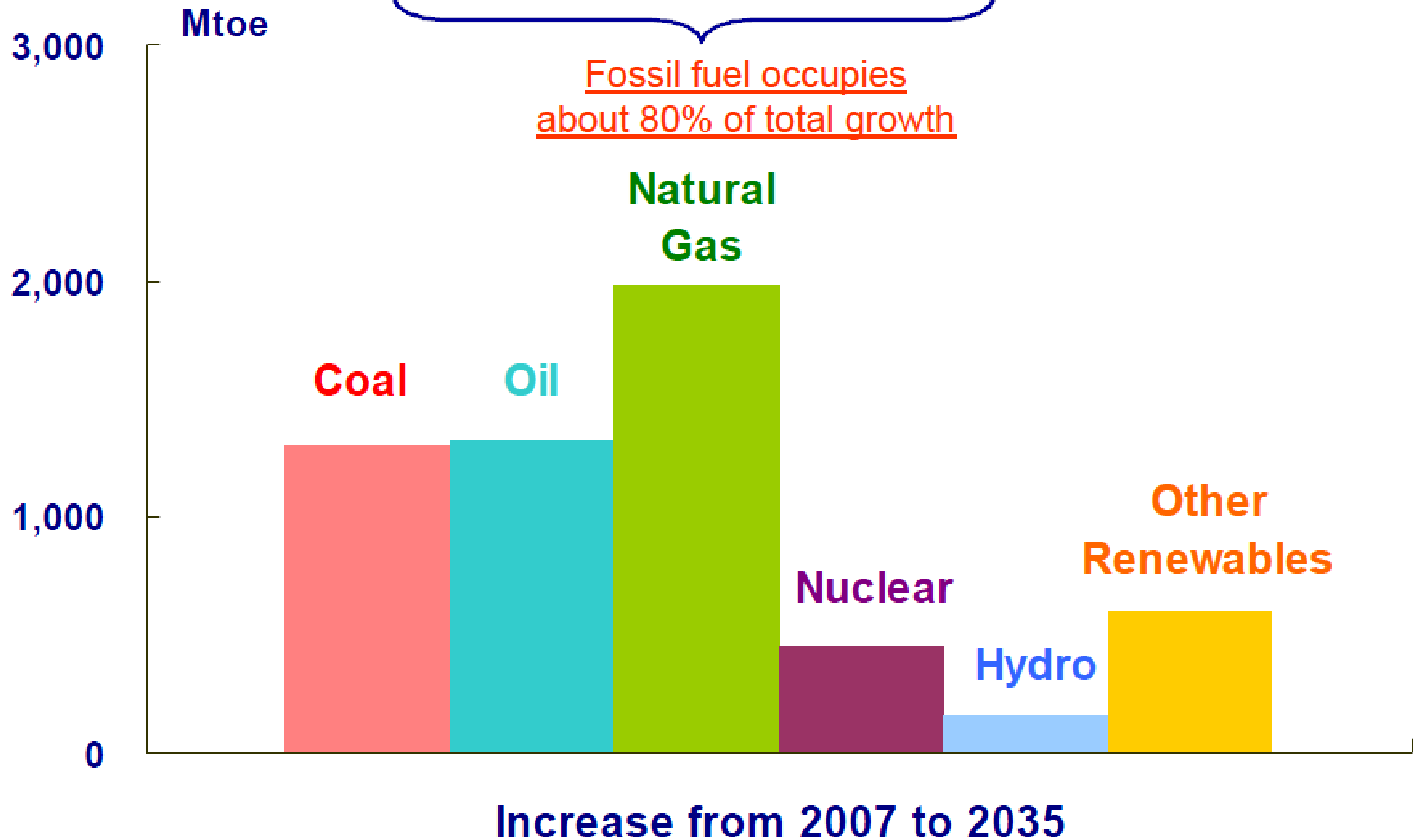
- Coal and Oil will continue to maintain its centrality over Asian energy demand until 2035.
- The share of natural gas will grow substantially to 16% by 2035, driven mainly by power generation. Fossil fuel dominates 88% of total energy supply and plays a key role by 2035.

Increase in Primary Energy Demand by Fuel ; World

2007-2035 Increase

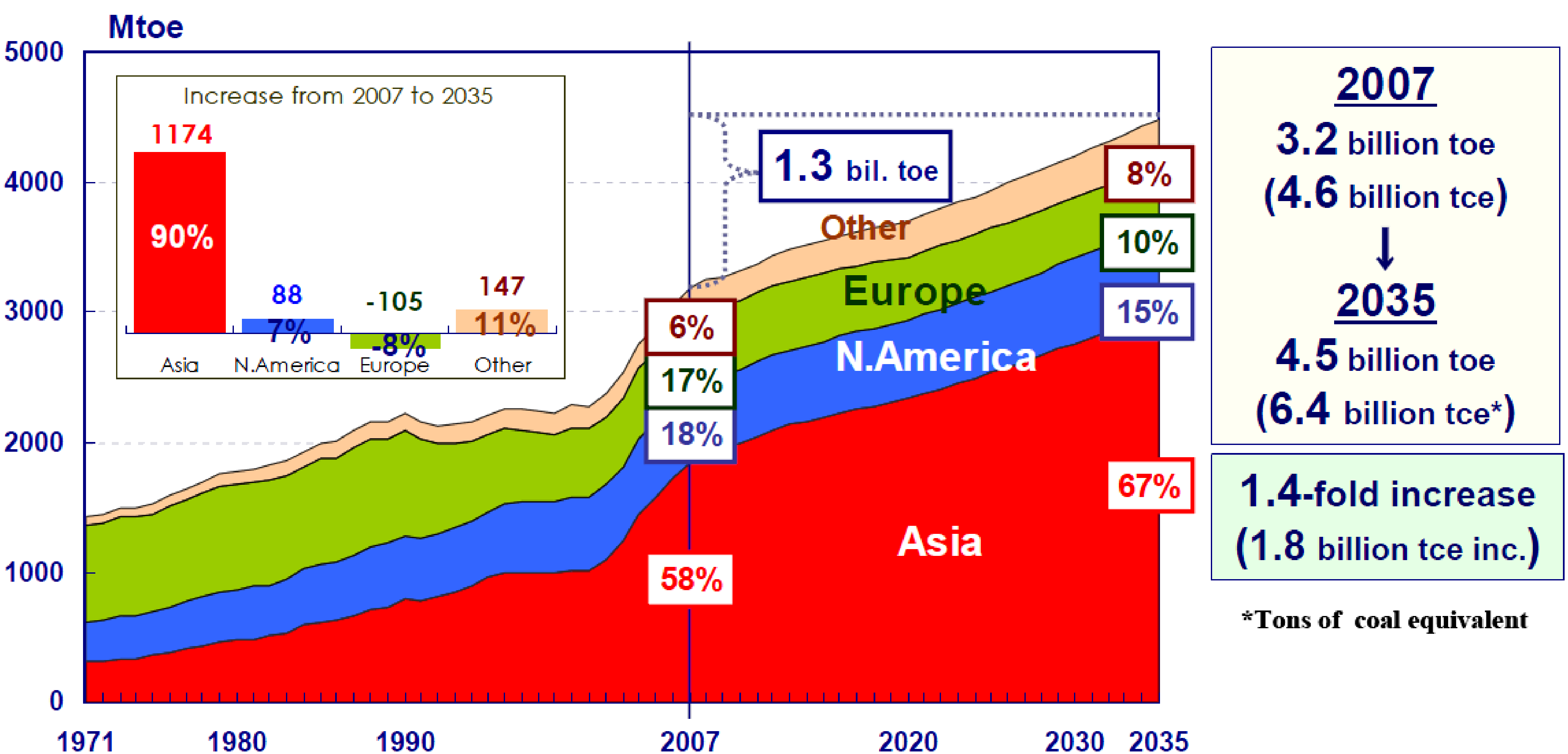
Coal	Oil	Gas	Nuclear	Hydro	Other Renewables
23 %	22 %	34 %	8 %	3 %	10 %

Fossil fuel occupies about 80% of total growth



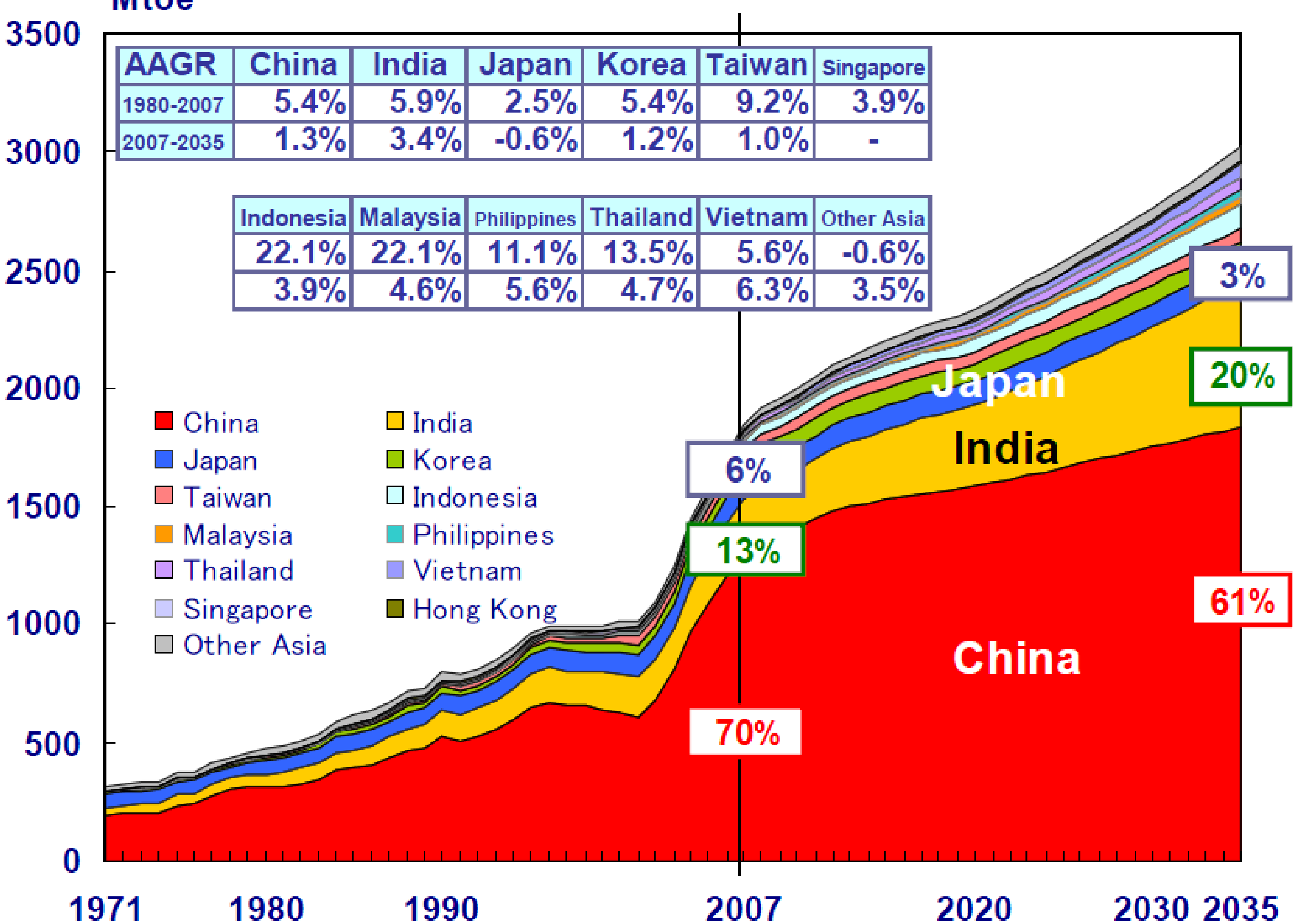
- 79% of global energy growth by 2035 will be concentrated on fossil fuels
- Fossil fuel demand growth to 2035 in Non-OECD will be responsible for about 90% of global fossil demand increasing.

Coal Demand by Region ; World



- 90% of global coal demand increase is derived from Asia, and the share of Asia in total coal demand eventually expands to 67%. Non-OECD is responsible for 96% of the increase in world coal demand.
- 35% of the increase in global CO_2 emissions from 2007 to 2035 is from coal combustion in Asian region; In order to address global warming problem, environmentally compatible coal use is quite important agenda in Asia.

Coal Demand by Region ; Asia



AAGR	China	India	Japan	Korea	Taiwan	Singapore
1980-2007	5.4%	5.9%	2.5%	5.4%	9.2%	3.9%
2007-2035	1.3%	3.4%	-0.6%	1.2%	1.0%	-

Indonesia	Malaysia	Philippines	Thailand	Vietnam	Other Asia
22.1%	22.1%	11.1%	13.5%	5.6%	-0.6%
3.9%	4.6%	5.6%	4.7%	6.3%	3.5%

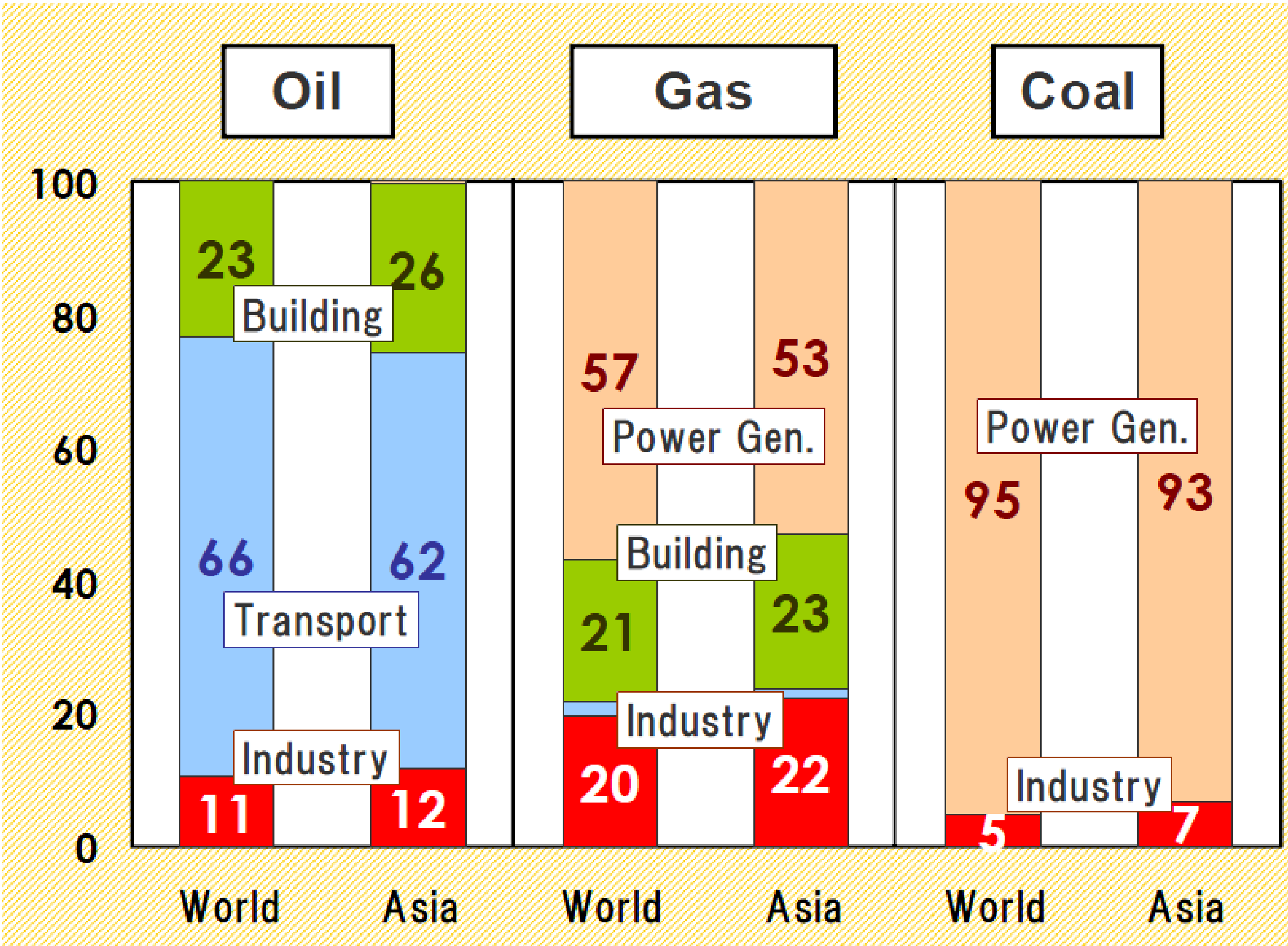
2007
1.8 billion toe
(**2.6** billion tce)
↓
2035
3.0 billion toe
(**4.3** billion tce)

1.7-fold increase
(**1.7** bil. tce inc.)

Coal will be consumed in the power sector in order to meet growing electricity requirements, particularly in China and India, both of which have abundant availability of domestic reserves

Increase in World Fossil Fuel Demand by Sector

【Increase by sector,2007-2035】



Majority of oil will be used for transportation,
while gas and coal will be consumed mainly for power generation.

Electricity Demand ; Asia

2007-2035 AAGR(%)	Electricity demand	Total Final Energy Demand
China	3.2	2.7
India	5.7	3.9
Korea	1.5	1.5
Indonesia	5.6	3.3
Malaysia	4.6	2.5
Thailand	4.4	3.4
Philippines	5.4	4.6
Asia (exc. Japan)	3.7	2.9
Japan	0.7	-0.3
OECD	1.2	0.4
Non-OECD	3.4	2.6
World	2.3	1.6

Asia

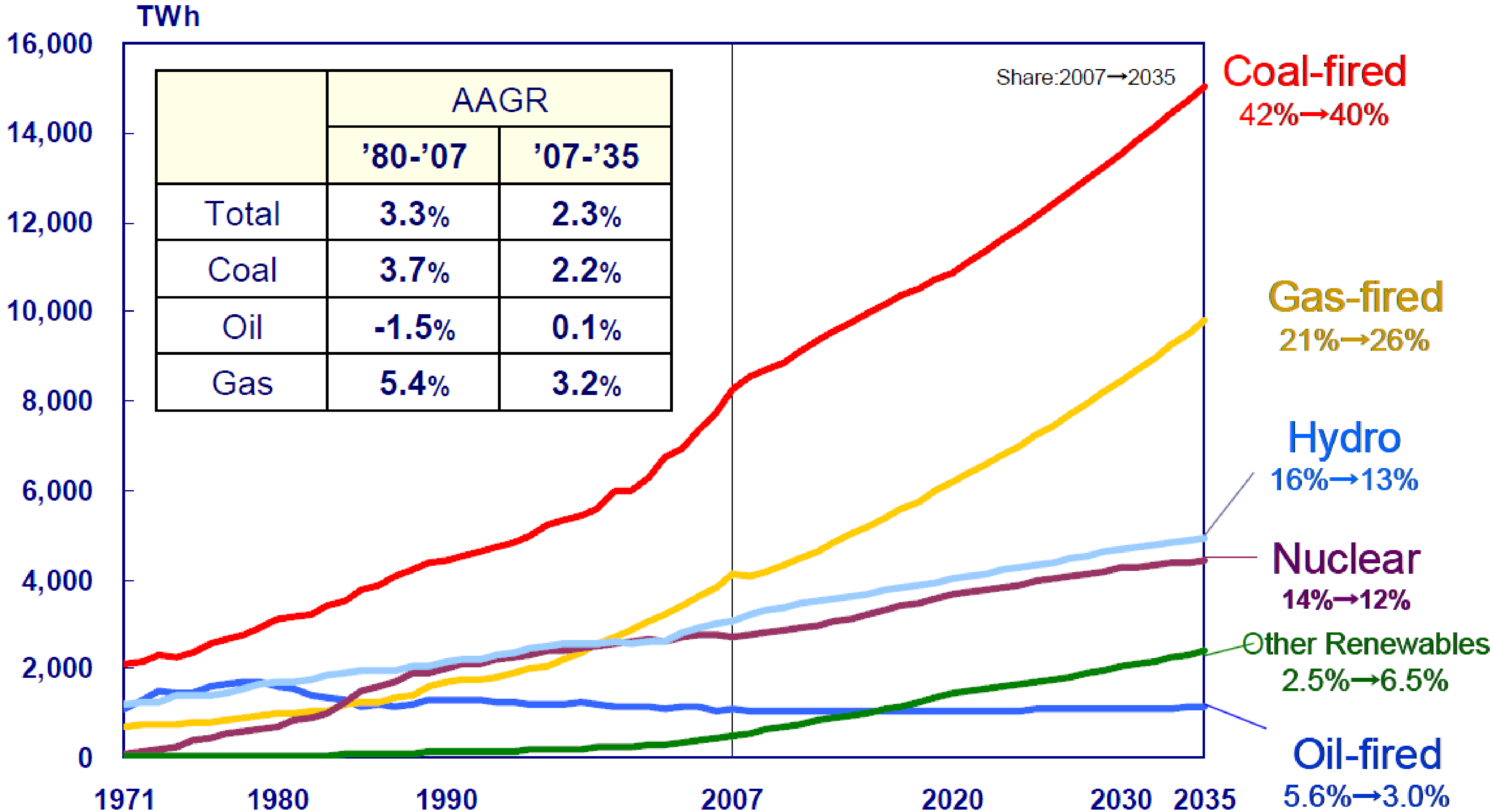
2007
6,700TWh
↓
2035
16,500TWh
(2.5-fold inc.)

China / India

2007
3,300TWh 800TWh
↓
2035
7,700TWh 3,500TWh
(2.3-fold inc.) (4.4-fold inc.)

■ Electricity demand in Asia will increase rapidly by sophistication of energy utilization driven by the improvement of life style.

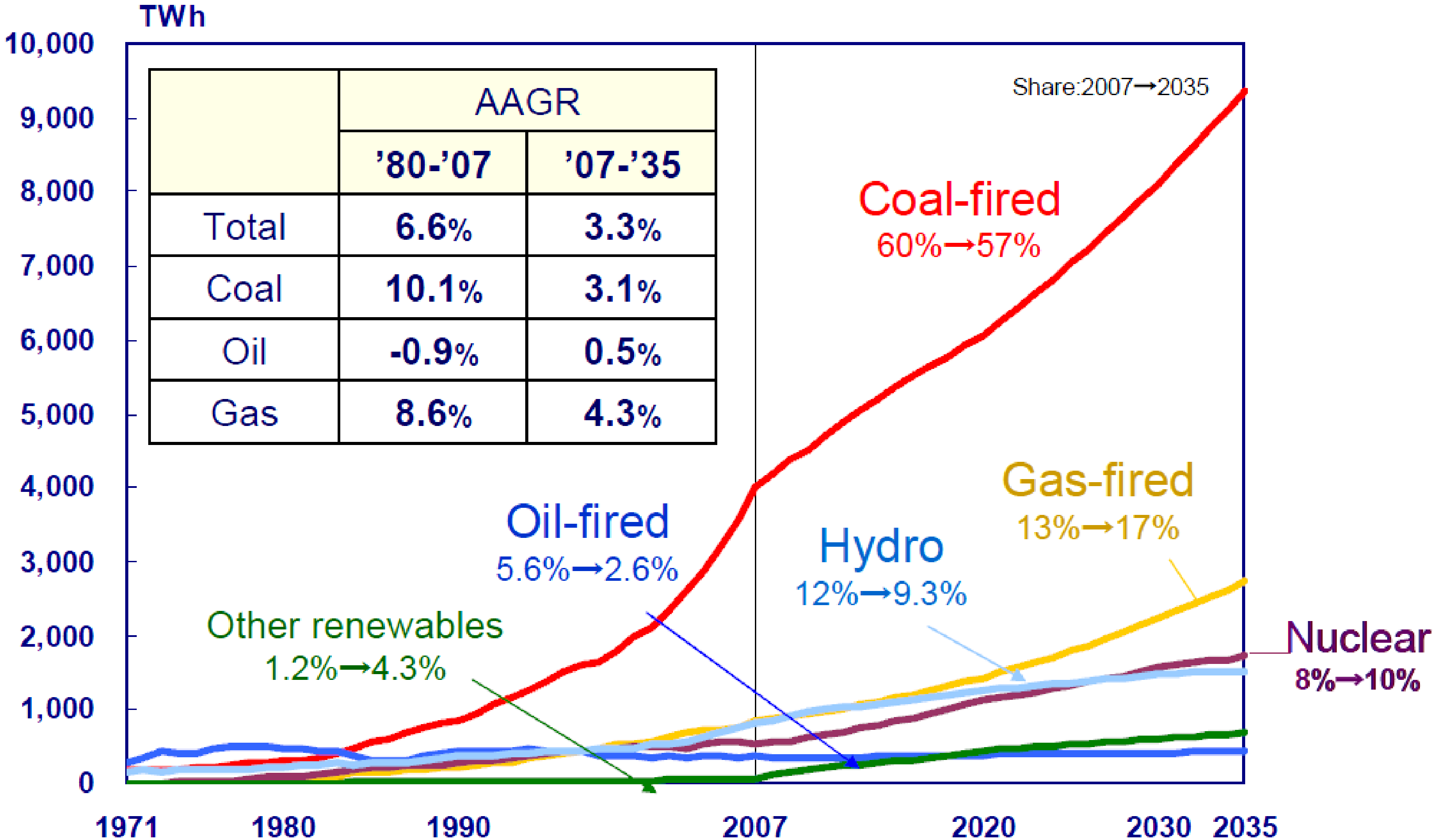
Power Generation Mix by Fuel ; World



	AAGR	
	'80-'07	'07-'35
Total	3.3%	2.3%
Coal	3.7%	2.2%
Oil	-1.5%	0.1%
Gas	5.4%	3.2%

- Coal-fired power generation still remains dominant power supply option by 2035. Natural gas-fired power generation is projected to increase significantly worldwide at the highest rate among fossil fuels.Renewables excluding hydro will expand its share in power generation mix to 6.5% by 2035 from 2.5% in 2007.
- The CO_2 emissions from coal-fired power generation currently dominates about 30% of global CO_2 emissions. CO_2 emissions from coal-fired generation will increase from 8.2 Gt-CO_2 in 2007 to 12.6 Gt-CO_2 in 2035. coal technology (CCT) is expected to play an important role in addressing GHG issues.

Power Generation Mix by Fuel ; Asia

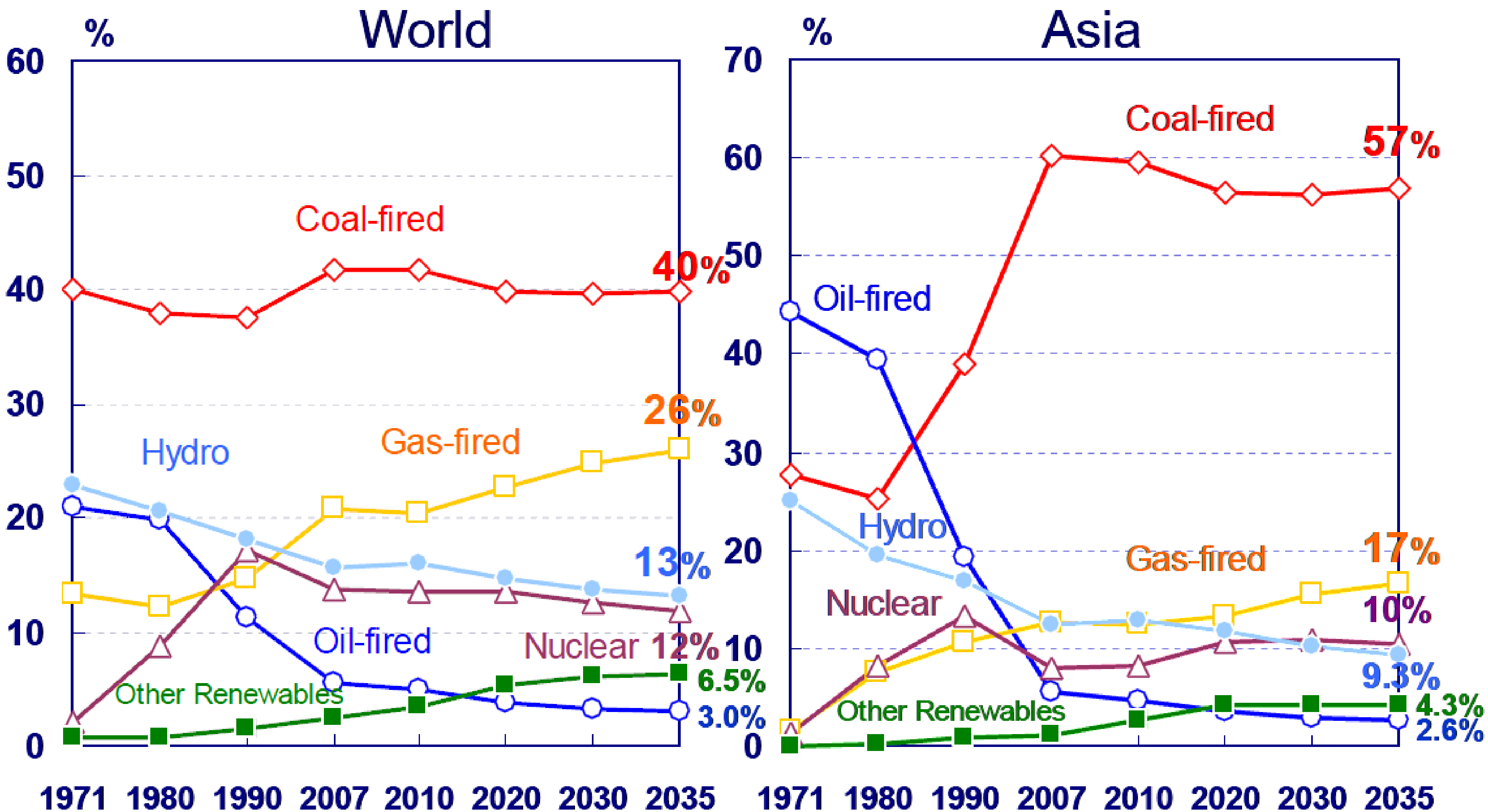


	AAGR	
	'80-'07	'07-'35
Total	6.6%	3.3%
Coal	10.1%	3.1%
Oil	-0.9%	0.5%
Gas	8.6%	4.3%

■The share of coal use in Asia will remain larger than 50%, reflecting abundant resources and the economic advantages. Gas will show a growing trend, the share of which eventually expands to 17% by 2035.The share of nuclear power generation will increase from 8% to 10%; Nuclear plays a important roll in power generation mix.

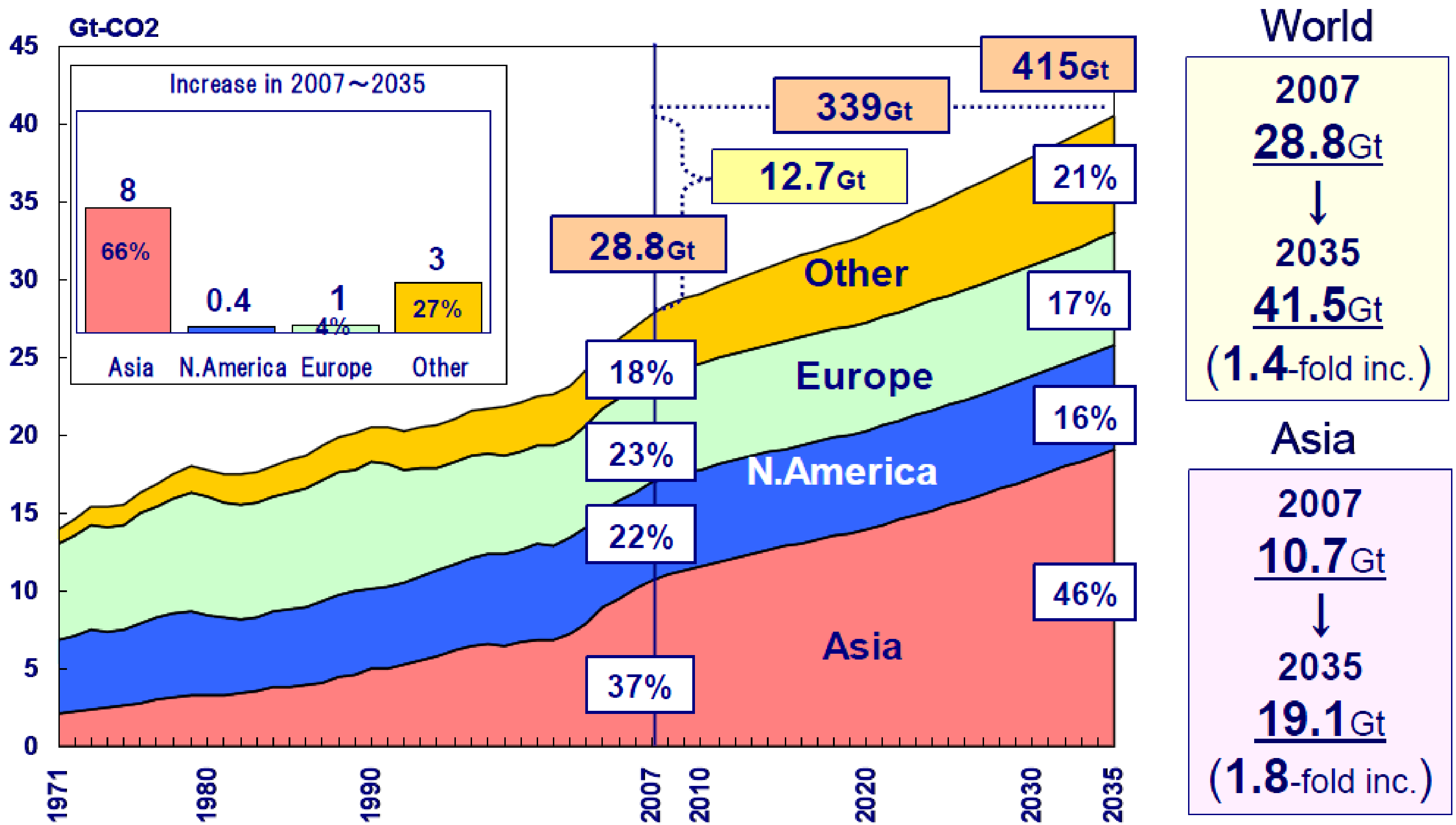
■The CO_2 emissions from coal-fired power generation currently dominates about 30% of global CO_2 emissions. CO_2 emissions from coal-fired generation in Asia will expand by 3.8 Gt-CO_2 from 4.1 Gt-CO_2 in 2007 to 7.9 Gt-CO_2 in 2035, this growth being about 30% of global CO_2 emissions increase. Clean coal technology (CCT) expected to play an important role in addressing GHG issues.

Power Generation Mix by Fuel ; World and Asia



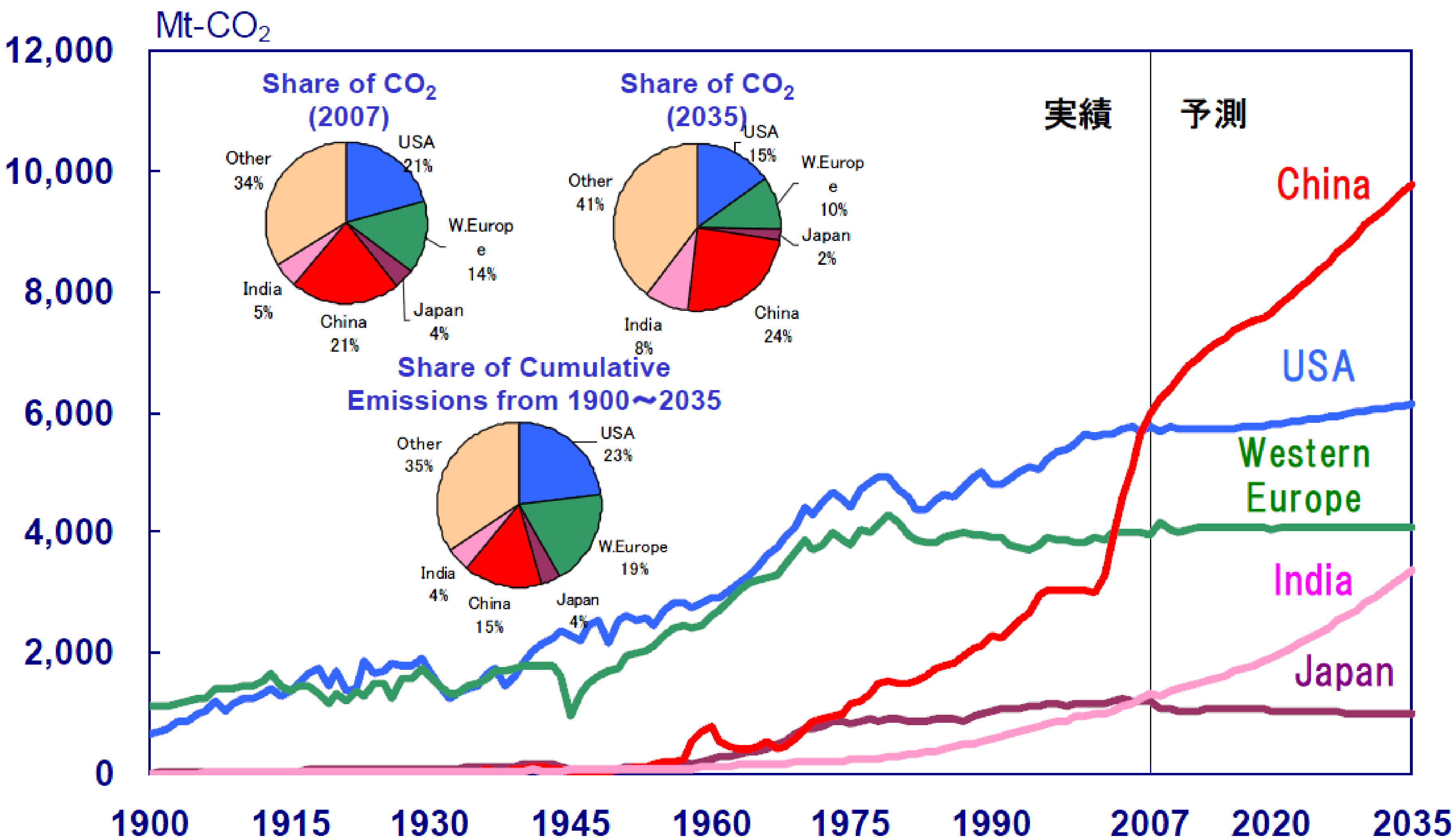
Coal-fired power plant is indispensable power supply option in both world and Asia with its economic advantages and the stable availability of its input fuel.

CO_2 Emission by Region ; World



Increase in Asia will account for 66%, with N.America and Europe together responsible for only 4%.

CO_2 Emissions (World)



Cumulative CO_2 emissions from 1990 of India will outstrip that of Japan by 2030

Technologically Advanced Scenario (Tech. Adv. Scenario)

Assumptions on Technologically Advanced Scenario

Countries all over the world more strengthen the numerous measures contributing to ensuring energy security and mitigating global warming issues. Combined with that, technological development and international transfer of technology will be promoted and advanced technology internationally becomes commercially available as a result.

<u>Regulation, National target, SSL etc.</u>

Carbon tax, Emissions Trading, RPS, Subsidization、FIT、Efficiency Standard, Automobile Fuel Efficiency Standard, Low Carbon Fuel Standard, Energy Efficiency Labeling, National Target etc.

<u>Promotion of R&D, International Cooperation</u>

Encouragement of Investment for R&D, International Cooperation on Energy Efficient Technology, Support on Establishment of Efficiency Standard

【Demand Side Technology】

■ Industry

Best available technology on industrial process such as steel making, cement, paper, oil refinery etc. become internationally penetrated

■ Transport

Clean energy vehicles (high fuel efficient vehicle, Hybrid vehicle, Plug-in hybrid vehicle, Electric vehicle, Fuel cell vehicle) globally expand.

■ Building

Efficient electric appliance (Refrigerator, TV etc.), High efficient water-heating system (heat-pump etc.), Efficient air conditioning system, Efficient lighting, Strengthening heating insulation

【Supply Side Technology】

■ Renewable

More expansion of Wind, PV, CSP, Biomass power generation, Bio-fuel

■ Nuclear

Acceleration of more nuclear power plant, Enhancement of operating ratio

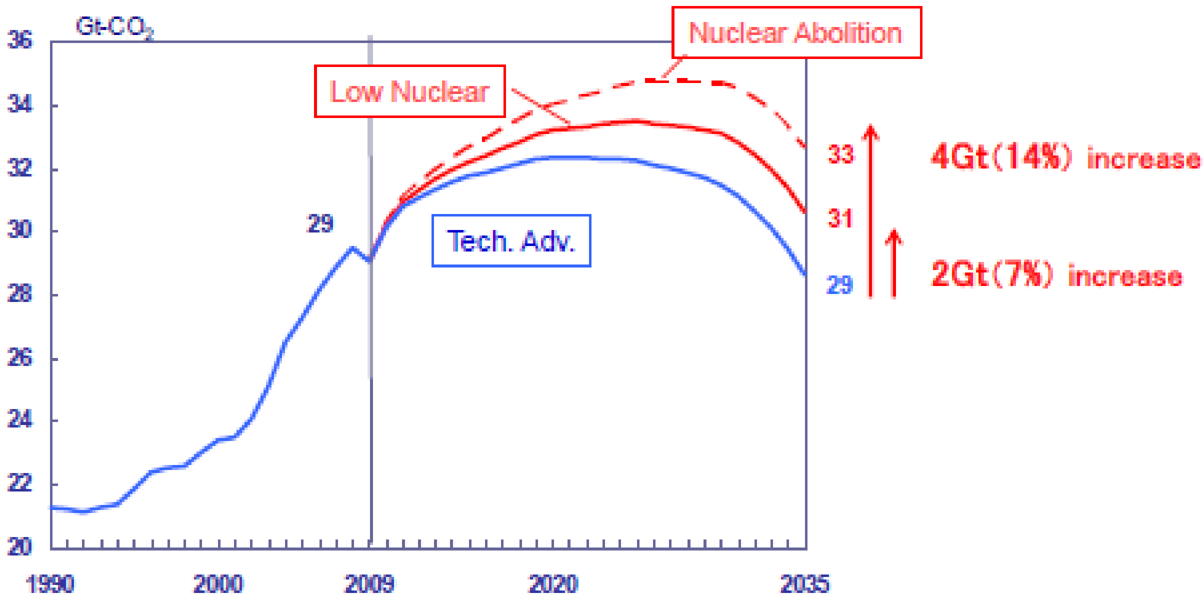
■ High Efficient Fossil-fired Power Plant

More expansion of Coal-fired power plant (USC, IGCC, IGFC), Natural gas MACC

■ CCS

Introduction in power generation (coal-fired, gas-fired) and industrial sector

Assumptions on Tech. Adv. Scenario (World、2035)



Non-fossil fuel
Mtoe

2007
1300 Mtoe
↓
2035

Reference	Tech. Adv.
2500 Mtoe	**3000 Mtoe**
2-fold inc)	(2.3-fold inc)

Share of non-fossil fuel

2007
12%
↓
2035

Reference	Tech. Adv.
15%	**21%**

■ In the low nuclear scenario, CO_2 emission in 2035 will increase by 2Gt or 7% when nuclear is replaced by fossil fuel-fired power generation.

■ If nuclear power is completely shut-down by 2035, CO_2 emissions will increase by 4Gt or 14% in 2035.

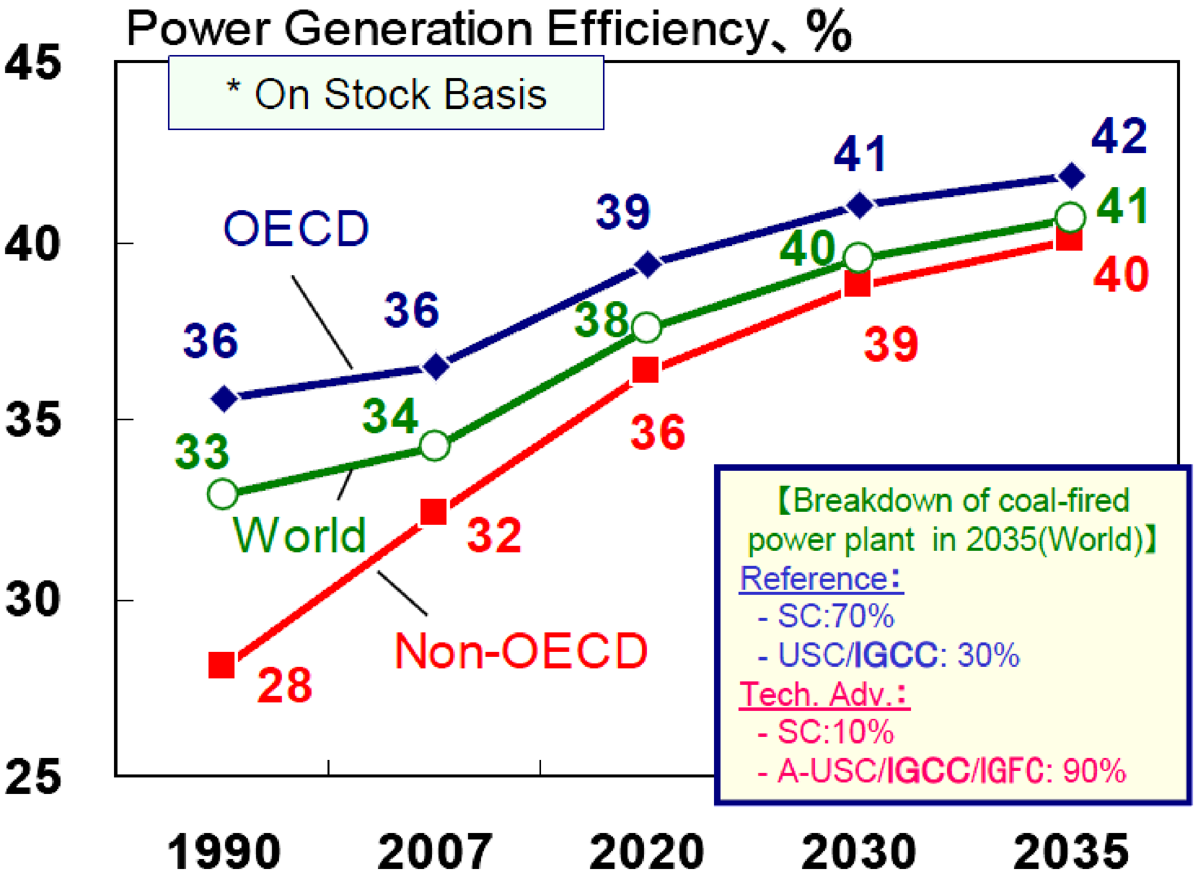
with food production and land use, becomes commercially viable.

■ Industry sector, building sector and transport sector respectively achieves 300Mtoe(9% saving), 500 Mtoe (14% saving) and 400 Mtoe (14% saving) of energy saving in 2035 compared with reference scenario.

■ Average efficiency of fossil fuel-fired power generation reach 47% at 2035 in Tech. Adv. Scenario while that in reference scenario shows 42%

Clean Coal Technology (CCT):
Power Generation Efficiency of Coal-fired Power Plant

Power Generation Efficiency of Coal-fired Power Plant *(Reference)



【Breakdown of coal-fired power plant in 2035(World)】

Reference:
- SC:70%
- USC/**IGCC**: 30%

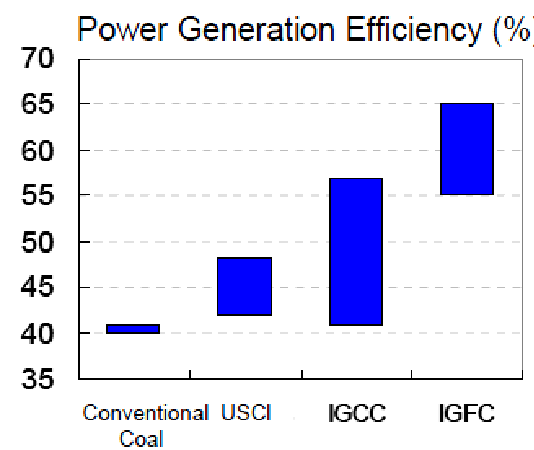
Tech. Adv.:
- SC:10%
- A-USC/**IGCC/IGFC**: 90%

Stock-based Efficiency of Coal-fired Power Plant (World)

2007
34 %
↓
2035

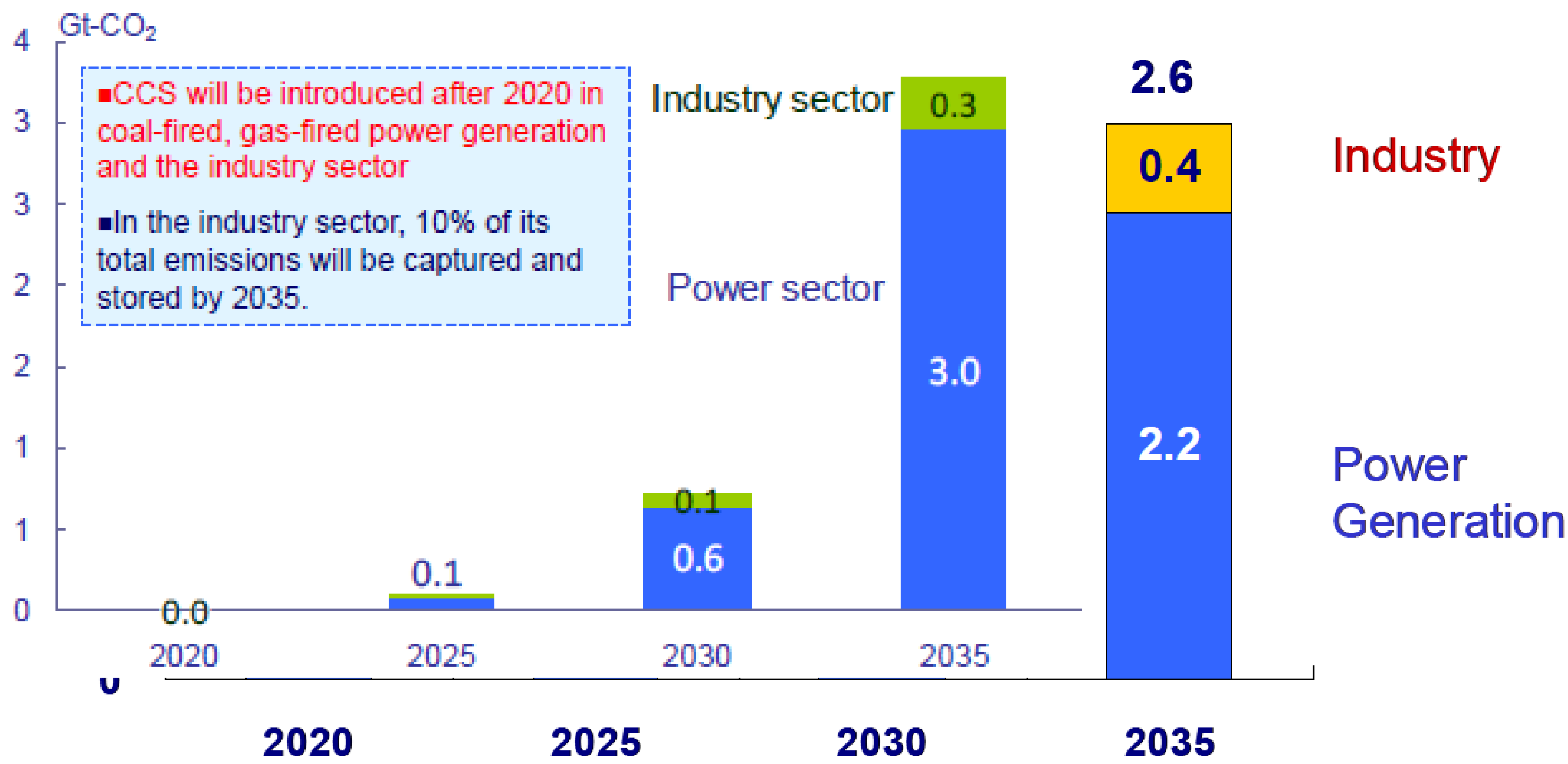
Reference	Tech.Adv.
41 %	**45 %**
(**7**points up)	(**11**points up)

Advanced Coal-fired Plant



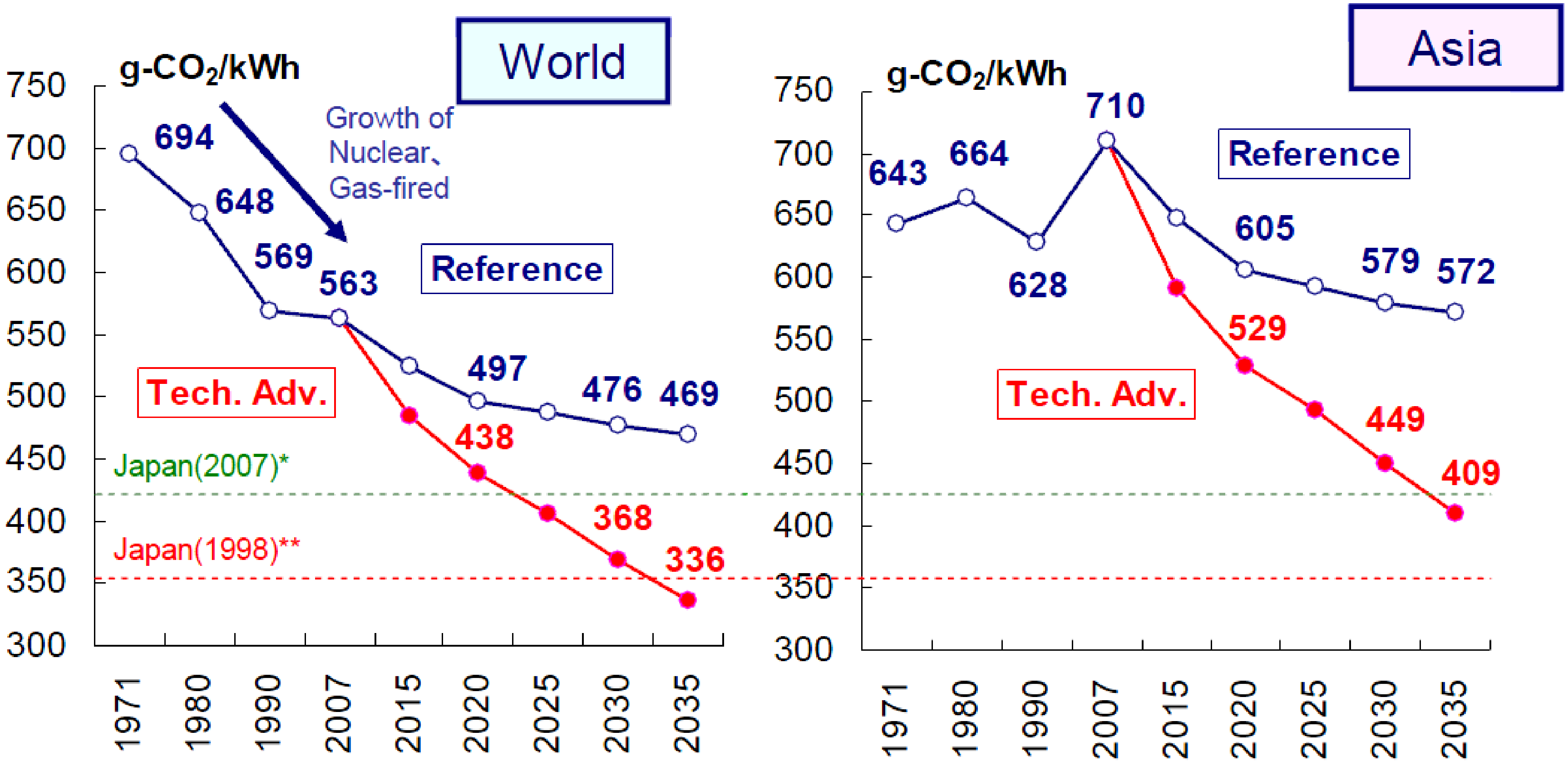
In Tech. Adv. Scenario, additional 1.0 Gt-CO2 will be reduced due to the enhancement of power generation efficiency compared with Reference Scenario.

Clean Coal Technology (CCT): CO_2 Capture & Storage (CCS)



▪ Cumulative captured and stored CO2 from 2020 to 2035 amounts to 14 Gt-CO2.Theoretical potential of CCS in geological structure is estimated to 10 trillion ton, and that of depleted gas field, oil field and coal field, 1 trillion ton, which is sufficient to accommodate the captured CO2 in Tech. Adv. Scenario.

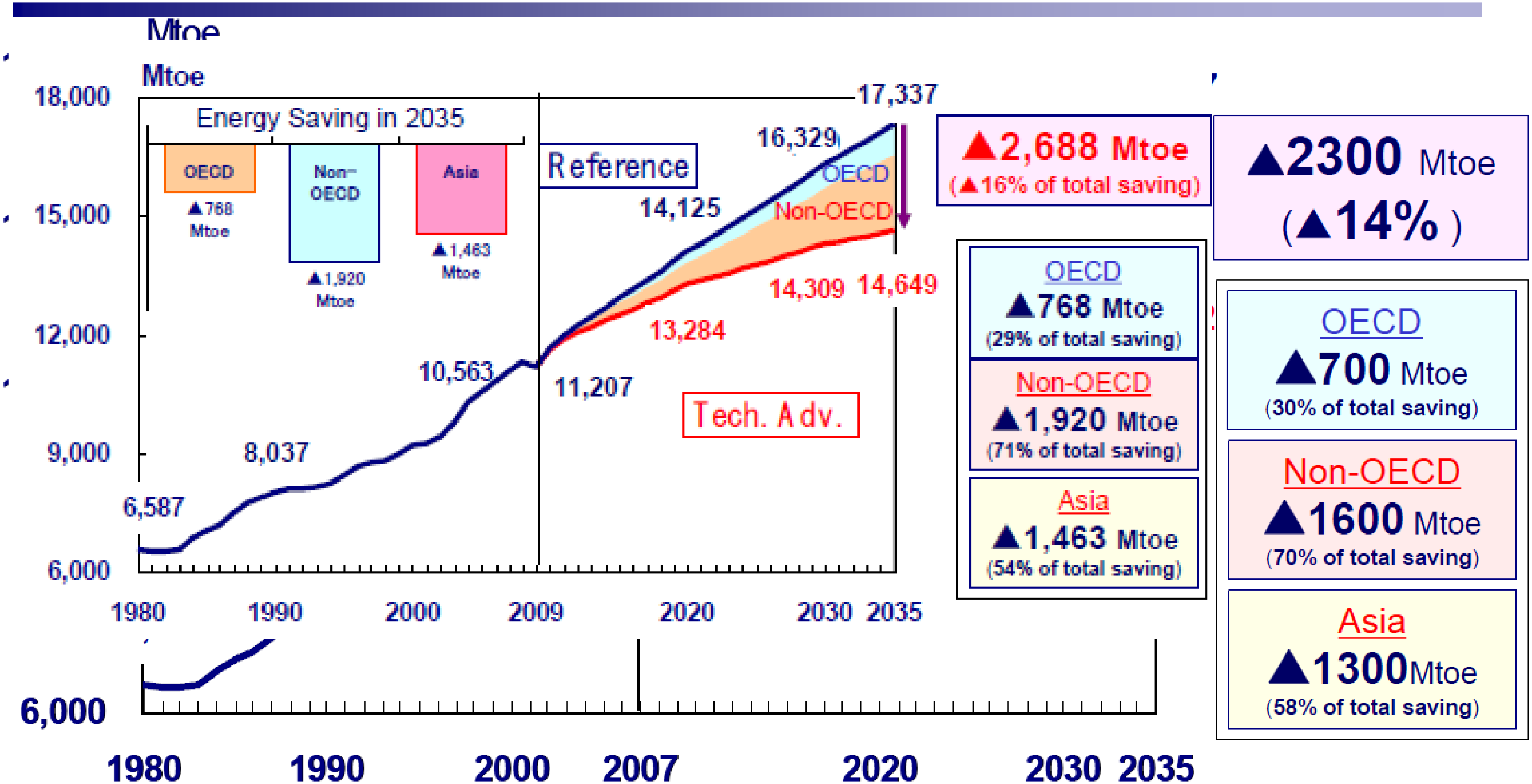
CO_2 Emissions per kWh



*420g-CO2/kWh **350g-CO2/kWh

■In Tech. Adv. Scenario, CO2 emissions per kWh represents dramatic reduction due to the further expansion of nuclear, renewable and improvement of efficiency of fossil-fired power generation.

Primary Energy Demand (World)



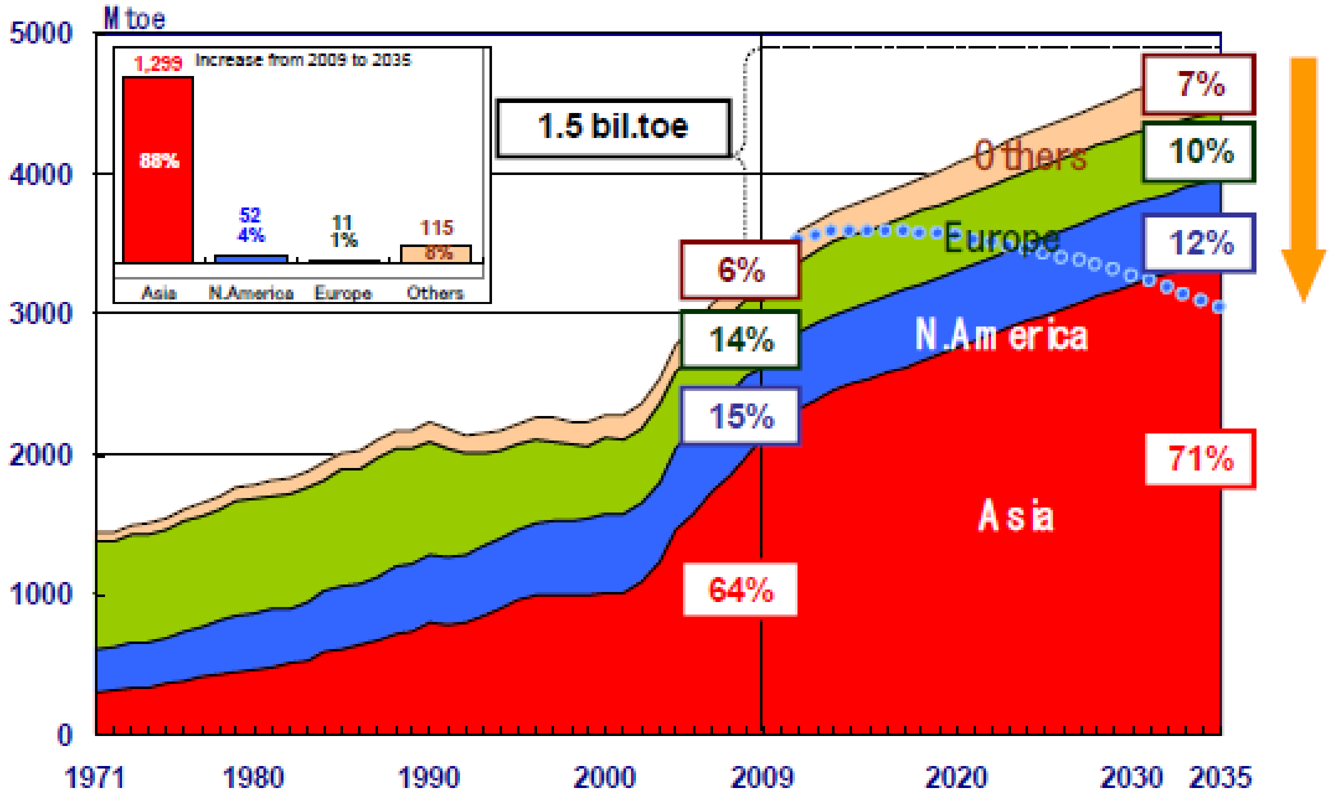
- In 2035, world total primary energy demand in Tech. Adv. Scenario decreases by 2300 Mtoe in comparison with Reference Scenario. 2300 Mtoe is approximately 4 times as much as TPES of Japan.
- TPES saving of Non-OECD in 2035 is almost double as large as that of OECD. The saving potential in Asia is particularly immense amount.

Primary Energy Demand by Source (World)

Solid line: Reference
Dotted line: Tech. Adv.

Coal Demand by Region (World)

Reference
Tech. Adv.



▲1.7 billion toe
(▲36%)

2009
3.3 billion toe
(4.7 billion tce*)
↓
2035
Reference
4.8 billion toe
(6.8 billion tce*)
Tech.Adv.Scenario
3.0 billion toe
(4.3 billion tce*)

*Tons of coal equivalent

- Oil in both of the Tech. Adv. and Reference Scenarios will maintain the biggest share in primary energy mix by 2035. In the Tech. Adv. Scenario, oil demand will peak in 2030.
- Fossil fuels will continue to account for the largest share by 2035, though its share will slightly decrease from 88% in 2009 to 85% in the Reference Scenario in2035 or to 77% in the Tech. Adv. Scenario.
- Coal will have the largest potential for saving in the Tech. Adv. Scenario.

Primary Energy Demand (Asia)

Mtoe

8,000

Energy Saving in 2035

7,565

6,000

4,000

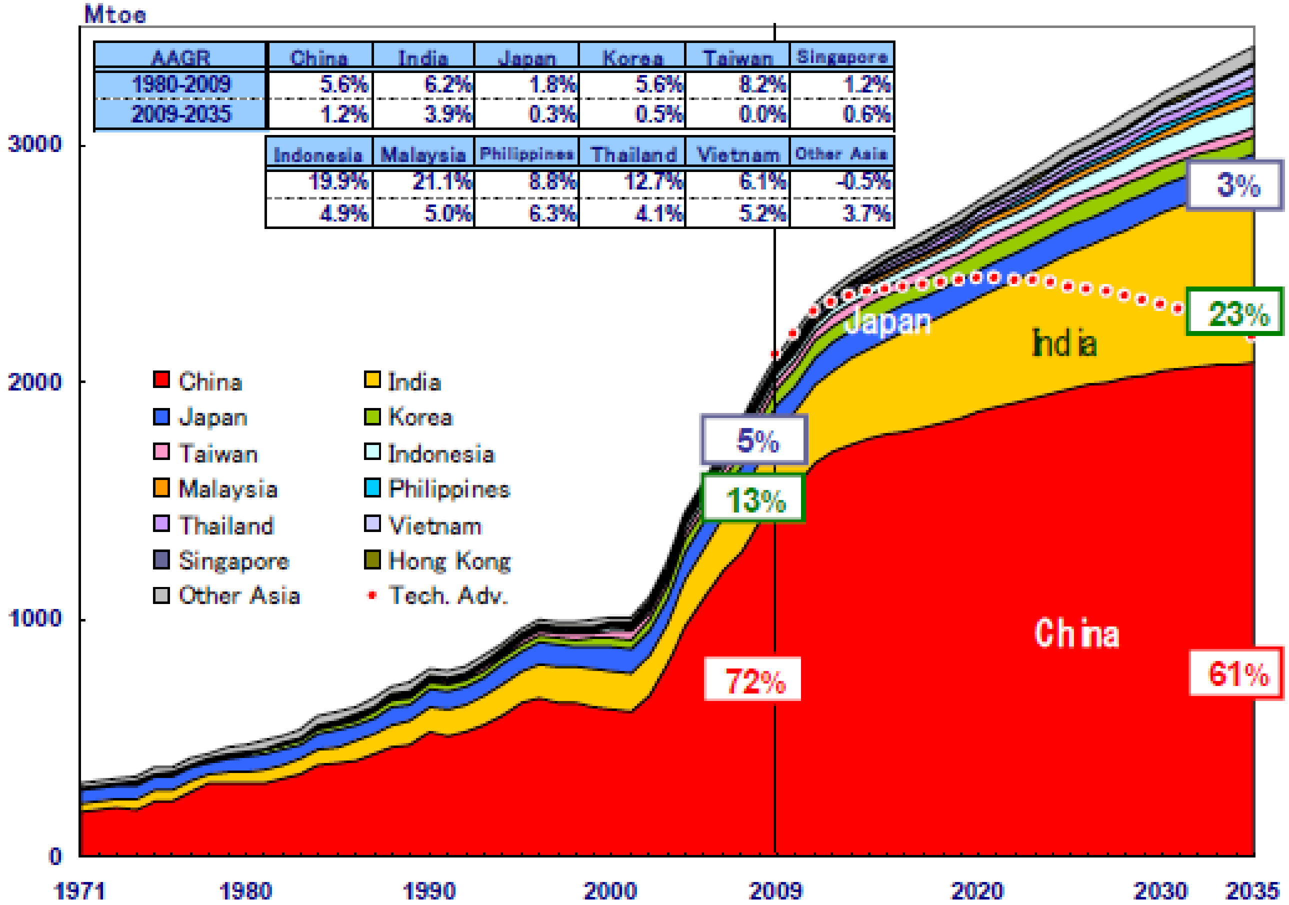
2,000

Coal Demand by Country (Asia)

Reference
Tech. Adv.

AAGR	China	India	Japan	Korea	Taiwan	Singapore
1980-2009	5.6%	6.2%	1.8%	5.6%	8.2%	1.2%
2009-2035	1.2%	3.9%	0.3%	0.5%	0.0%	0.6%

AAGR	Indonesia	Malaysia	Philippines	Thailand	Vietnam	Other Asia
1980-2009	19.9%	21.1%	8.8%	12.7%	6.1%	-0.5%
2009-2035	4.9%	5.0%	6.3%	4.1%	5.2%	3.7%



▲1.2 billion toe
(▲36%)

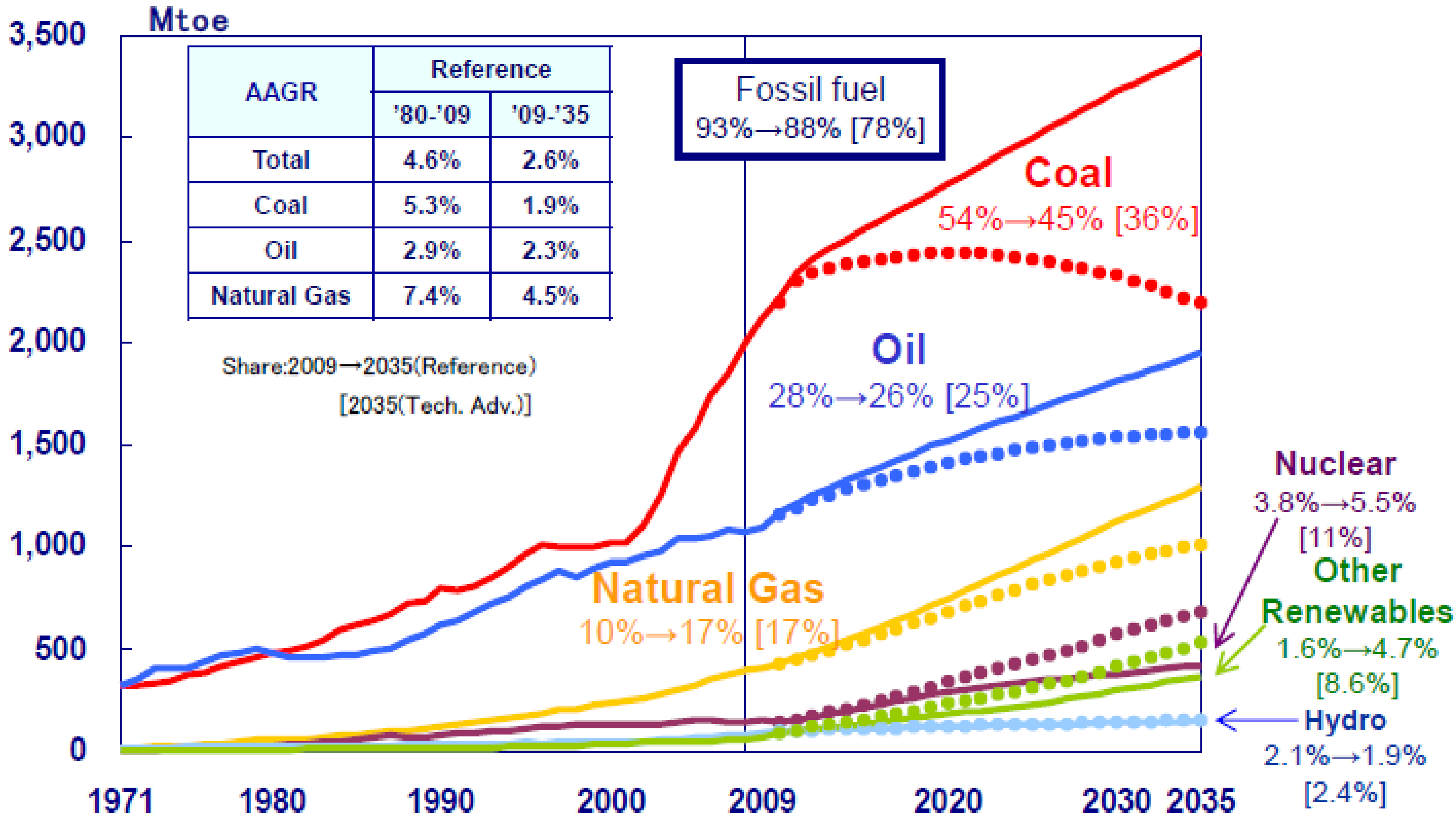
2009
2.1 billion toe
(3.0 billion tce)
↓
2035
Reference
3.4 billion toe
(4.9 billion tce*)

Tech.Adv.Scenario
2.2 billion toe
(3.1 billion tce*)

*Tons of coal equivalent

Primary Energy Demand by Source (Asia)

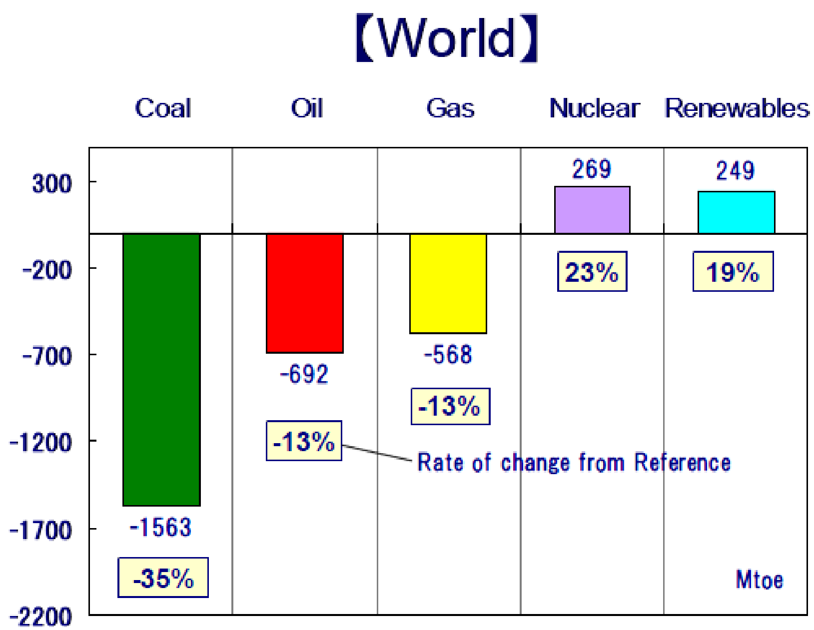
Solid line: Reference
Dotted line: Tech. Adv.

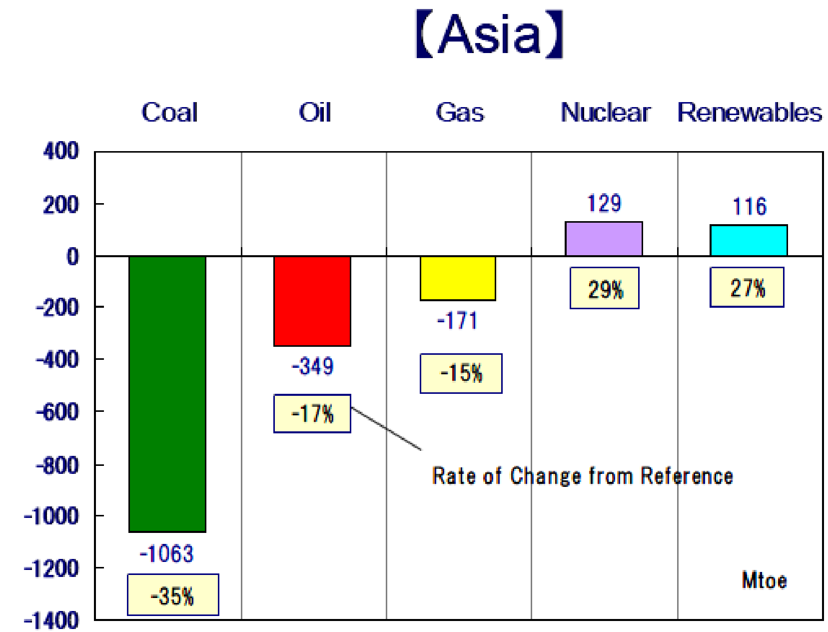


AAGR	Reference	
	'80-'09	'09-'35
Total	4.6%	2.6%
Coal	5.3%	1.9%
Oil	2.9%	2.3%
Natural Gas	7.4%	4.5%

- Coal and oil will continue to maintain the dominant share in Asian energy demand through 2035. The share of natural gas will increase substantially reaching 17% by 2035, driven mainly by power generation.
- Coal share in the Tech. Adv. Scenario will significantly decrease. It means the larger potentiality of saving can be realized by introduction of CCT in Asia.

Change of Energy Demand (2035)



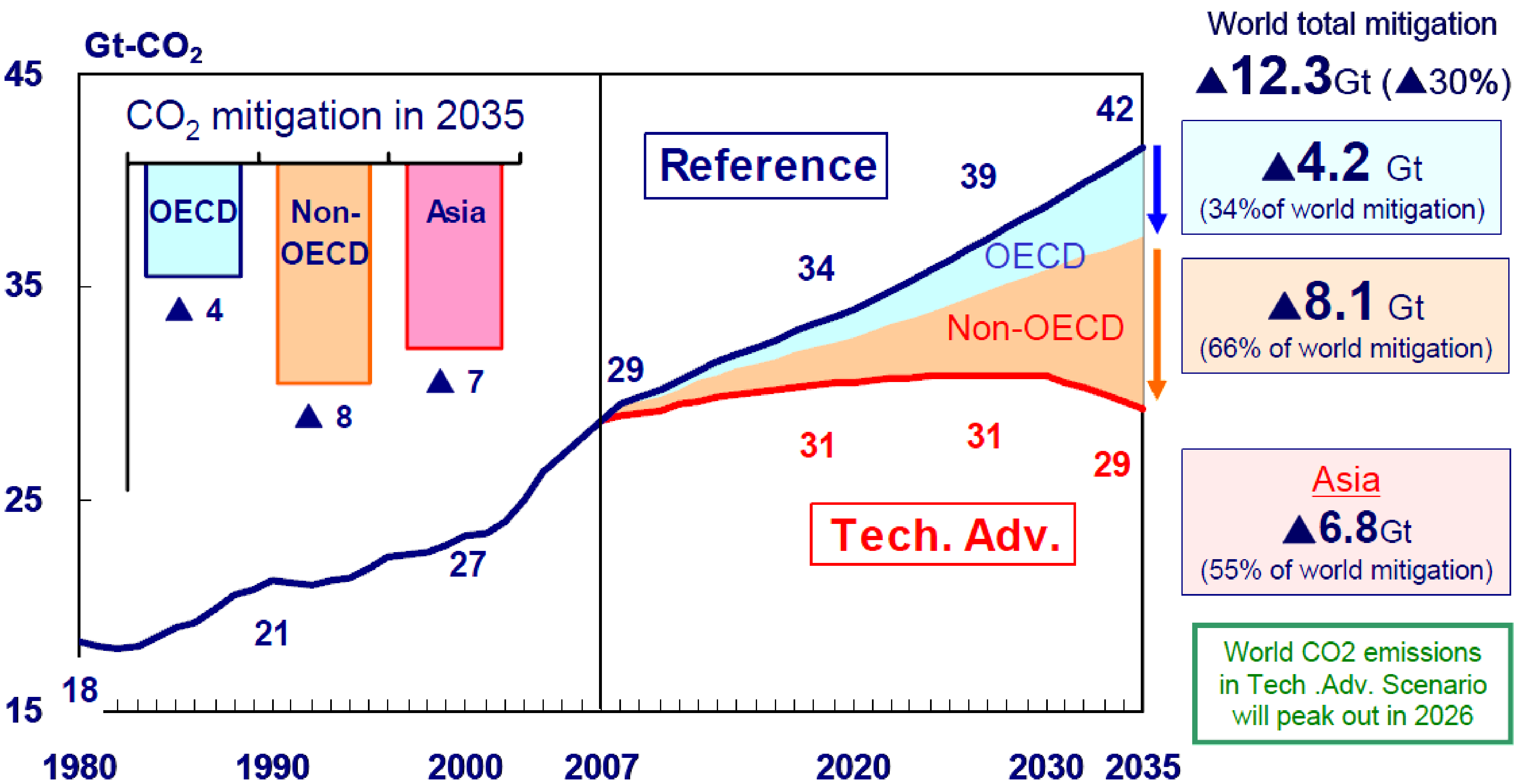


Fossil fuel decreases by 20%
(equal to 2800 Mtoe)

Fossil fuel decreases by 25%
(equal to 1600 Mtoe)

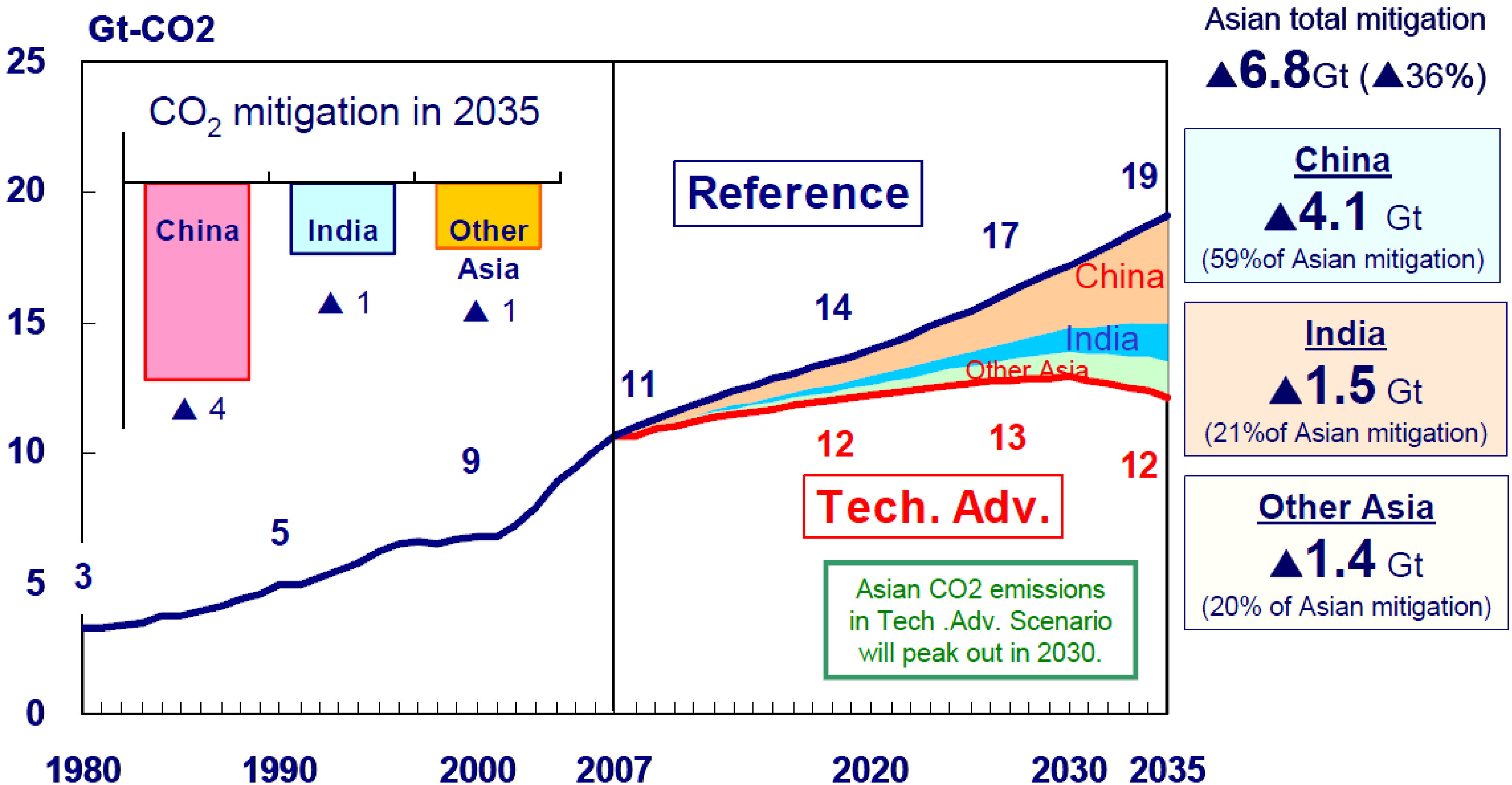
- Coal demand shows most notable reduction due to further penetration of clean coal technology (CCT), suggesting that CCT is expected to play a crucial role in Asia heavily relying on coal consumption.
- Clean energy vehicle is expected to contribute to mitigate oil demand and ensure international oil market.

CO_2 Emissions in Tech. Adv. Scenario (World)



- CO_2 mitigation of Non-OECD in 2035 is almost double as large as that of OECD. The saving potential in Asia shows particularly massive amount.
- Technology transfer and swift deployment of advanced technology in Asia is indispensable in order to address global warming problem.

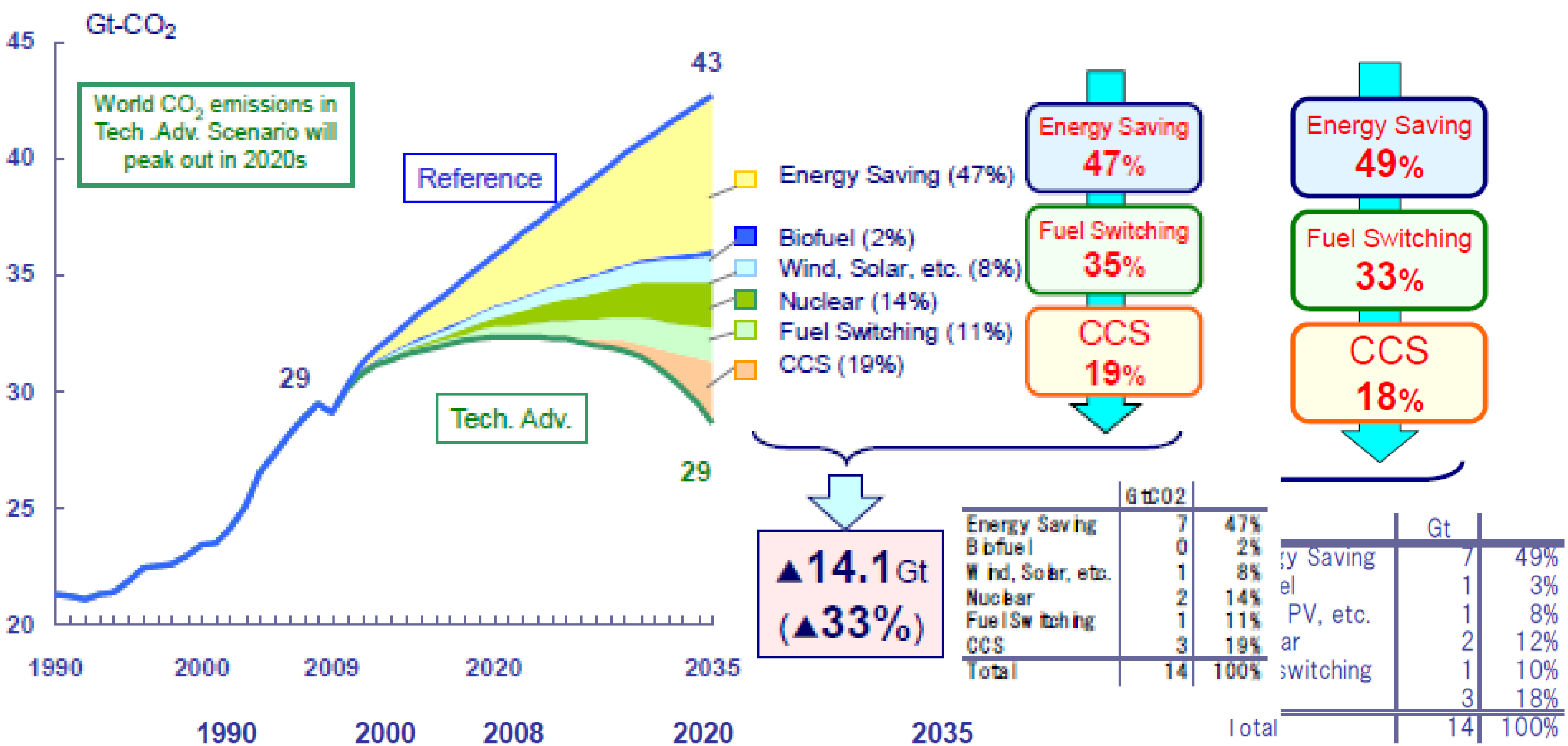
CO_2 Emissions in Tech. Adv. Scenario (Asia)



CO_2 mitigation potential in China and India is quite large. CO_2 reduction in China dominates about 60% of Asian mitigation potential.

CO_2 Emissions Reduction by Technology (World)

Reference
Tech. Adv.



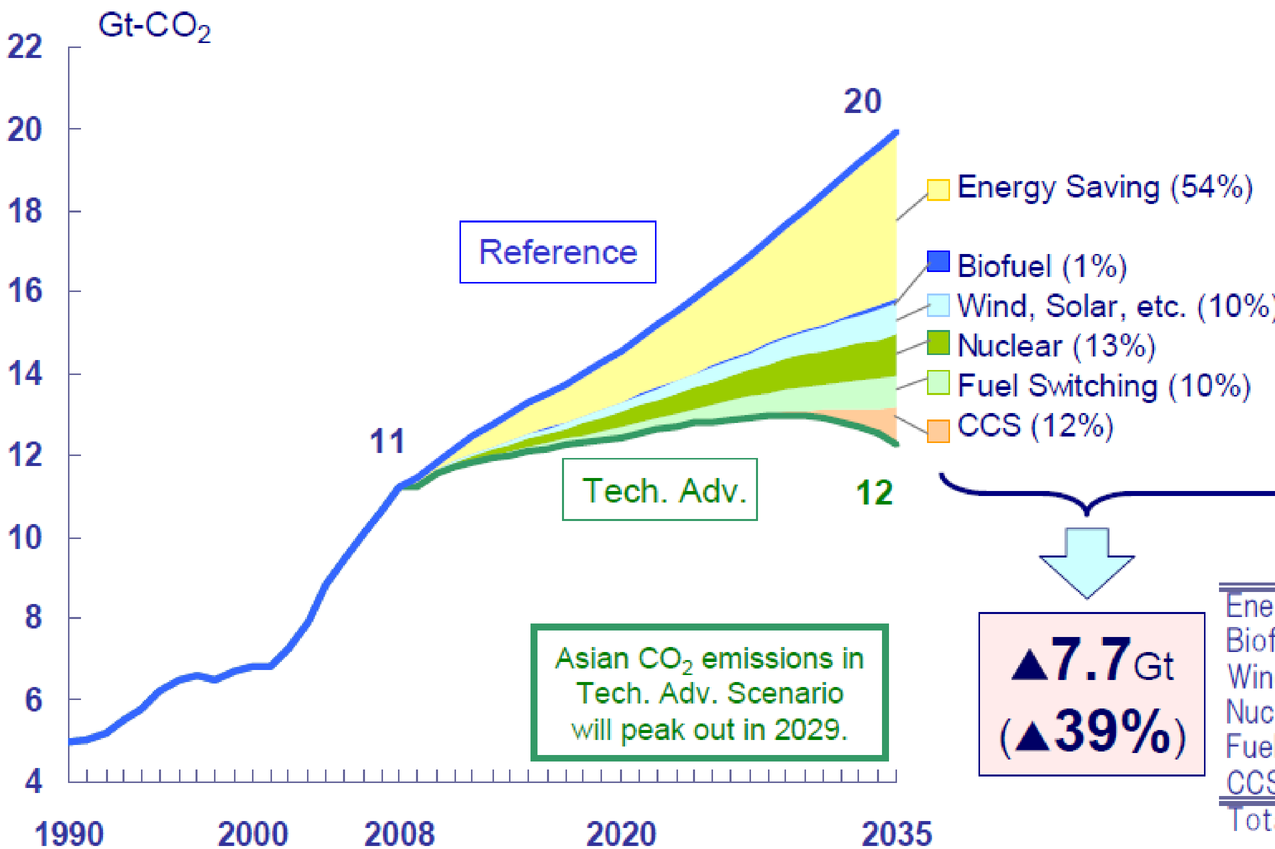
	GtCO2	
Energy Saving	7	47%
Biofuel	0	2%
Wind, Solar, etc.	1	8%
Nuclear	2	14%
Fuel Switching	1	11%
CCS	3	19%
Total	14	100%

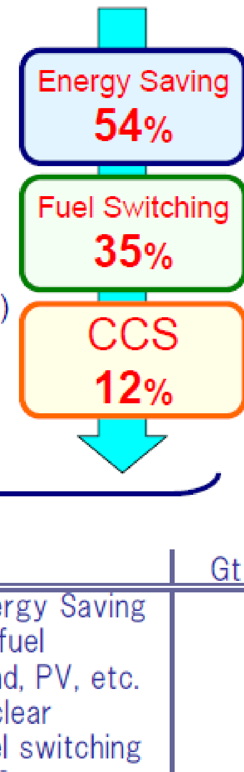
	Gt	
ɪy Saving	7	49%
el	1	3%
PV, etc.	1	8%
ar	2	12%
switching	1	10%
	3	18%
Total	14	100%

- In the Tech. Adv. Scenario, between 2005 and 2020 the world CO_2 emissions will increase by 3.5 Gt-CO_2 (or 13% up from the 2005 level), while the CO_2 emissions will reach its peak in 2024 with the introduction of advanced energy and environmental technologies.
- Various technological options, including energy saving, enhancement of power generation efficiency, renewables, nuclear, and CCS altogether contribute to massive CO_2 emissions reduction.

CO_2 Emissions Reduction by Technology (Asia)

Reference
Tech. Adv.

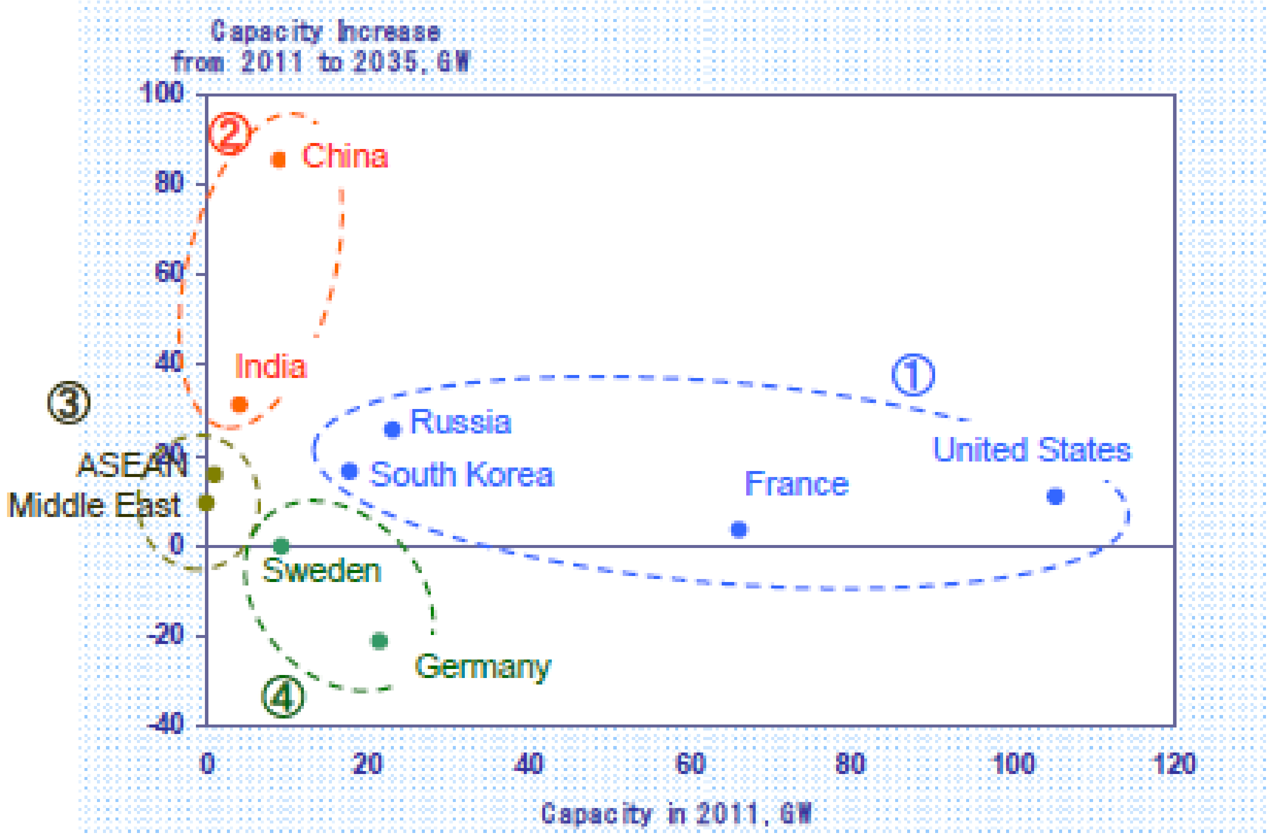




	Gt	
Energy Saving	4	54%
Biofuel	0	1%
Wind, PV, etc.	1	10%
Nuclear	1	13%
Fuel switching	1	10%
CCS	1	12%
Total	8	100%

- Aggressive development and deployment of advanced technologies in Asia enables to considerably reduce CO_2 emissions and realize its peak-out by 2030.

Nuclear Policies after Fukushima Accident



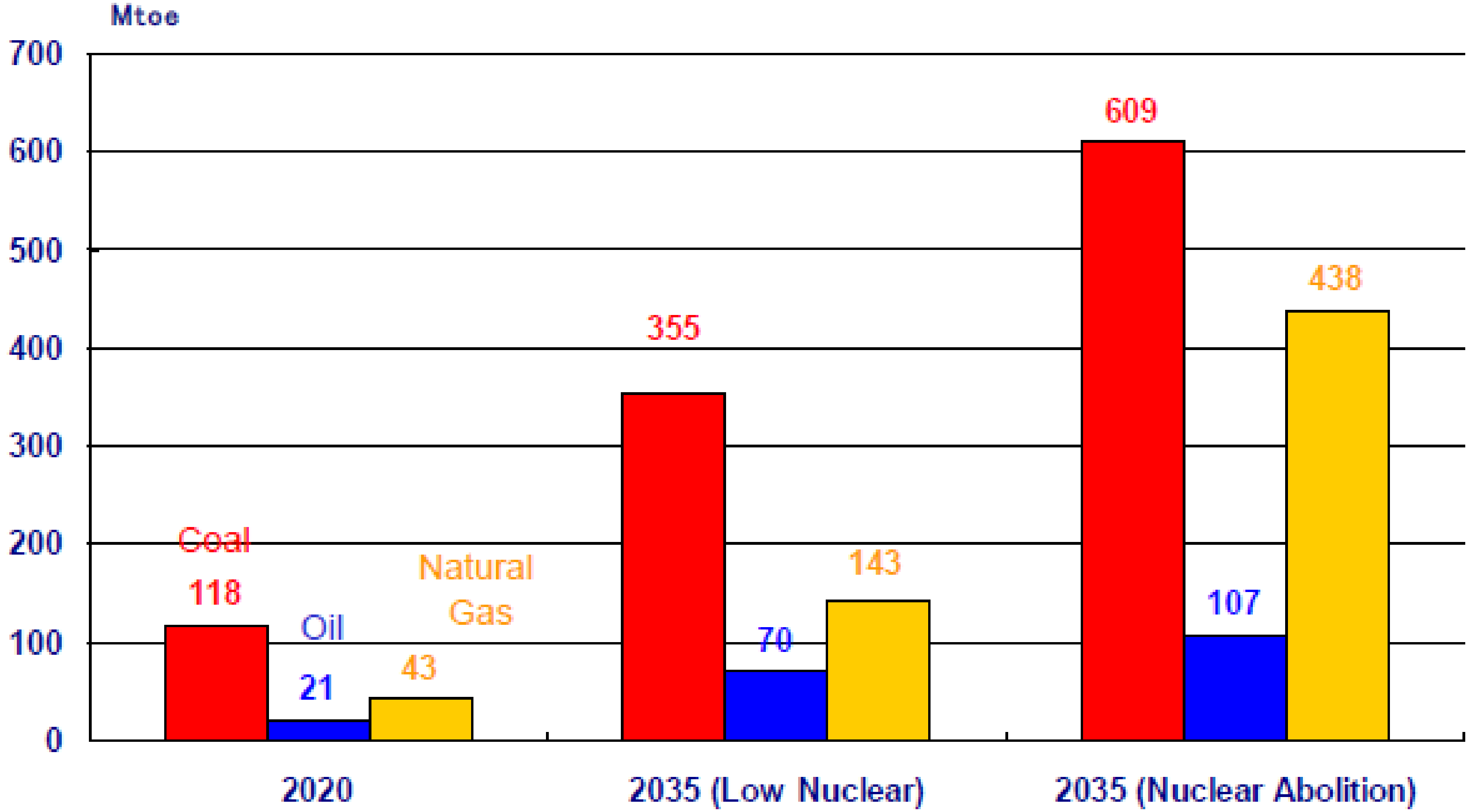
① Nuclear Promoting Countries (US, France, etc.) : Continue to make the best use of nuclear power.

② Emerging Countries (China and India) : No change of massive construction plans

③ Newcomer Countries (ASEAN and Middle East) : Reevaluate the construction plans in some countries

④ Phasing-out Countries (Germany, etc.) : Stop nuclear power after some decades of operation.

Effects on Fossil Fuel Consumption (Low Nuclear and Nuclear Abolition Scenarios)



- In the low nuclear scenario, world coal and natural gas consumption will increase by 500 M tons (355 Mtoe) and 140 bcm (143 Mtoe). The natural gas demand increase is equivalent to about half of the world's LNG trade in 2010.

Summary…….

1. By 2035, primary energy demand of Asia will double from the current level, reflecting high economic growth; 3.9 billion toe(2009) → 7.6 billion toe(2035).
2. Fossil fuel consumption will continue to increase in coming decades.

   → Cleaner use of fossil fuels as well as promotion of EE&C (Energy Efficiency & Conservation) will be the key.
3. Coal demand will increase mainly due to increasing demand for power generation.

   - Coal demand in Asia is forecast to keep increase while losing its share in the energy mix of 2035.

   - Coal has a largest potentiality among fossil fuels to be conserved in the Tec
4. In the low nuclear scenario, world coal and natural gas consumption will increase by 500 M tons (355 Mtoe) and 140 bcm (143 Mtoe), though CO_2 emission in 2035 will increase by 2Gt or 7%.

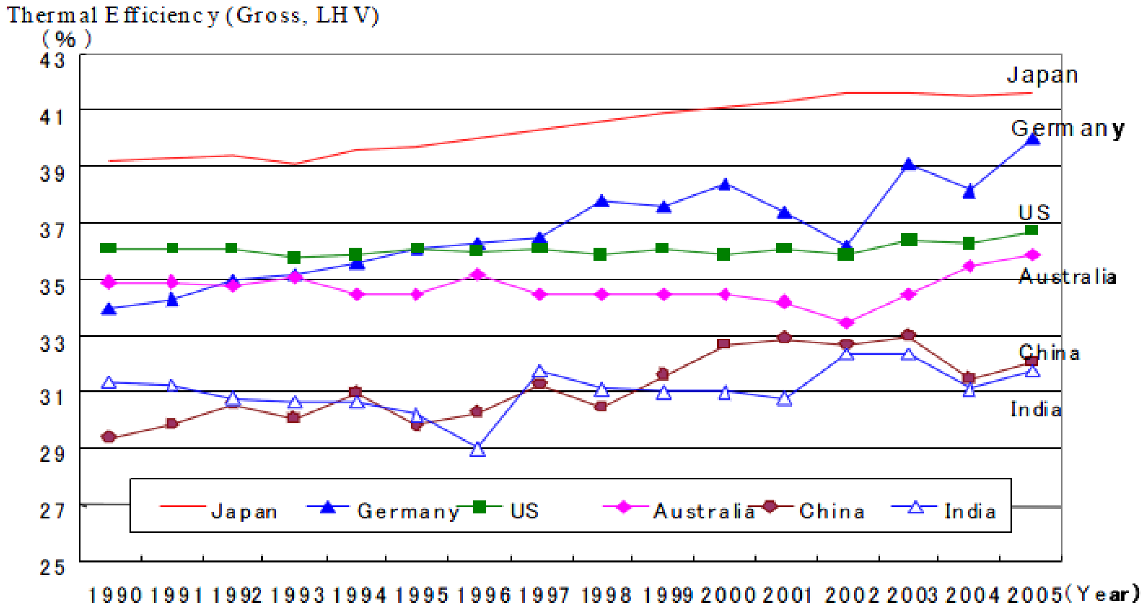
… and Conclusion

1. *Smart use of fossil fuel,* **shall be the key for the security of energy supply and sustainable development;**
   - Cleaner and efficient use of fossil fuel, especially coal, lead to curbing consumption, reducing pollution/GHG emissions, and enhancing security of energy supply.

2. *Best advanced technologies for coal (CCT)* **should be adopted for the sustainable development in Asia;**
   - Conversion of old coal-fired PP to high efficient power plants
   - Development, promotion of USC, IGCC and IGFC
   - Introduction of CCS in the long-way

Changes in the Coal-fired Thermal Power Plant Efficiency by Country

- Japan's coal-fired power generation has achieved world's highest thermal efficiency (41.6%).
- Many low-efficiency coal-fired thermal power plants exist in the world.



Source: ECOFYS, "INTERNATIONAL COMPARISON OF FOSSIL POWER GENERATION EFFICIENCY" (2008)

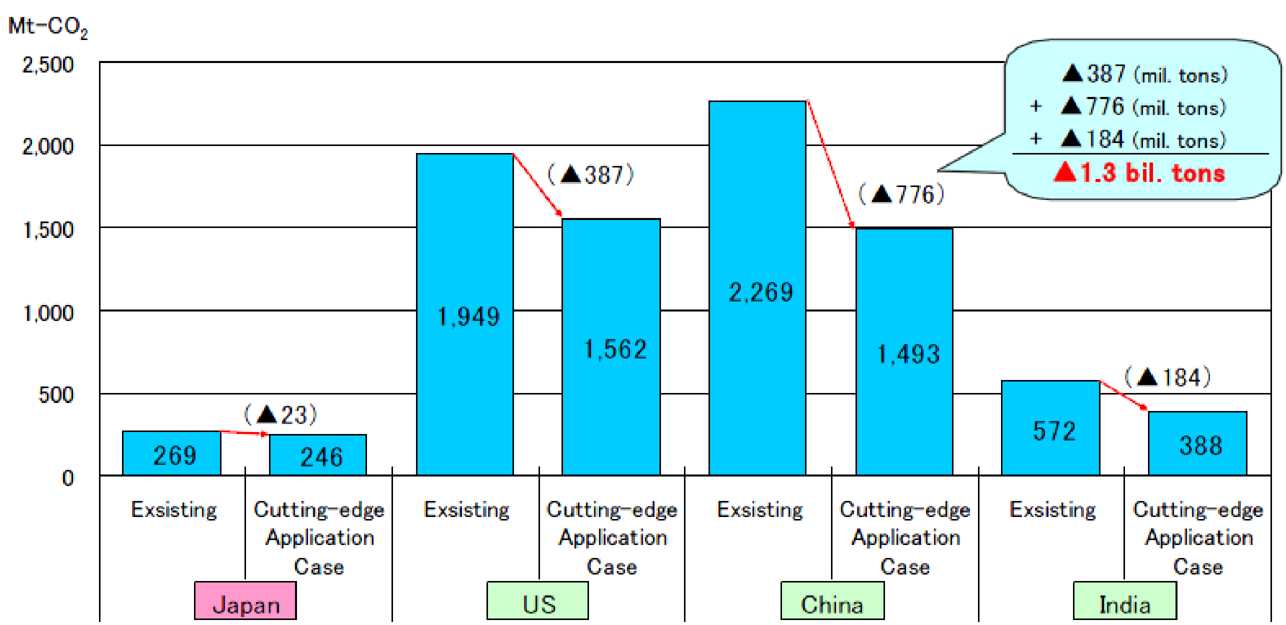
2006 results:

41.6% in Japan, 40.0 %% in Germany, 36.7% in the United States, 35.9% in Australia, 32.1% in China, and 31.8% in India

Simulation on the effects of transferring Japanese Thermal Power Plant Efficiency to other countries

High efficient use of coal contributes to reduce the CO2 emission and curb the decline of world's coal resources.

CO2 Emission of Coal-fired Thermal Power Plants (2004)



By applying the best practice of coal-fired power plants in Japan (highest efficiency among commercially operated plants) to that of the US, China and India, it is estimated to be reduced 1.3 billon tons of CO_2 which is equivalent to Japan's total CO_2 emission.

Note: In the case of applying the best practice (highest efficiency level of commercial power plants) of Japan to the existing plants of each country.

Source: The Institute of Energy Economics, Japan (IEE JAPAN), Achievement data: World Energy Outlook 2006 (IEA)

Assignment : CO_2 Emission Calculations

- Solid Fuel Specification
- Boiler Efficiency : In-direct method (ASME PTC 4.1)
- Turbine Efficiency : 45%
- LOI(UBC) : 5%

Value	Design Coal
C.V(kcal/kg)	6080
Proximate analysis	
Moi.	9.5
V.M	25.2
ASH	13.5
F.C	46.8
Element analys	
C	0.8195
H	0.0511
O	0.1033
N	0.0166
S	0.0095
ASH	0.1350

http://www.exoeng.com/boilereffcalc.htm

1. 프로그램을 이용하여 플랜트 효율을 계산하고 CO_2 배출량을 계산
2. USC, IGCC,IGFC 플랜트(48%) 경우 CO_2 배출량 계산하여 감축량 비교

2.1 CO_2 calculation (in Plant)

Sample code	Proximate analysis [As-received basis, wt%]			
	Moisture	Volatile matter	Ash	Fixed carbon
ICR	28.23	33.47	5.14	33.16
HCK-F-I/M/0.08-250	1.21	44.49	12.15	42.15
HCK-F-I/J/0.08-250	3.10	45.26	9.67	41.97
HCK-F-I/J/0.28-250	1.61	45.73	8.57	44.09

Sample code	Ultimate analysis [dry basis, wt%]					
	C	H	N	O	S	Ash
ICR	63.35	5.52	1.03	24.51	0.45	5.14
HCK-F-I/M/0.08-250	65.63	4.80	1.02	15.92	0.48	12.15
HCK-F-I/J/0.08-250	64.45	4.96	0.99	19.59	0.34	9.67
HCK-F-I/J/0.28-250	66.39	5.00	0.94	18.67	0.43	8.57

1. **Coal 공급량 계산**
2. **원소 분석의 C (%)를 통해**
   Coal 안의 Carbon량 계산
3. **Plant 효율 고려**
   [보일러 효율*터빈 (45%)]
4. **Plant UBC 고려 (5%)**
5. **CO_2 량 계산**

2.1 CO_2 calculation (in Plant)

- **Boiler 효율 계산 프로그램 (In-direct method)**

  http://www.exoeng.com/boilereffcalc.htm

Plant...............	
Unit...............	
Location..........	
Date...............	

Fuel Data:		Blend	Coal A	Coal B	Units
	Blend Fraction		100%	0%	
Carbon	C	51.04	51.04	0.00	%
Hydrogen	H_2	3.64	3.64	0.00	%
Sulfur	S	0.29	0.29	0.00	%
Oxygen	O_2	12.74	12.74	0.00	%
Nitrogen	N_2	0.66	0.66	0.00	%
Moisture	H_2O	26.57	26.57	0.00	%
Ash		5.06	5.06	0.00	%
Other		0.00	0.00	0.00	%
Total:		100.00	100.00	0.00	%
HHV		8,867	8,867	0	Btu/lb_m
Moisture in Air		0.0135	(lb/lb dry air)		
Additional Moisture		0.0000	(lb/100lb fuel)		

Air, Gas & Fuel Temperatures:		
Calculation Reference Temp	80	°F
FD Fan Inlet Air Temp	60	°F
Fuel Temperature (Default = T_{ref})	60	°F
Boiler Efficiency Losses, Manual Input:		
Radiation and convection (Default = .17)	0.17	%
Unaccounted for losses (Default = 0.50)	0.50	%

Ash Data:		
Ash Location	Ash Split (%)	LOI (%)
Bottom Ash	20	0.26
Economizer Ash	5	0.26
Air Heater Ash	0	0.00
Precipitator Ash	75	0.26
Baghouse Ash	0	0.00
Dust Collector Ash	0	0.00
Total Ash (Must	100	

Economizer Exit Gas Data:		
Ex	2.50	%
O	1	

Fuel Flow Determination Data:		
For total fuel flow determination enter at least one of the following groups:		
Gr	392,027	pph
OR		
Gr		MBtu/hr
OR		
Group C: For non-reheat units, enter all of the following:		
Steam Flow		pph
Steam Enthalpy		pph
Feedwater Enthalpy		pph

Performance at Tested Air Heater Leakage

Furnace Data @ Tested AH Leakage:		
Heat Input	3,476	MBtu/hr
Steam Flow	0	pph
Fuel Flow	392,027	pph
Total Air Flow	2,982,562	pph
Furnace Excess Air	15.56	%
Wet Gas Flow Leaving Furnace	3,625,951	pph
Air Heater Exit Gas Data @ Tested AH Leakage:		
Excess O_2 (% by Vol)	4.26	%
Excess O_2 Measurement Basis: 1 = Wet, 0 = Dry	1	
AH Gas Exit Temp Corrected (Measured)	321	°F
AH Gas Exit Temp Uncorrected (ie, No Leakage)	349	°F
To correct the efficiency for "Uncorrected AH Gas Out Temp" enter "1" at right. If not, leave blank.		
Air Heater Leakage (pph)	361,584	pph
Air Heater Leakage (%) *(Mass Method)*	9.97	%
Air Heater Leakage (%) *O_2 Method)*	9.52	%
We	3,987,536	pph
We	1,271,016	acfm
Flue Gas Constituents: (% by Volume)		
Oxygen (O_2)	4.26	%
Carboc Dioxide (CO_2)	12.93	%
Sulfur Dioxide (SO_2)	0.02753	%
Moisture (H_2O)	11.93	%
Nitrogen (N_2)	70.85	%
Total	100.00	%

Boiler Efficiency Heat Losses @ Tested AH Leakage:		
Los	6.17	%
Los	7.71	%
Los	0.14	%
Los	0.02	%
Los	0.17	%
Ma	0.50	%
Tot	14.72	%
Boi	85.28	%

Performance at Design (or other) Air Heater Leakage

Furnace Data @ Design (or other) AH Leakage:		
Heat Input	3,476	MBtu/hr
Steam Flow	0	pph
Fuel Flow	392,027	pph
Total Air Flow	2,982,562	pph
Furnace Excess Air	15.56	%
Wet Gas Flow Leaving Furnace	3,625,951	pph
Air Heater Exit Gas Data @ Design (or other) AH Leakage:		
Excess O_2 (% by Vol)	9.50	%
Excess O_2 Measurement Basis: 1 = Wet, 0 = Dry	1	
AH Gas Exit Temp Corrected (Measured)	238	°F
AH Gas Exit Temp Uncorrected (ie, No Leakage)	349	°F
To correct the efficiency for "Uncorrected AH Gas Out Temp" enter "1" at right. If not, leave blank.		
Air Heater Leakage (pph)	2,122,884	pph
Air Heater Leakage (%) *(Mass Method)*	58.55	%
Air Heater Leakage (%) *O_2 Method)*	55.26	%
We	5,748,835	pph
We	1,637,109	acfm
Flue Gas Constituents: (% by Volume)		
Oxygen (O_2)	9.50	%
Carboc Dioxide (CO_2)	8.76	%
Sulfur Dioxide (SO_2)	0.01865	%
Moisture (H_2O)	8.77	%
Nitrogen (N_2)	72.95	%
Total	100.00	%

Boiler Efficiency Heat Losses @ Design (or other) AH Leakage:		
Los	5.93	%
Los	7.46	%
Los	0.14	%
Los	0.02	%
Los	0.17	%
Ma	0.50	%
Tot	14.23	%
Boi	85.77	%

NOTES:

yellow/red cells are for input data, to be completed by user.

Design (or other) data set does not need to be completed. It is just available for comparison.

Fuel flow and heat input are not used to calculate boiler efficiency, but are necessary for calculation of air and gas flows.

Fuel Flow determination will attempt to access Group A data first, Group B data second, and Group C data last.

Heat Input determination will attempt to access Group B data first, Group A data second, and Group C data last.

2.1 CO_2 calculation (in Plant)

	Designed coal	ICR	HCK-F-I/M/0.08-250	HCK-F-I/J/0.08-250	HCK-F-I/J/0.28-250
Coal supply [ton/h]	193	296	199	197	197
Carbon supply [ton/h]	121.8	131.9	128.8	122.6	128.5
ACV of coal [kcal/kg]	6080	4170	5908	5959	5962
Plant efficiency [%]	40	38	40	40	40
Required net ACV [kcal/h]	4.70×10^8	4.70×10^8	4.70×10^8	4.70×10^8	4.70×10^8
Required gross ACV [kcal/h]	1.17×10^9	1.23×10^9	1.18×10^9	1.17×10^9	1.17×10^9
Flow rate of flue gas [kg/s]	440.0	666.7	468.9	450.9	466.0
CO_2 content of flue gas [wt%]	27.3	20.0	26.7	26.5	26.9
CO_2 flow rate [ton/day]	10382.2	11525.8	10816.5	10312.1	10816.3

1.2 Greenhouse effect & impacts on the climate

Table 1.1 Present concentrations of greenhouse gases and their contribution to the natural and anthropogenic greenhouse effect (data from IPCC (2007b) and Beising (2006))

Greenhouse gas	Carbon dioxide CO_2	Methane CH_4	Chloro-fluorocarbons CFCs	Nitrous oxide N_2O	Ozone O_3	Water vapour
Concentration: pre-industrial time (about 1800)	280 ppm	0.7 ppm	0	270 ppb	–2.6%	
Today (2005)	379 ppm	1.8 ppm	0.5 ppb	319 ppb	25 ppb	2.6%
Increase rate (2005)	+1.9 ppm/a	+2 ppb/a		0.8 ppb/a		
Emissions (2005)	26 Gt/a	400 Mt/a	0.4 Mt/a	15 Mt/a	0.5 Gt/a	
Contribution to natural greenhouse effect = temperature rise	26%	2%	–	4%	8%	60%
Contribution to anthropogenic greenhouse effect	61%	15%	11%	4%	9%	–

[1] One tonne of carbon corresponds to 3.67 tonnes of carbon dioxide.

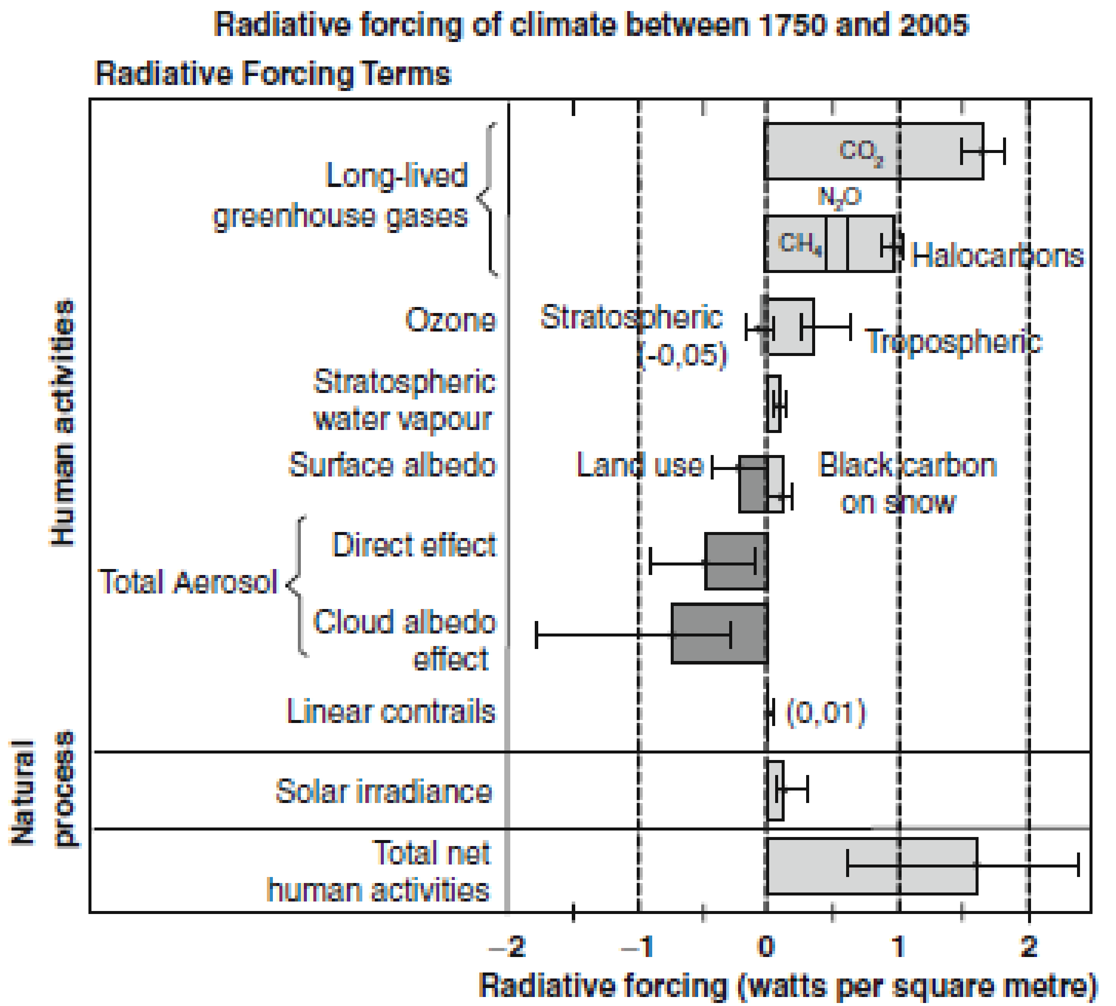
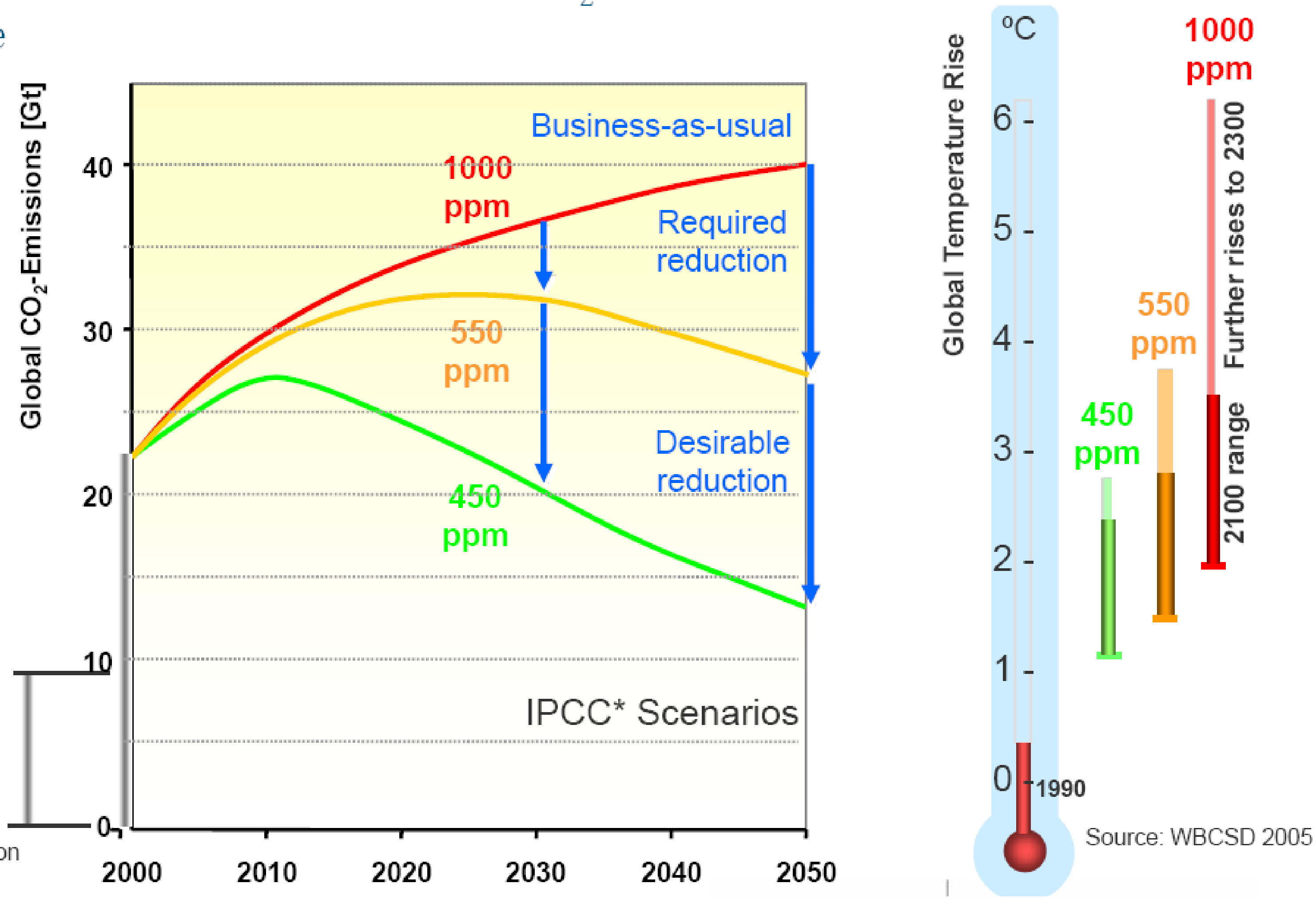


Fig. 1.8 Change in radiative forcing in the period 1750–2005 (IPCC 2007b)

Outlook of global CO2 emissions

Goal: A longterm moderate stable CO_2 concentration in the atmosphere



~40% caused by power generation

* Intergovernmental Panel on Climate Change

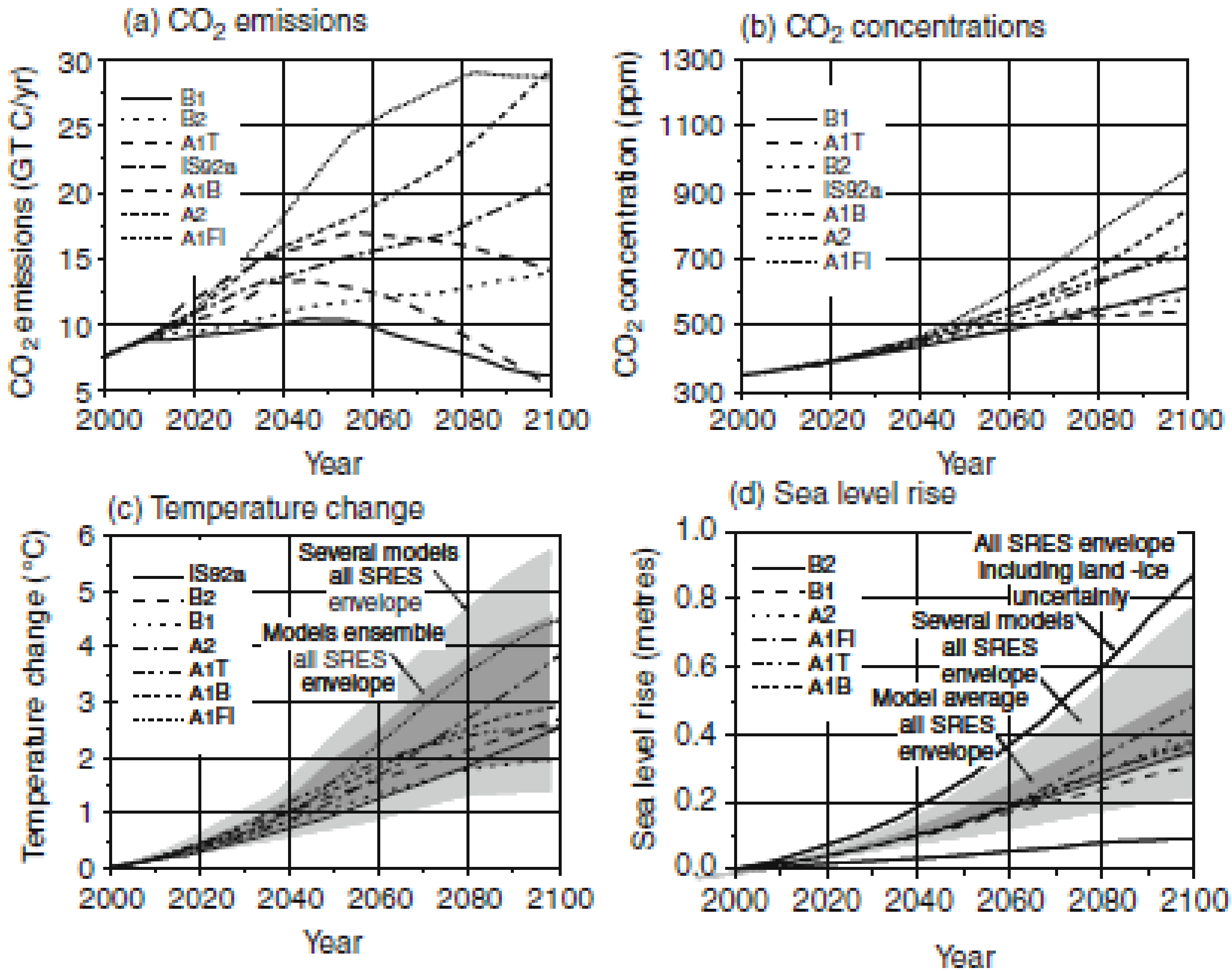


Fig. 1.9 Scenarios of the global CO_2 emissions (**a**), CO_2 concentration (**b**), temperature rise (**c**) and sea level (**d**) (IPCC 2001b)

1.3 Strategies of CO2 Reduction

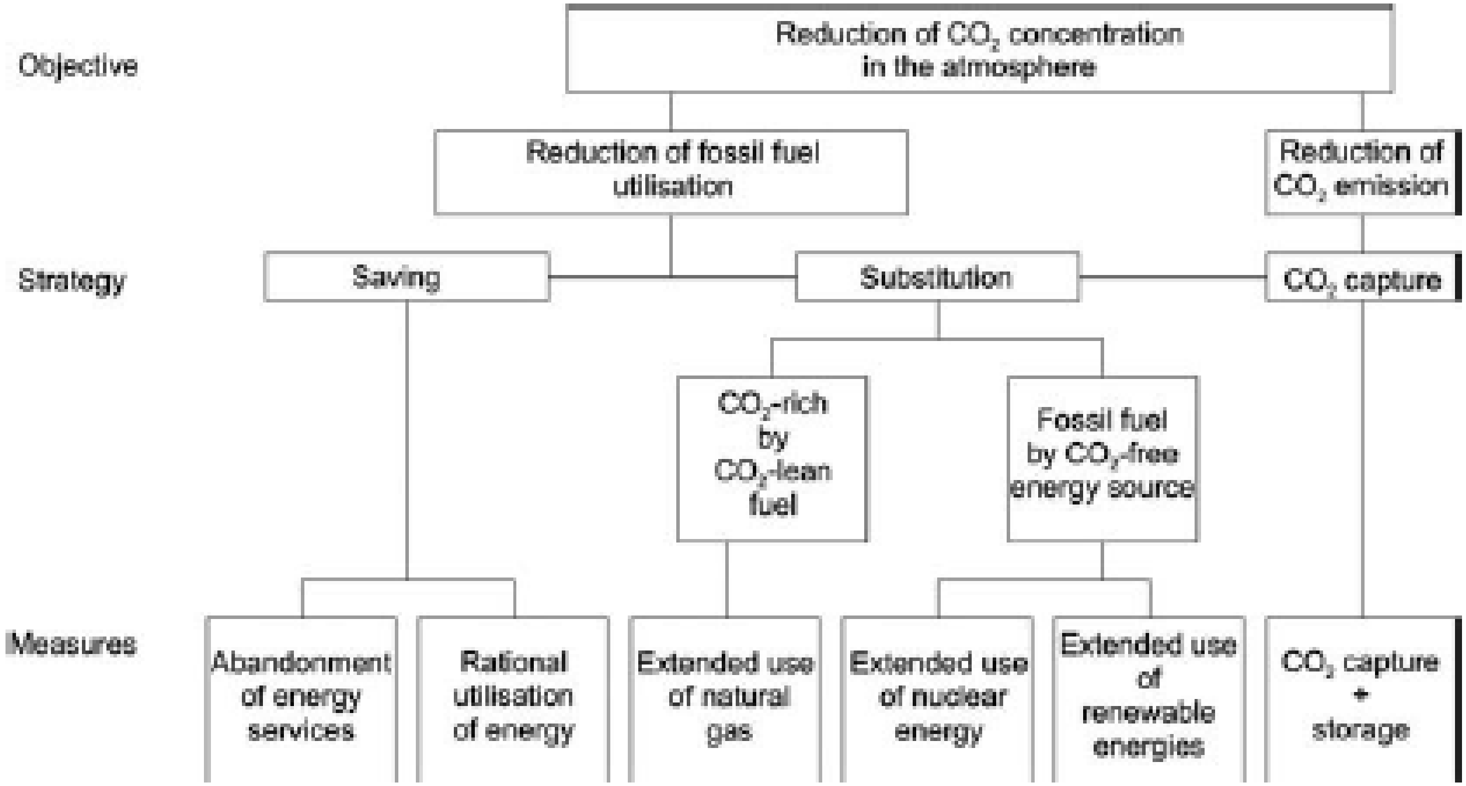


Fig. 1.10 Strategies to reduce the CO_2 emissions to the atmosphere from the energy sector

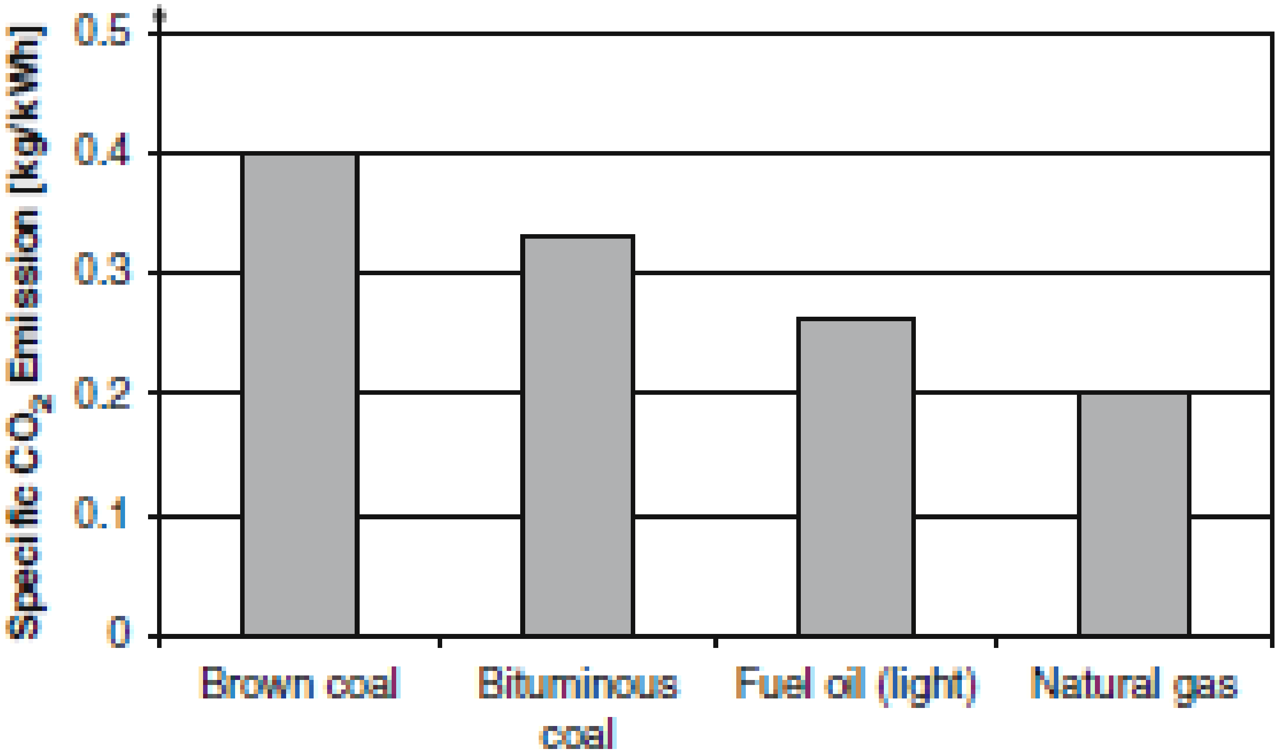
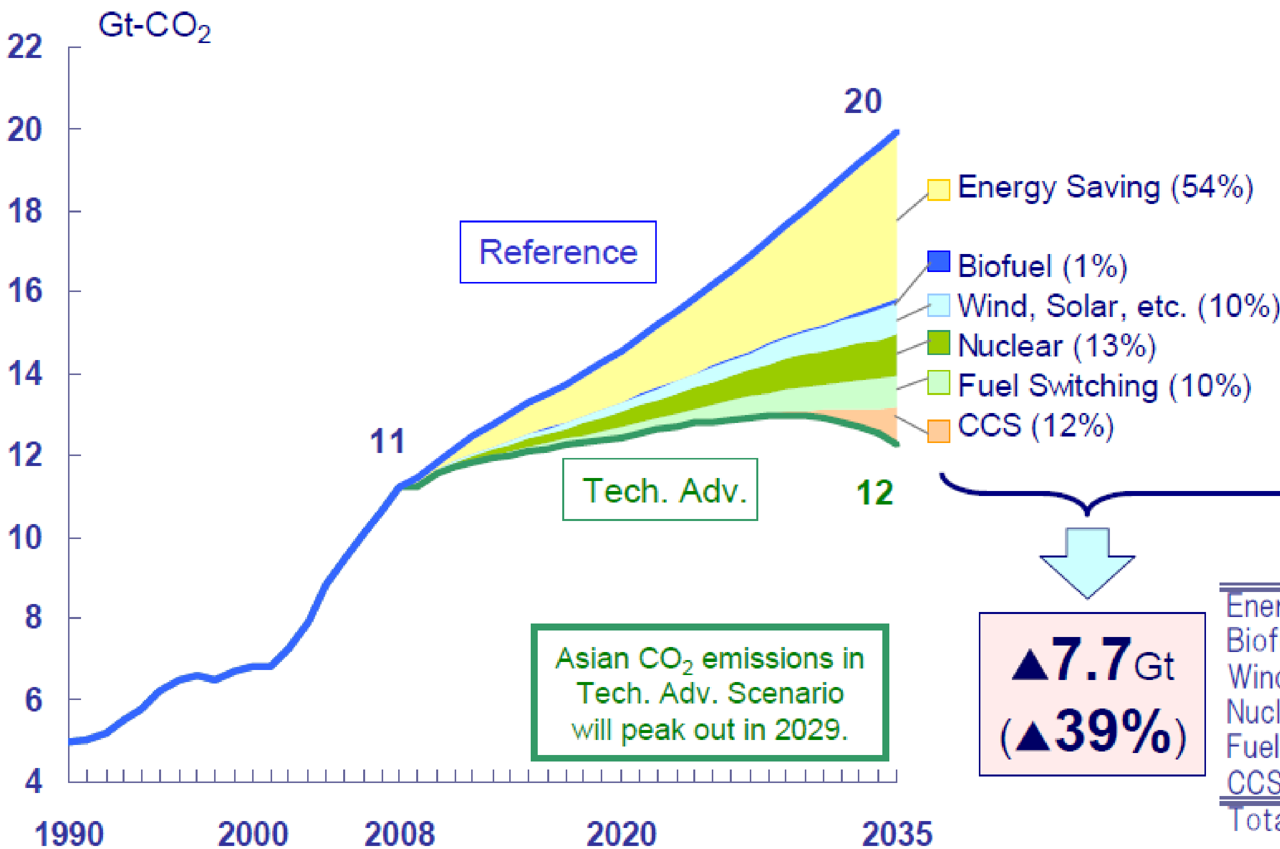
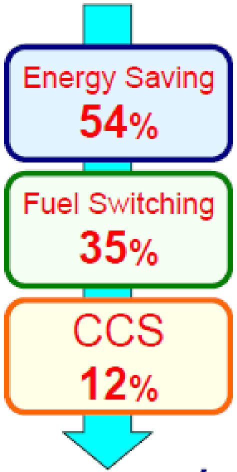


Fig. 1.11 CO_2 emissions of fossil fuels in respect to their calorific value

CO_2 Emissions Reduction by Technology (Asia)

Reference
Tech. Adv.





▲7.7Gt
(▲39%)

	Gt	
Energy Saving	4	54%
Biofuel	0	1%
Wind, PV, etc.	1	10%
Nuclear	1	13%
Fuel switching	1	10%
CCS	1	12%
Total	8	100%

- Aggressive development and deployment of advanced technologies in Asia enables to considerably reduce CO_2 emissions and realize its peak-out by 2030.

UK Government policy on CCS

Matthew Billson
Co-Programme Director, Energy2050
University of Sheffield
m.billson@sheffield.ac.uk
0114 215 7202

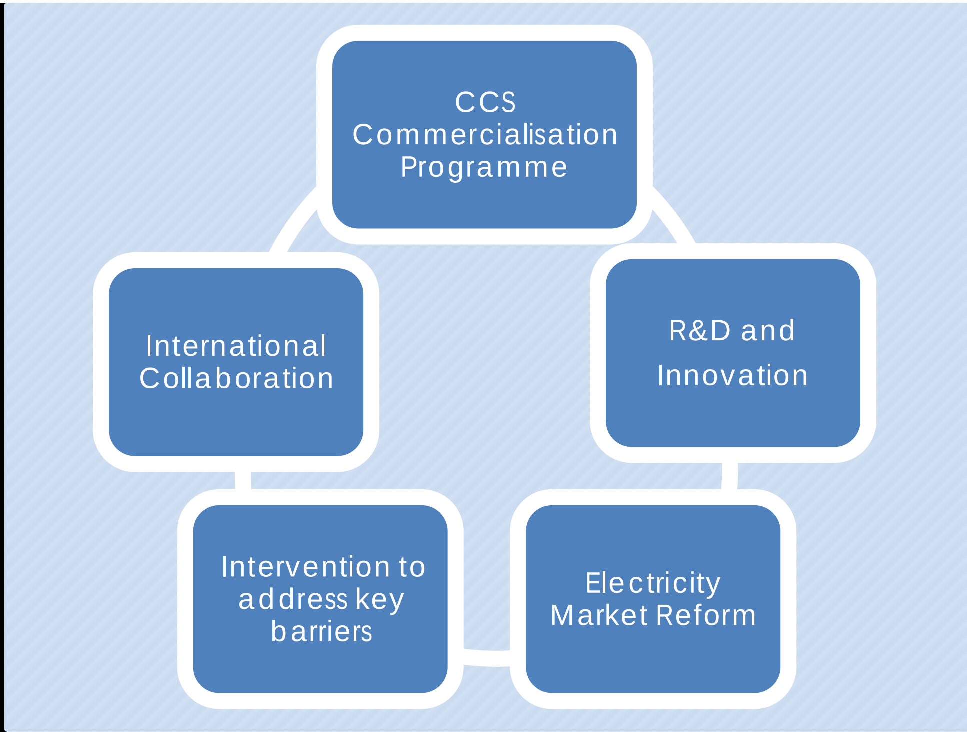
[July 2010 – Dec 2014]
Head of Strategy & International
Office of CCS
Department of Energy & Climate Change (DECC)

Challenges

- Current reliance on coal+gas power stations (c65% of electricity)
- 80% CO_2 reduction target by 2050
- c20% of power stations closing in next 10 years
- Cost of investment:
  - Wholesale electricity: £30 - £40 MW/hr
  - Nuclear: £92 MW/hr
  - Offshore wind: £150 MW/hr
  - [CCS: £160 MW/hr predicted – no comment from DECC]
  - Marine: £305 MW/hr
- Cost of inaction: Without CCS, low carbon energy system will cost extra £30billion in 2050

2012 CCS Roadmap

- CCS Commercialisation Programme
  - £100m FEED
  - c£900m construction + £Xm pa
- Electricity Market Reform
- R&D
  - £125m 2011-2015
- Enabling Actions
- International Collaboration



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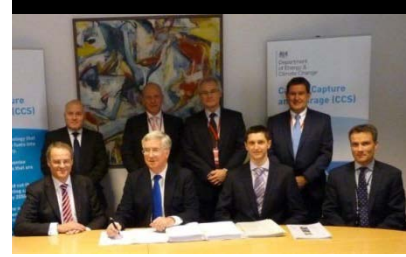
UKCCSRC PACT FACILITIES

Commercialisation Programme

Progress

- FEED Contracts signed:
  - ✓ **White Rose** December 2013
  - ✓ **Peterhead** February 2014
- £100m investment
- Final Investment Decision Late 2015 / Early 2016?



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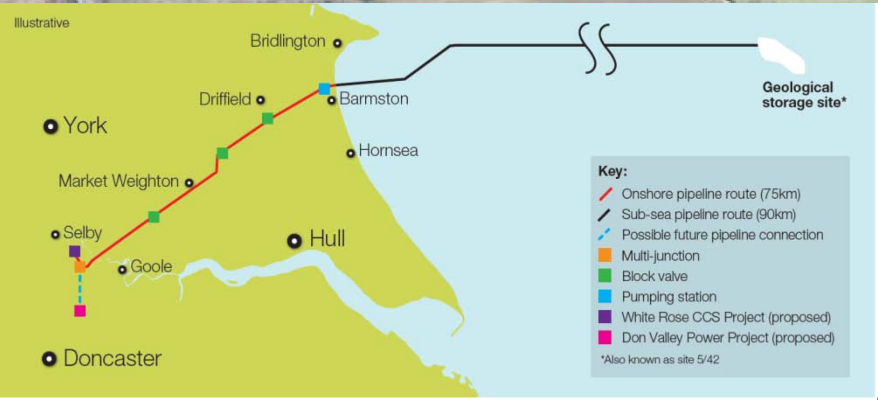
UKCCSRC PACT FACILITIES



WHITE ROSE CARBON CAPTURE & STORAGE PROJECT

ALSTOM

Drax

BOC A Member of The Linde Group

nationalgrid

White Rose

- New ultra-supercritical 426MWe (gross) Oxy-Power plant at Drax Site, Yorkshire
- Enough low carbon electricity to power the equivalent of 630,000 homes
- 100% of flue-gas treated with 90% CO_2 capture rate. Estimated 2 million tonnes CO_2/year captured
- Potential biomass co-firing leading to zero (or negative) CO_2 emissions
- Anchor project for National Grid's regional CO_2 transport & offshore storage network
- CO_2 storage in a deep saline formation off-shore beneath the North Sea

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UKCCSRC PACT FACILITIES

• Peterhead

- World's first full scale gas CCS project
- A 340MW post-combustion capture retrofitted to part of an existing CCGT power station at Peterhead, Scotland
- Enough low carbon electricity to power the equivalent of 500,000 homes
- 85% CO_2 capture rate. Estimated 1 million tonnes CO_2/year captured
- Reuse of North Sea infrastructure - linking into the existing offshore pipeline from St Fergus to the store
- Storage in the depleted Goldeneye reservoir

EU 2030 Climate and Energy Package

October 2014

- EU target of 40% reduction of **greenhouse gas emissions** by 2030
- 27% renewable energy and energy efficiency targets at EU level
- reform of ETS to support all low carbon technologies
- CCS as part of the mix – funded through NER400

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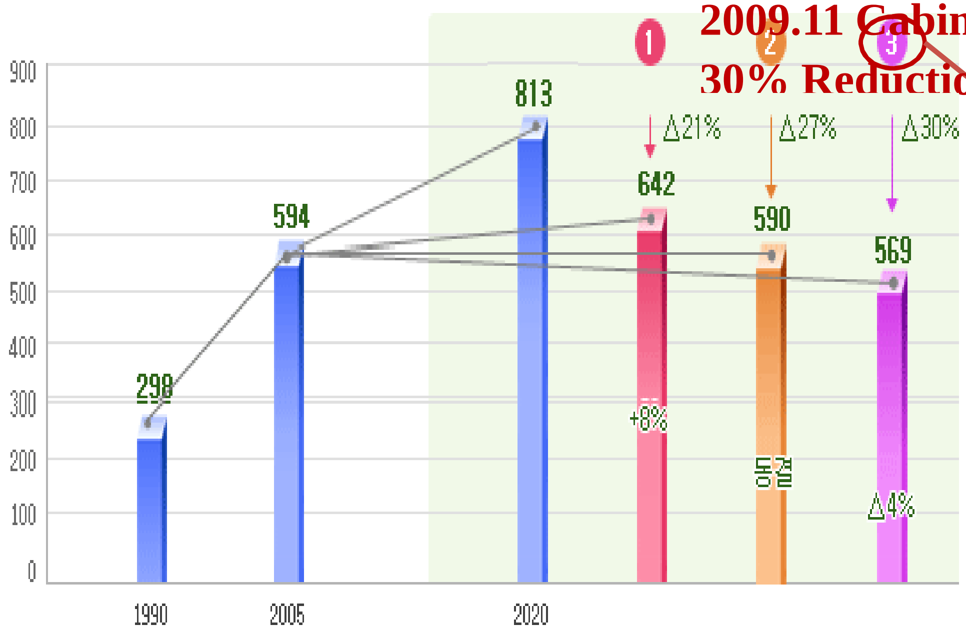
UKCCSRC PACT FACILITIES

Korean National Plan for Reduction of CO2 Emission

- **South Korea : 8th Most GHG Emitting Country (2009)**
- **Emission Reduction Target :**
  BAU 30% Reduction of CO_2 Emission by 2020 (Nov. 2009)

Expected (BAU)

2009.11 Cabinet Meeting: (BAU 30% Reduction)



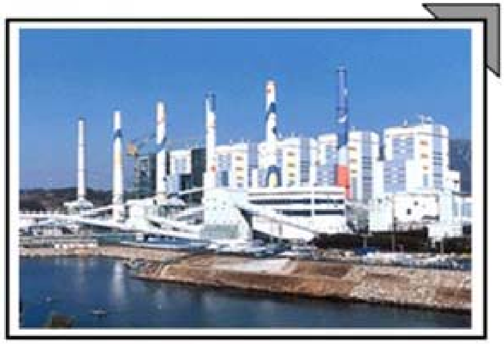
Major Carbon Gas Emission Sources in Korea

Cement

40 million tons/yr

Iron & Steelmaking

POSCO Kwangyang
3.2 million tons/yr



S

Power Plants

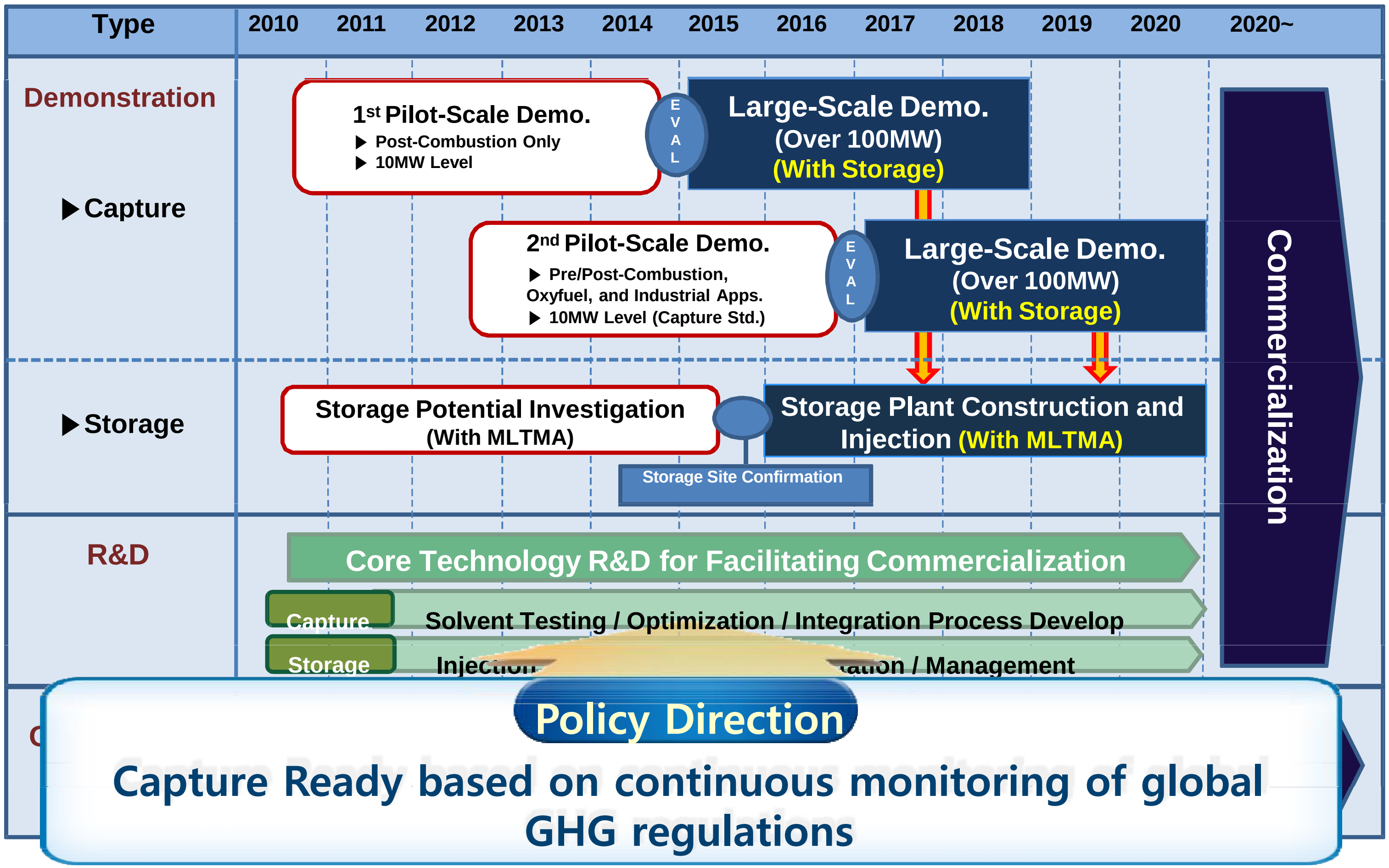
KCC **KEPCO 158 million tons/yr**

Petrochemical

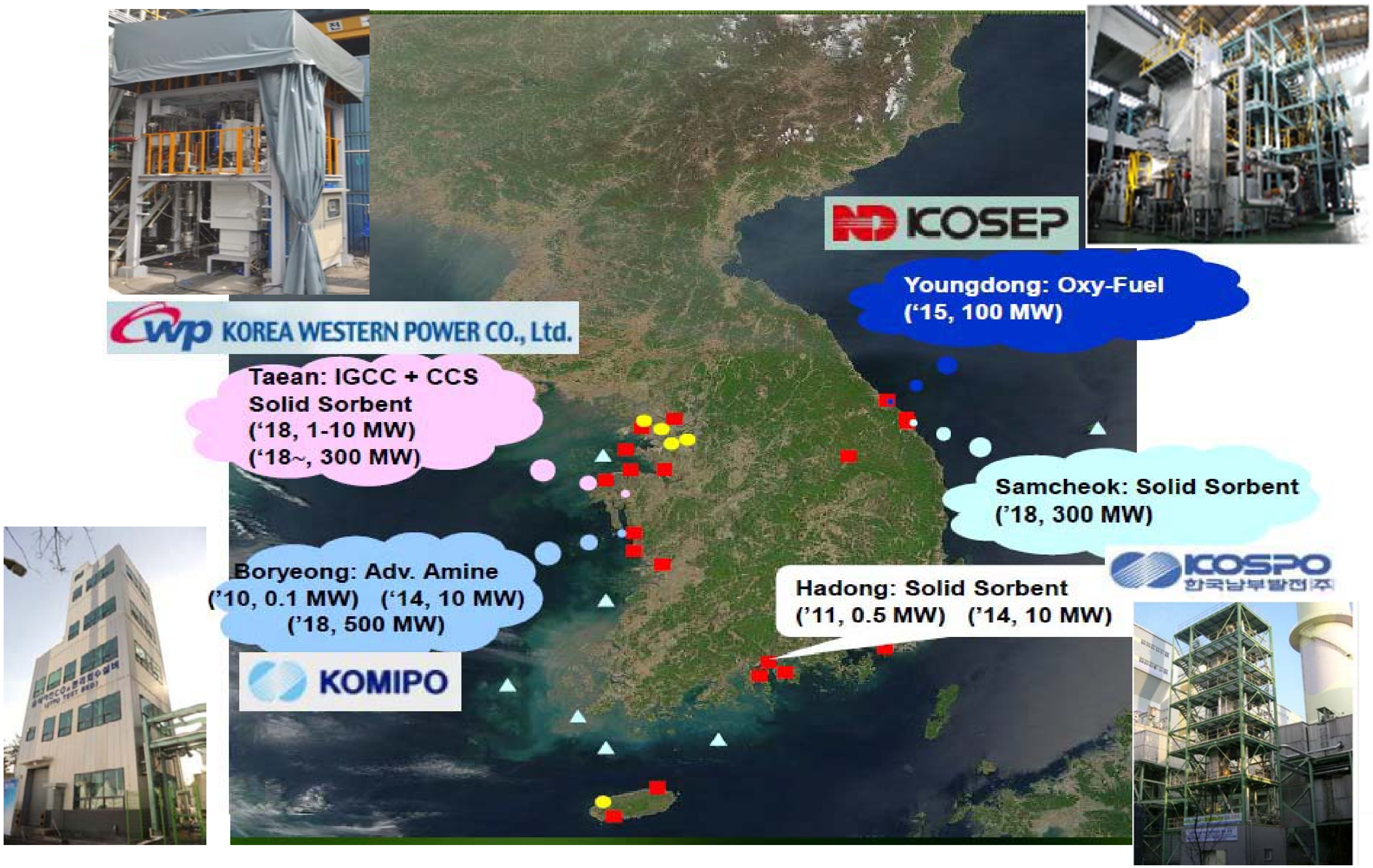
40 million tons/yr

Korean National Roadmap for CCS

(2009)



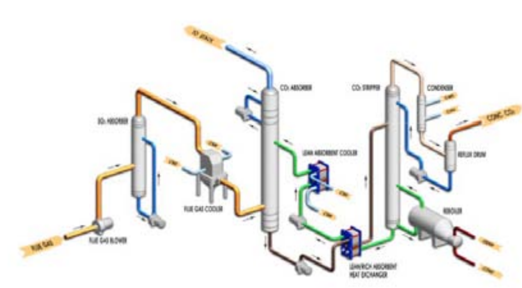
Demo Sites of CO_2 Capture Plants



Ongoing CCS Projects in Korea

- **Advanced Amine Solvent : KoSol (Korea Solvent)**
  - **0.1MW Test Bed Constructed (2010. 12) → 10MW Pilot Plant (2014)**

    → 100~300MW Demonstration Plant (2018)



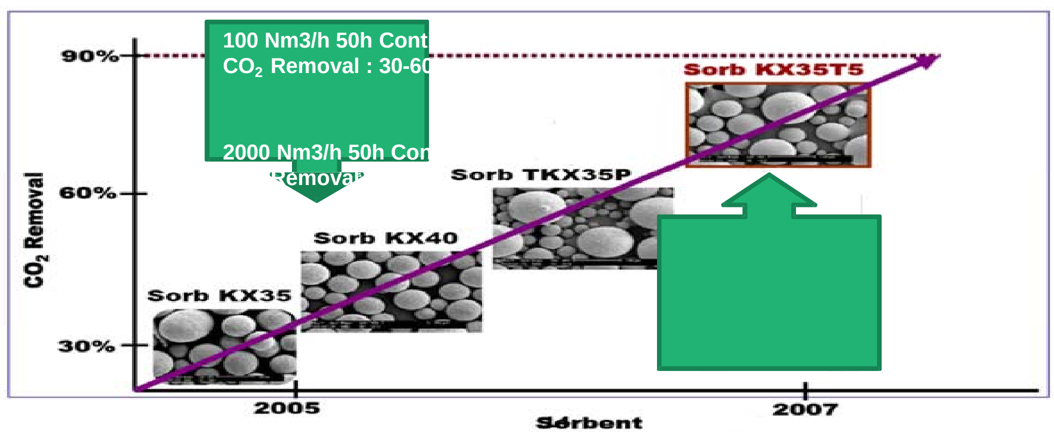
Ongoing CCS Projects in Korea

- **Dry Re-generable Solvent**
  - **0.5MW Test Bed Constructed (2010. 3)**

    → 10MW Pilot Plant (2014)

    → 100~300MW Demonstration Plant (2018)

2005	2006	2007	2010.3
•Improvement of CO_2 removal % (above 65%)	•Improvement of regeneration *Removal > 80%, *Regeneration>90%	•Basic Process Design for 2000Nm3/h	• 0.5MW Demonstration



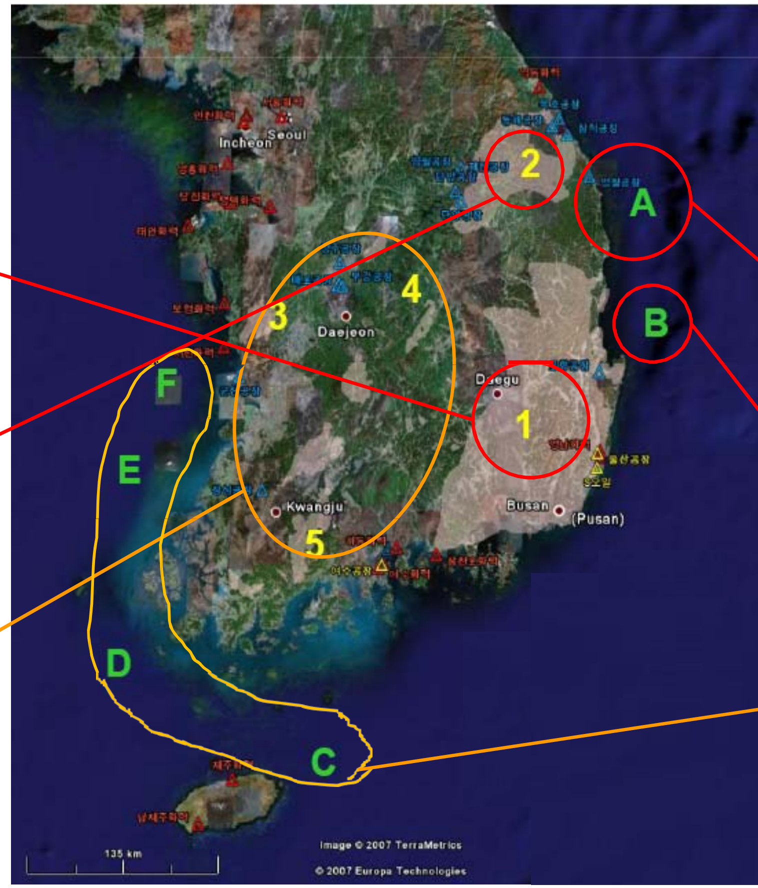
Potential CO_2 Storage Sites in Korea

Underground Storage
(1.8 billion ton estimated)

Kyoungsang Basin 680 million ton
Priority Rank 1

Taebaek Basin 180 million ton
Priority Rank 2

3: Chungnam Basin
4: Moonkyung Basin
5: Honam Basin
Priority Rank 3



Undersea Storage
(Expected to have great storage potential)

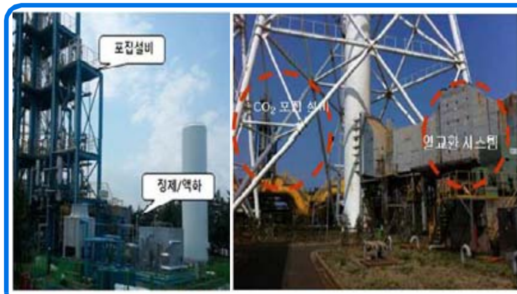
Ulleung Basin (Dolgorae Gas field)
Priority Rank 1

Pohang Basin
Priority Rank 2

C: Chuju Basin D: Haenam Basin E: Kyukpo Basin F: Koonsan Basin
Priority Rank 3

Industrial Applications of CCS

- **As alternatives for storage,**



CO2 capture in Steel industry (POSCO)

[27 million(USD), 2009~2014]

- Capture CO_2 from blast furnace using ammonia liquid (10 ton/day, 0.5MW equiv)
- Purification/liquefaction process integrated with capture facility
- Production of liquid CO_2 using the capture facility (3 ton/day)

CO2 conversion using microalgae (Korea District Heating Co.)

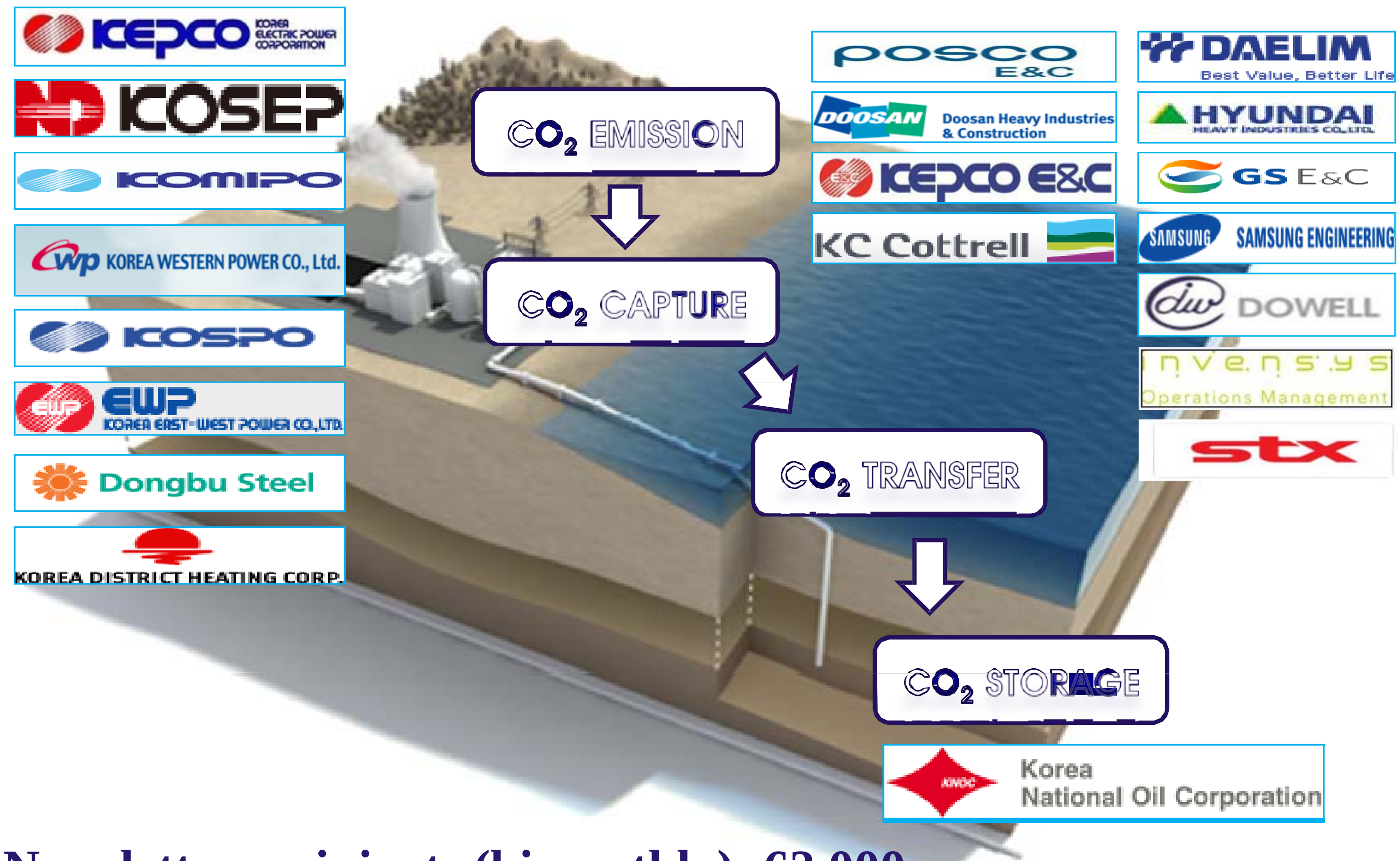
[11 million(USD), 2012~2017]

-CO_2 fixation through microalgae photosynthesis
-Conversion of CO_2 into high value-added products (astaxanthin)
process (1 ton
)

Green Polymer (SK)

-Convert CO_2 into polymerized compound and produce plastic
-Aims for commercialization in 2014

Members of KCCSA:
All Major Players in Korea



*** Newsletter recipients (bimonthly): 62,000**

Active Participation in International CCS Networks

*IEA-GHG: International Energy Agency GreenHouse Gas R&D Program
*CSLF: Carbon Sequestration Leadership Forum
*CO2CRC: CO2 Cooperative Research Center
*CCPP: Climate Change Policy Partnership, Duke University

*GCCSI: Global CCS Institute
*CCSA: Carbon Capture Storage Association
*NETL: National Energy Technology Laboratory
*MIT CSI : MIT Carbon Sequestration Initiative

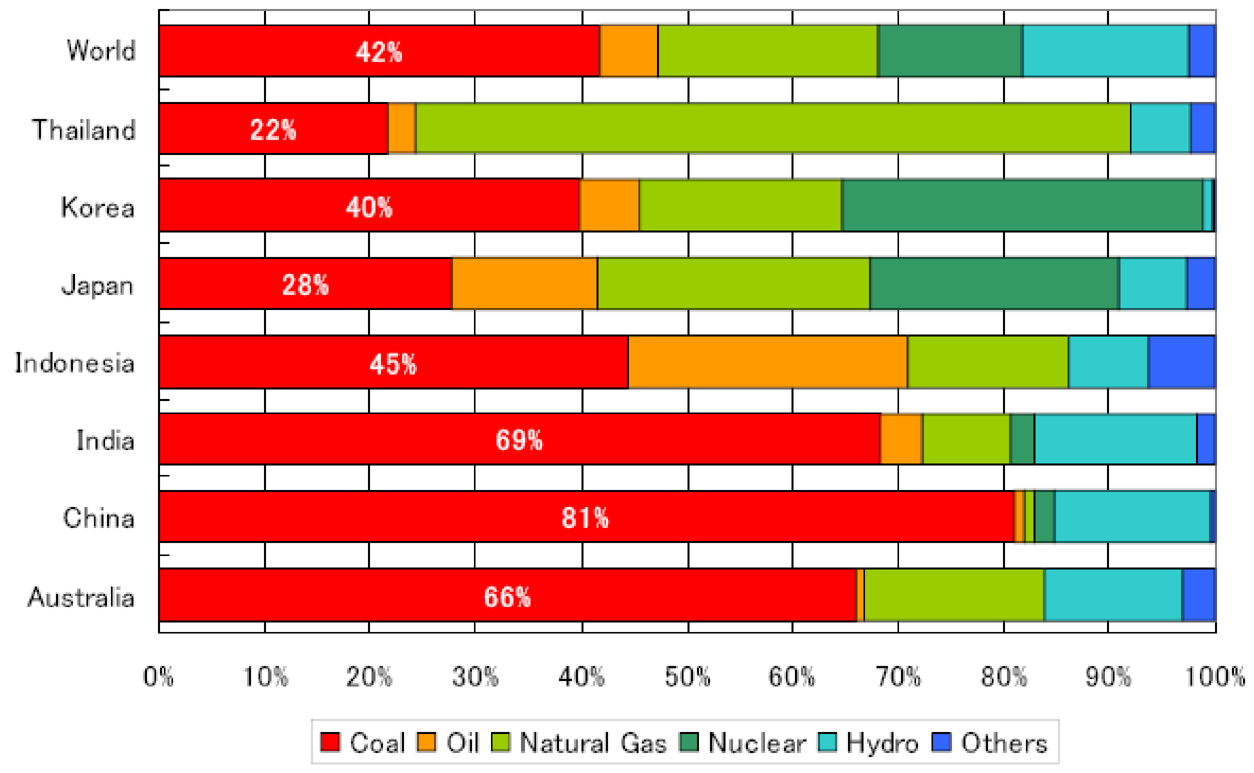
- **CCS will play an important role in CO_2 emission reduction.**
- **Large scale integration projects (LSIP) may be postponed until international regulation on CO_2 emission is to be effective.**
- **Capture-Ready may be required for new power plants in the future.**
- **Korea will keep investing in CCUS R&D.**
- **Korea needs international collaboration in CCS in general, and Storage in particular.**

End of Chapter 1

Share of coal in power generation

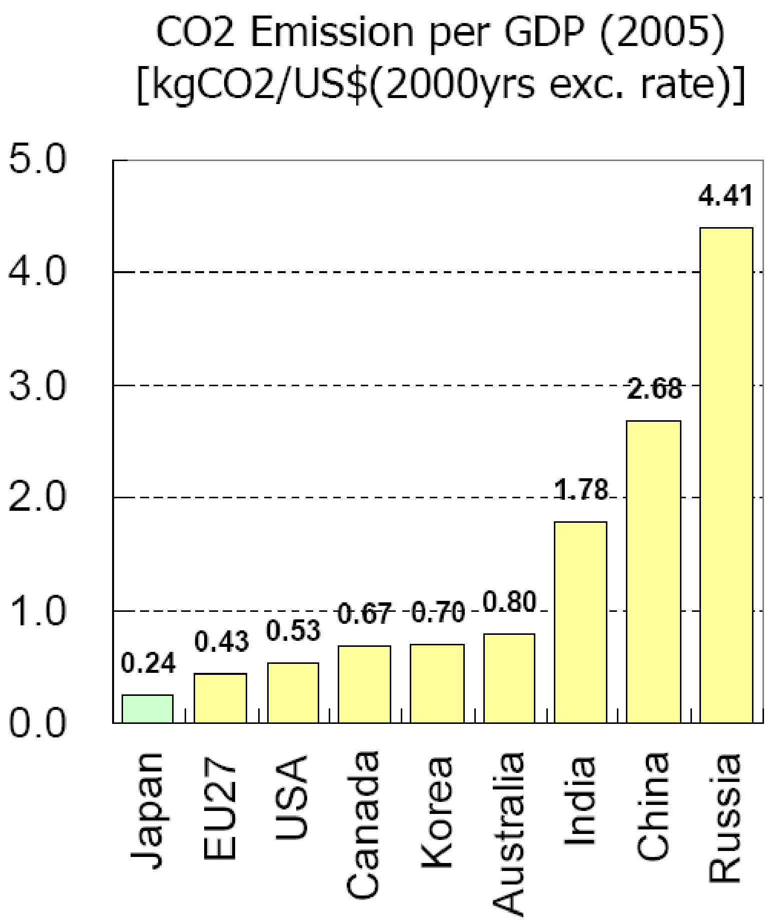
- Coal is one of a major resource for power generation.

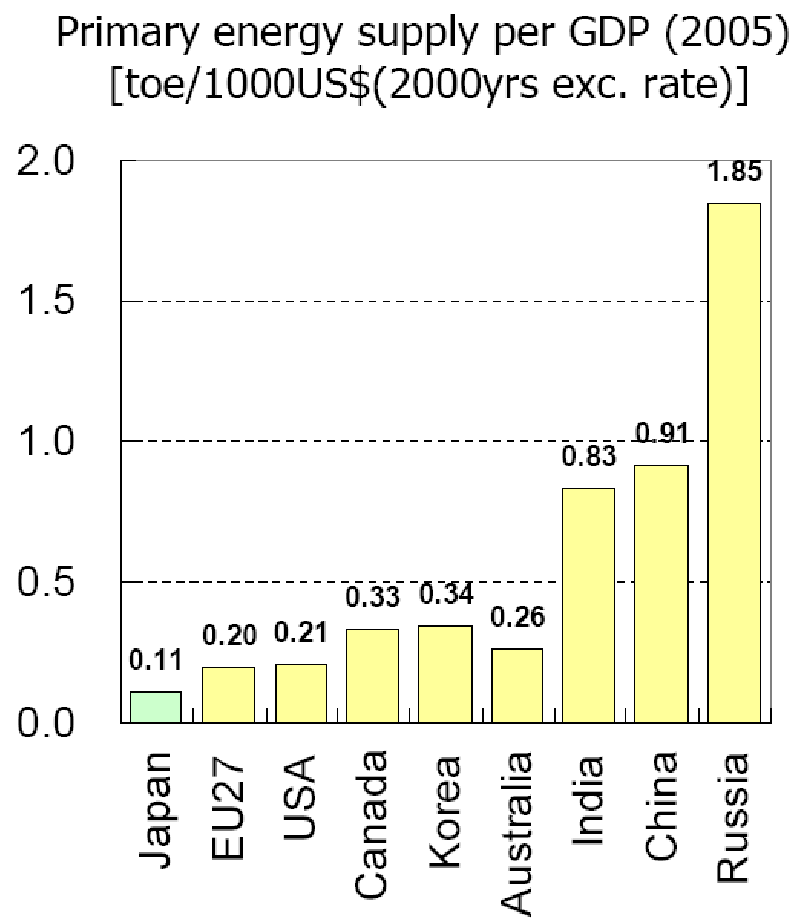
Share of Coal in Power Generation (2007)



source) IEEJ, Asia/World Energy Outlook, Oct 2009
* Australia is sum of Australia and New Zealand

Low carbon economy in the world



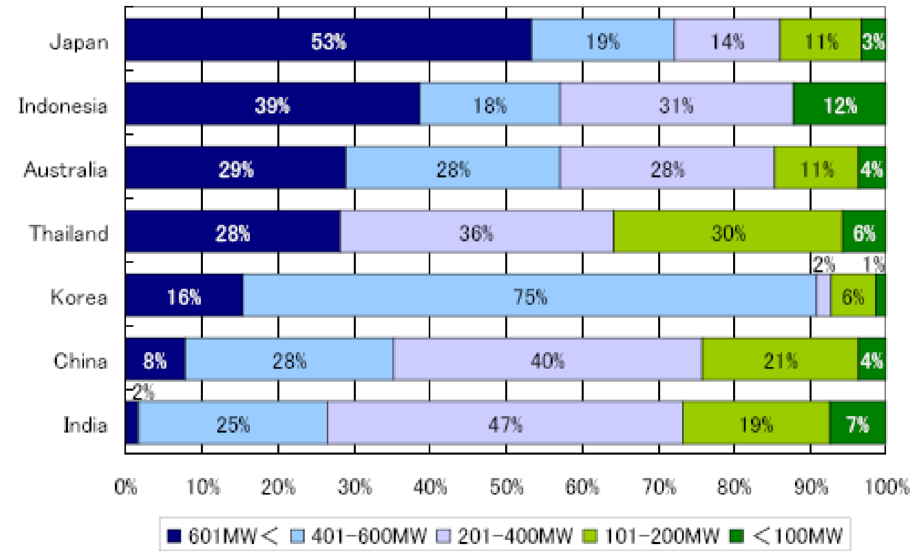


Source: IEA(2007),"CO2 emission from fuel combustion 1971-2005

Capacity and steam condition

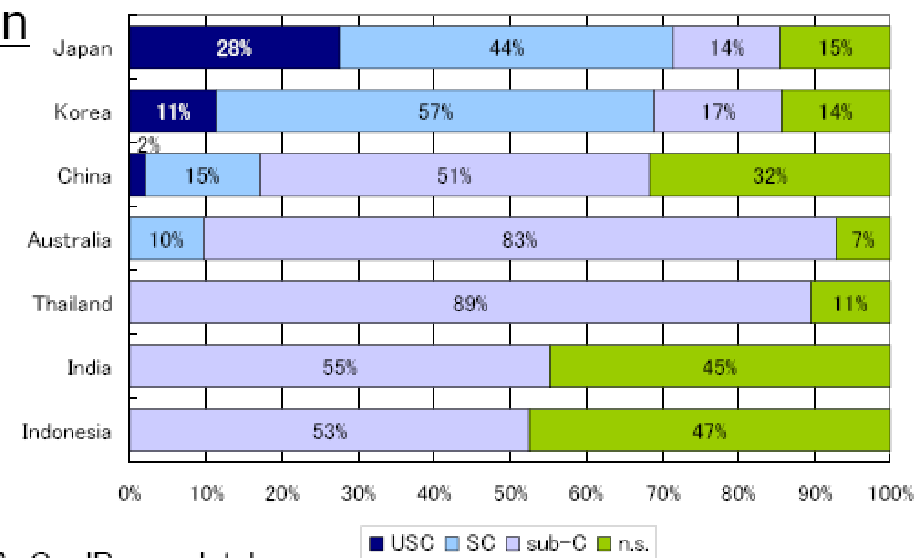
Coal Power Plant by Capacity

- In many countries, majority is 201-600MW plant.
- While in Japan and Indonesia, the share of above 600MW capacity is relatively high.



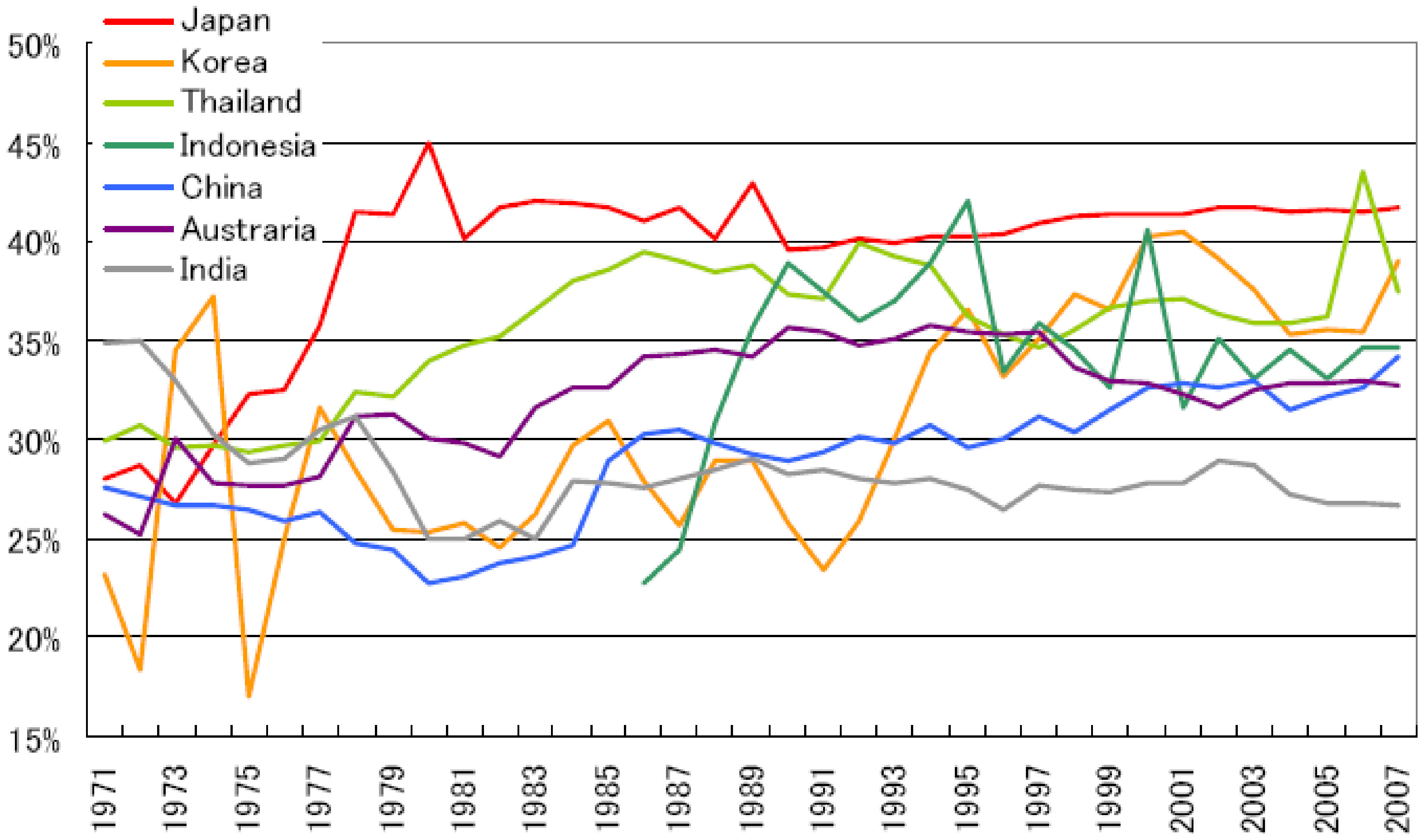
Coal Power Plant by Steam Condition

- In many countries, majority is sub-critical plant.
- While in Japan and Korea, Ultra-Super Critical and Super Critical plant has a dominant share.



source) IEA, CoalPower database

Efficiency of coal-fired power plant

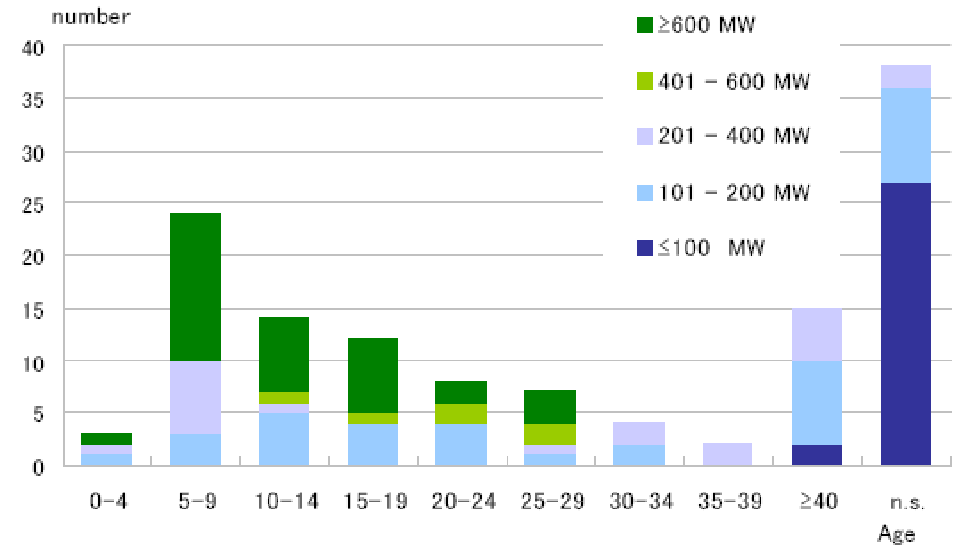


source) IEA, Energy Balance 2009

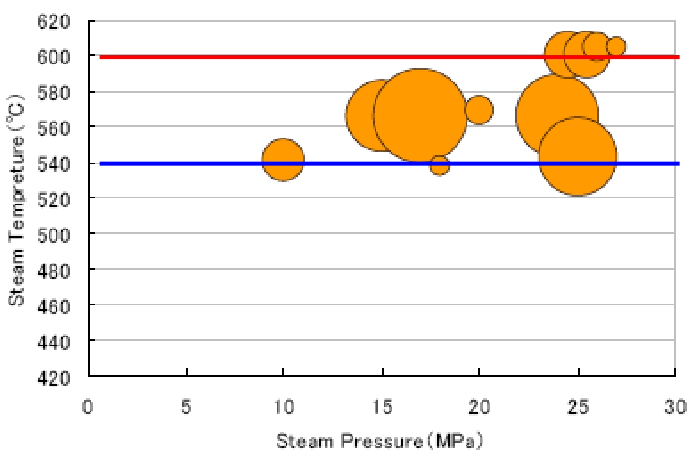
Coal Power Plant in Japan

- Capacity above 600MW had been increase.
- Efficiency stayed at level since early 1980's.
- High pressure and temperature steam condition is largely used.

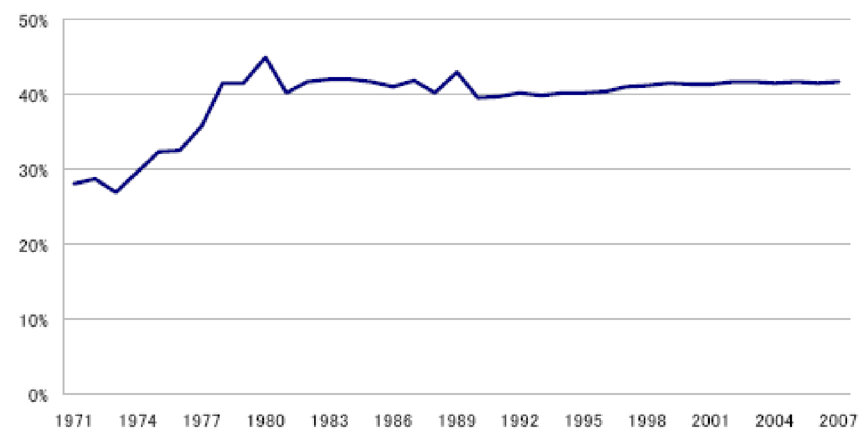
Number of Coal Power Plant by Age, by Capacity



Steam Condition



Generating Efficiency of Coal Power Plant

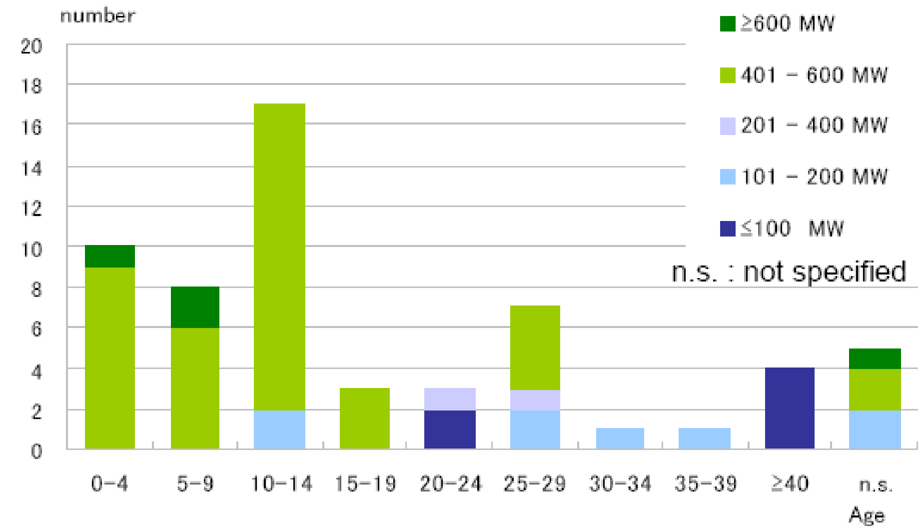


source) IEA, CoalPower database, Energy Balance

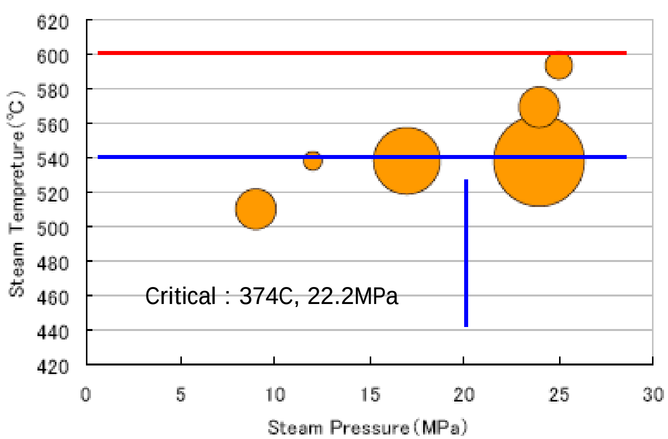
Coal Power Plant in Korea

- Majority of plants are new and large scale.
- Efficiency is fluctuating but gradually rising.
- Steam condition is relatively high.

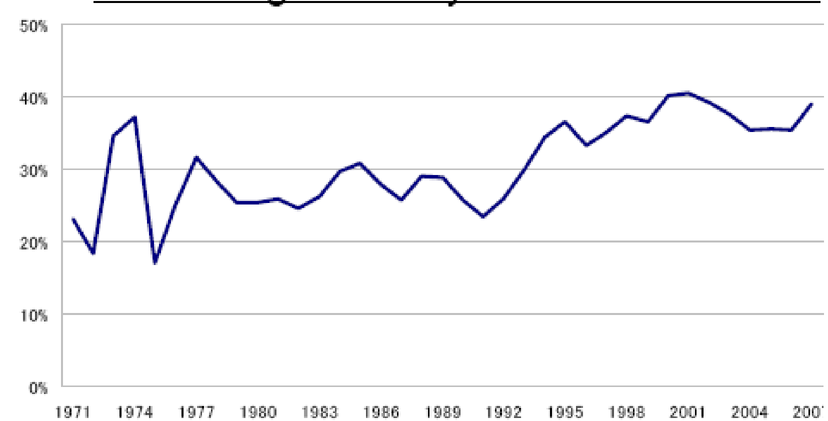
Number of Coal Power Plant by Age, by Capacity



Steam Condition



Generating Efficiency of Coal Power Plant



source) IEA, CoalPower database, Energy Balance

CO_2 emission reduction potential by improving efficiency of Coal-Fired Power Plant

De-carbonization of energy at supply-side

Expanding use of non-fossil energy sources

- Promotion of nuclear power generation based on the premise safety assurance and restoring confidence
- Development and expansion of use of renewable energy sources
  - *Hydroelectric, geothermal, solar, wind, and biomass power generation

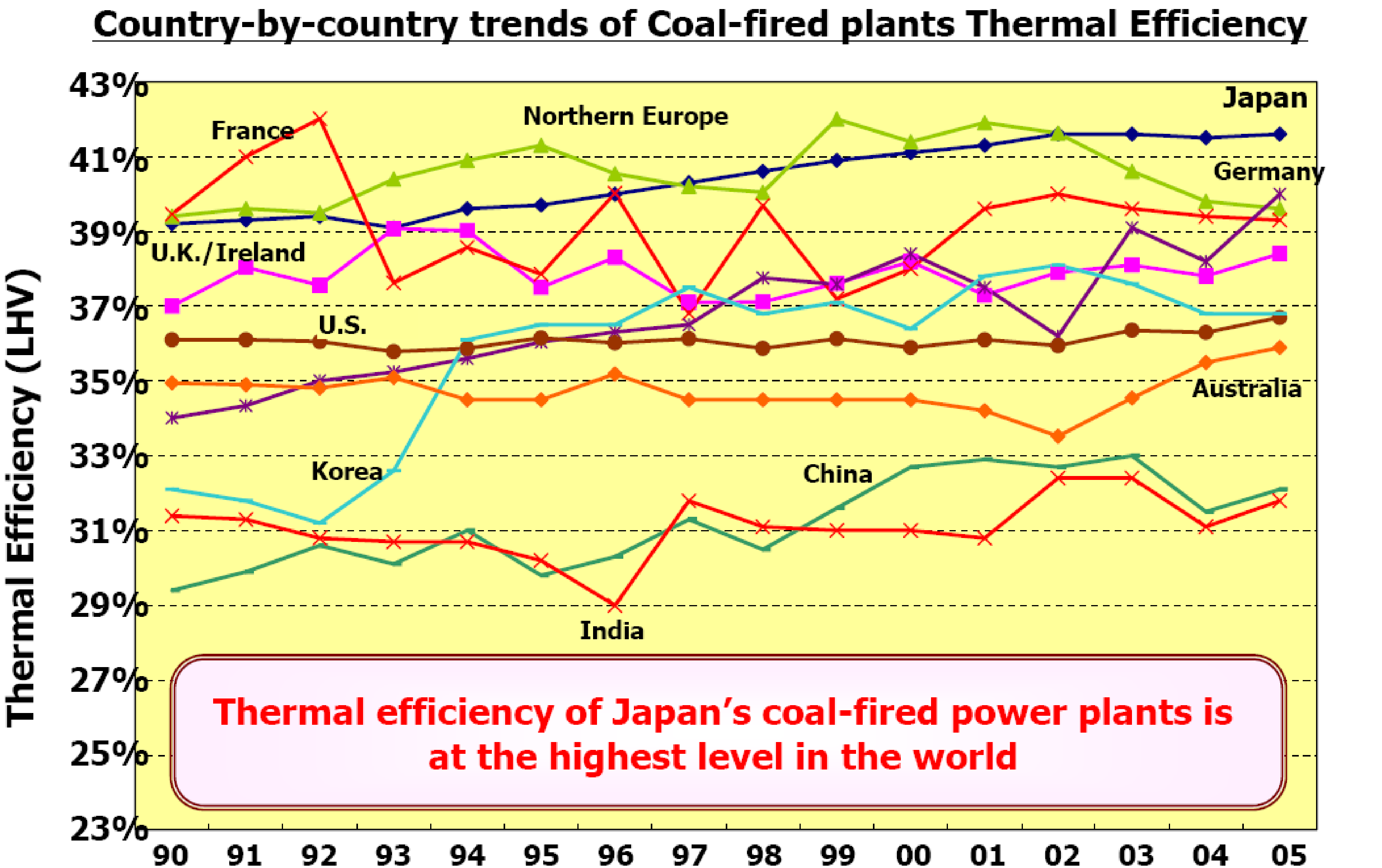
Improving efficiency of electric power equipment

- Further improvement of thermal efficiency of thermal power plants
  - *Introduction of LNG combined-cycle power plant, Clean Cool Technology
- Reduction of transmission and distribution loss
  - *High-voltage transmission, low-loss transformers

International efforts

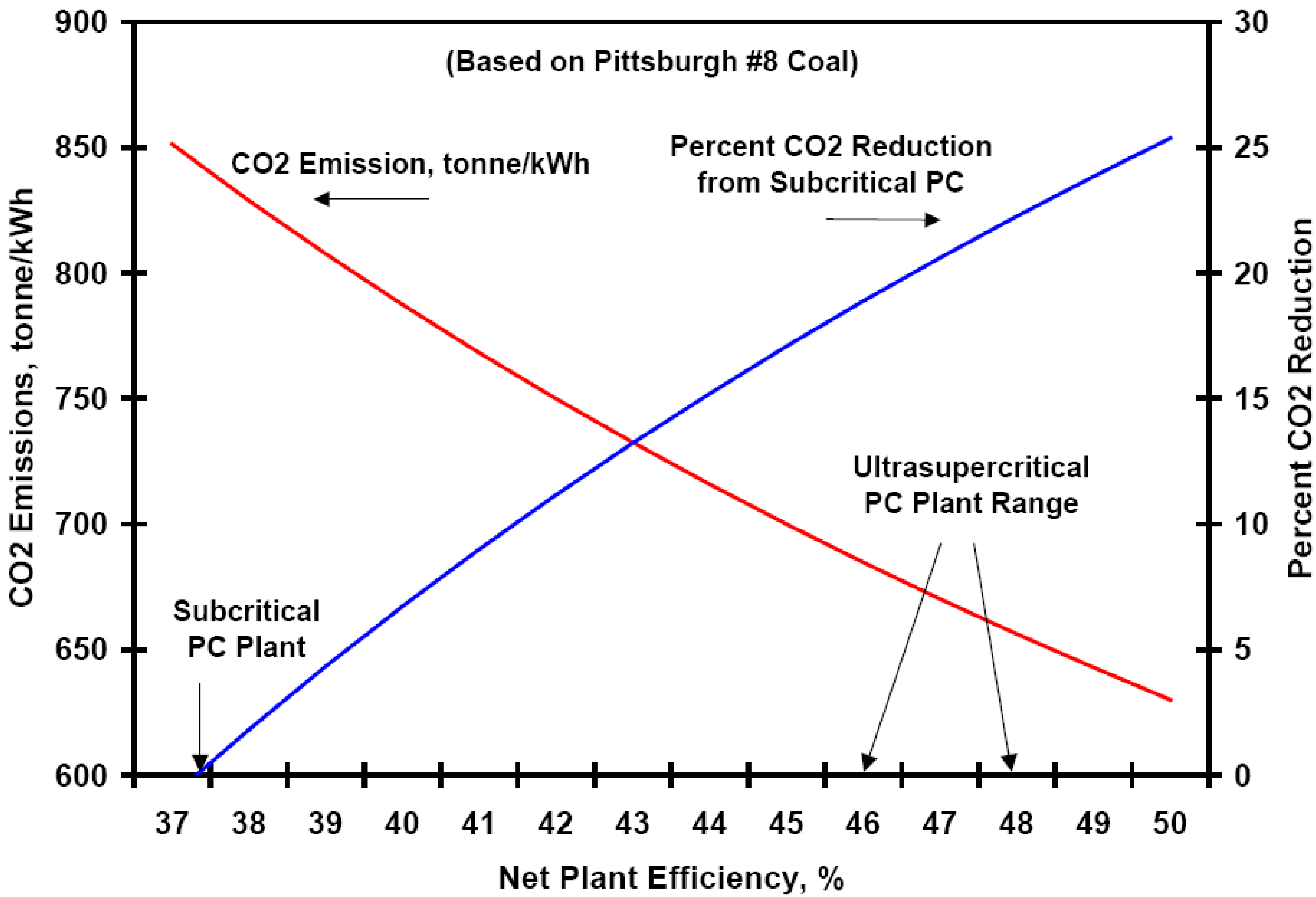
- Active utilization of the Kyoto Mechanisms
  - *Active utilization of the Clean Development Mechanisms & investment in Carbon Funds
- Sectral approaches
  - *Participation in the Asia-Pacific Partnership (APP) (Peer Review Activities, etc)

Further improvement of thermal efficiency of power plants



Source: INTERNATIONAL COMPARISON OF FOSSILE POWER EFFICIENCY AND CO2 INTENSITY(2008) (ECOFYS)

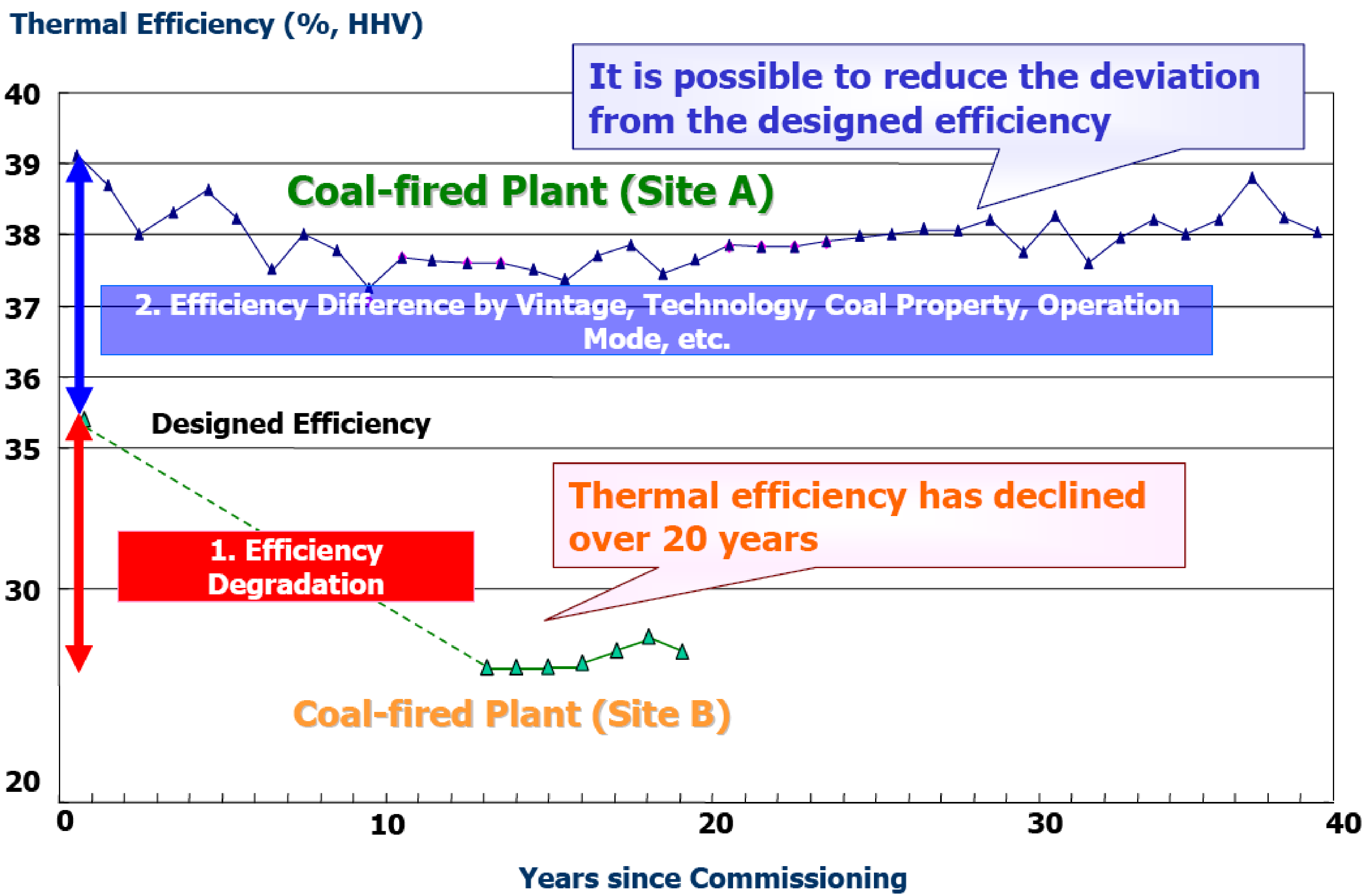
CO2 emission reduction from increasing efficiency



Combustion Technology University Alliance Workshop, August 4, 2003, Columbus, OH

EPRI

Issues of increasing efficiency for existing power plants



Issues of increasing efficiency for existing power plants

연구 과제명	**500MW급 표준석탄화력 출력증강 및 효율향상 기술 개발**
연구목표	노후 발전설비의 성능개선을 위한 최적화 기술개발 및 실증 검증
연구내용	1. 노후발전설비의 성능개선을 위한 시스템 최적화 기술 2. 터빈발전기 출력증강 및 효율향상 기술개발 3. 보일러 열용량 및 성능향상 기술개발
연구예산	총 480억(정부지원 : 240억, 기업부담 :240억)

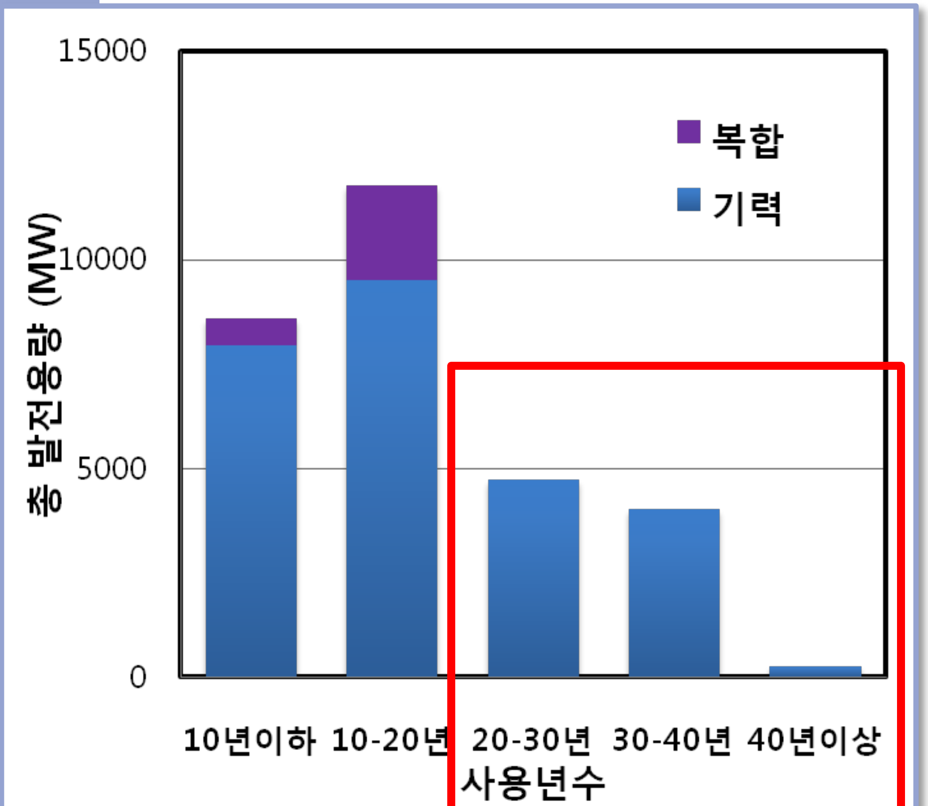
Issues for existing power plants – domestic status

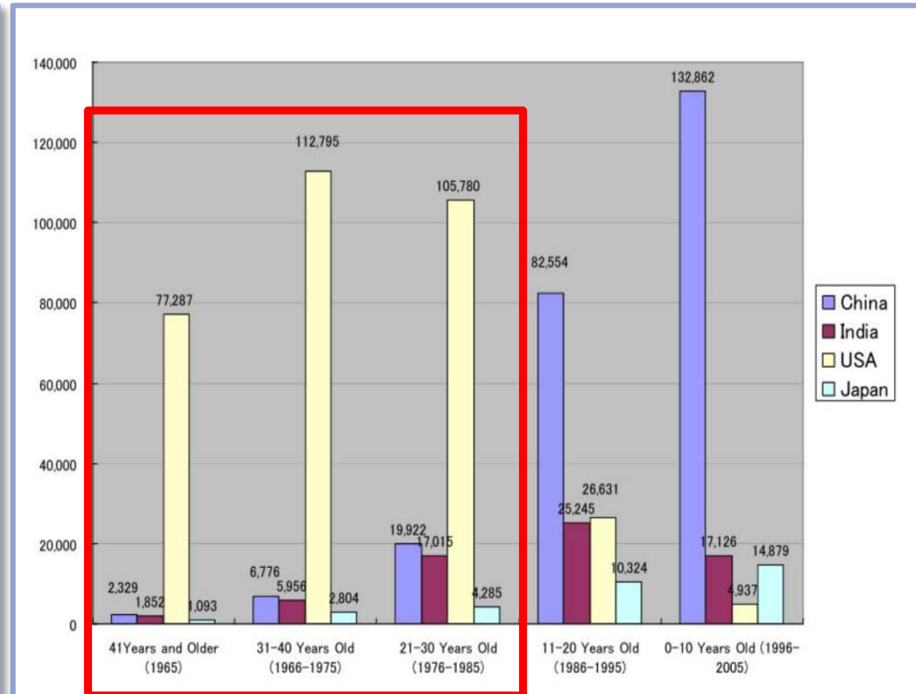
◆ **국내 93기 화력발전설비 중 31기가 25년 이상 운전되어 설계 수명 도래**

✓ 수명연장 및 설비 개선의 필요성 대두

◆ **세계적으로 30년 이상 설비: 500 GW (20%)**

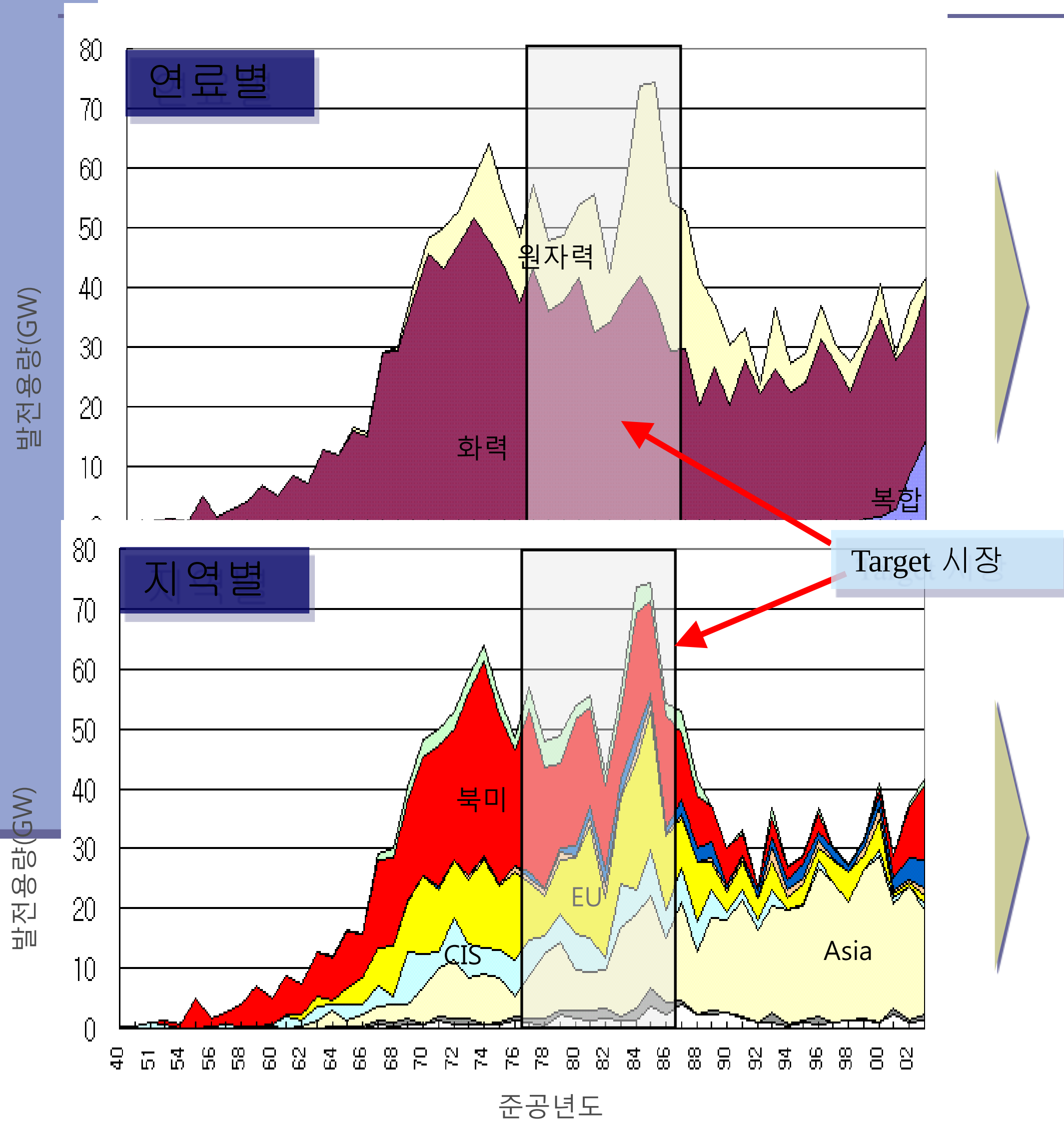
✓ 대부분은 북미/EU에 집중되어 있으나 향후 아시아권의 설비 급속한 노후화 예상





Sources: **Pradeep J. Tharakan, USAID-ECO-Asia Clean Development and Climate Program,** ASEAN Energy Business Forum (AEBF) 22nd -24th Aug.,2007 and Coal Note 2005/2006

Issues of increasing efficiency for existing power plants



* 출력 200MW 이상, 운전년수 21~30년 사이의 발전소
* Source : World Energy Outlook 2004, UDI Report 2004

- 노후설비의 급격한 증대로 수명연장 또는 설비개선의 필요성 대두
- CO_2 배출량의 규제 등으로 기존설비의 효율개선 요구 증가
- 지속성장을 위한 안정적인 전력공급을 위해 출력 증강 필요

성능개선 시장은 연평균 3.3%성장 예상

- 인도, 동남아, 중국, 이스라엘, 호주 등 신흥 경제국가 발전설비 급증
- 향후 수명연장 및 성능개선 시장 급증 예상되나 현재 시장은 선진 OEM 사 독점

노후설비 성능개선의 기반구축 필요

Issues for existing power plants – international status

Year	OEM	Modification Package	RPM	MW	Performance Improvement (MW or % Efficiency)
1992	Mitsubishi	40 inch LP blade package; stators only	Unspecified		Unspecified
1992	Toshiba	40 inch LP L-0 titanium blade and hollow stator	3600	700	1.2%[a]
1993	Toshiba	40 inch LP L-0 titanium blade, leaned stators	3600	700	1.6%[a]
1993	ABB	LP section replacement	1800	950	12.17 MW[d]
1993	Westinghouse	47 inch LP package; stators, blades, seals, diffuser	1800	1155	13.7 – 15.5 MW[e]
1994	Mitsubishi	40 inch LP L-0 titanium blades, I-shroud reaction	3000	700	1.5%[b]
1994	ABB	LP steam path and diffuser package	Unspecified		Unspecified
1994	ABB	46 inch LP L-0 blade-stator replacement	1800	1040	17 MW[f]
1995	GEC	57 inch Next generation nuclear turbine	1500	1500	2%[g]
1996	General Electric	38 inch LP rotor replacement; nozzle & buckets	1800	540	14 MW[h]
1996	ABB	31 inch LP steam path and diffuser package	3600	855	1.8 – 2.1%[i]
1996	SPC	32 inch LP steam path with added blade row	3600	306	2.4 – 2.7%[j]
1996	Westinghouse	LP section replacement	3000	1300	42 MW[k]
2001	Skoda	Moisture extraction through L-0 stationary blades	3000	950	Not measured yet

3) NanChang Power Plant (China) Capacity (MCR)= 125 MW Date Refurbished: Year 2004(AH); 2006 (Burners) Units No. 10 & 11	*Air Heater*	Each Unit: $ 214,286 or RMB 500,000	Leak reduction from 28% to 12%	assume efficiency gain of 5% based on Hangzhou Banshan Case
	Boiler Burner	Each Unit: $51,429 or RMB 360,000	Boiler Efficiency increased by 2%	This case is good candidate for study
	Boiler Soot-blowers	Each Unit: $85,714 or RMB 600,000		
	Induced Draft Fan	Each Unit: $ 85,714 or RMB 600,000		
	Condenser	Each Unit: $171,429 or RMB 1,200,000	Turbine Heat Rate has improved by 0.37 kJ/kWh (0.35 BTU/kWh)	This case is good candidate for study
	Steam Turbine	Unit No. 11 $2,857,143 or RMB 20,000,000	Turbine Heat Rate has improved by 777.89 kJ/kWh (737.3 BTU/kWh)	This case is good candidate for study
	Instrumentation and Control	$285,714 or RMB 2,000,000 (each unit)	No specific claim of monetary improvement	The improved control must have contributed to improved heat rate of the unit
	Addition: **New FGD to each unit** (added on May 2007)	$3,571,429 or RMB 25,000,000 (total both units)	Mitigated emission pollution	This effort is to mitigate pollution which is necessary in permitting regulations

- 현재 기술의 경우 개별 기기의 성능개선에 초점
- 시스템적인 측면에서의 성능개선 기술이 매우 중요하나 부족
- 국내 시스템 해석 및 운영 기술 적용 시 노후 설비 성능개선 시장 경쟁력 확보 가능

Issues of increasing efficiency for existing power plants - Japan

*Source : Cleaner Coal Workshop in Ha Long, Vietnam (August 19, 2008)

1. Model Plant to be Retrofitted

- Super Critical Single Reheat
- Net Plant Output : 500 MW
- Main Steam Pressure : 24.1 MPa
- Main Steam Temperature : 538 deg-C
- Reheat Steam Temperature : 538 deg-C

2. Conclusions

- A-USC Technology :
  - Suitable for retrofitting old supercritical plants
  - Economical and environmentally-friendly
  - Thermal efficiency reduces CO_2 : 15~20%
  - Development of New Ni-base alloys
- Technology available by 2016.

Feasibility Study of Retrofitting with A-USC Technology Project Participants

NIMS
IHI
MITSUBISHI HEAVY INDUSTRIES, LTD.
Fuji Electric Systems
SUMITOMO METALS
HITACHI Inspire the Next
TOSHIBA Leading Innovation
Babcock-Hitachi K.K.

- 재료기술을 기반으로 한 USC 기술 적용
- **국내 적용 시 타당성 의문: 외국 재료 사용으로 인해 경제성 저하 및 경쟁력 확보 불투명**
- **국내 기 확보된 경쟁력있는 기술을 토대로 성능개선 기술 확보 필요**

Issues of increasing efficiency for existing power plants

노후 발전설비의 성능개선을 위한 최적화 기술개발 및 실증 검증

- 표준석탄화력 설계용량 대비 출력**10%**이상 증대 **(500MW→550MW)**
- 플랜트 효율 **2%** 증대 **[40% → 42%]**
- 이산화탄소**(CO_2)** 배출량 **5%**이상 저감

1 단계

성능개선 표준설계 및 핵심기술 개발

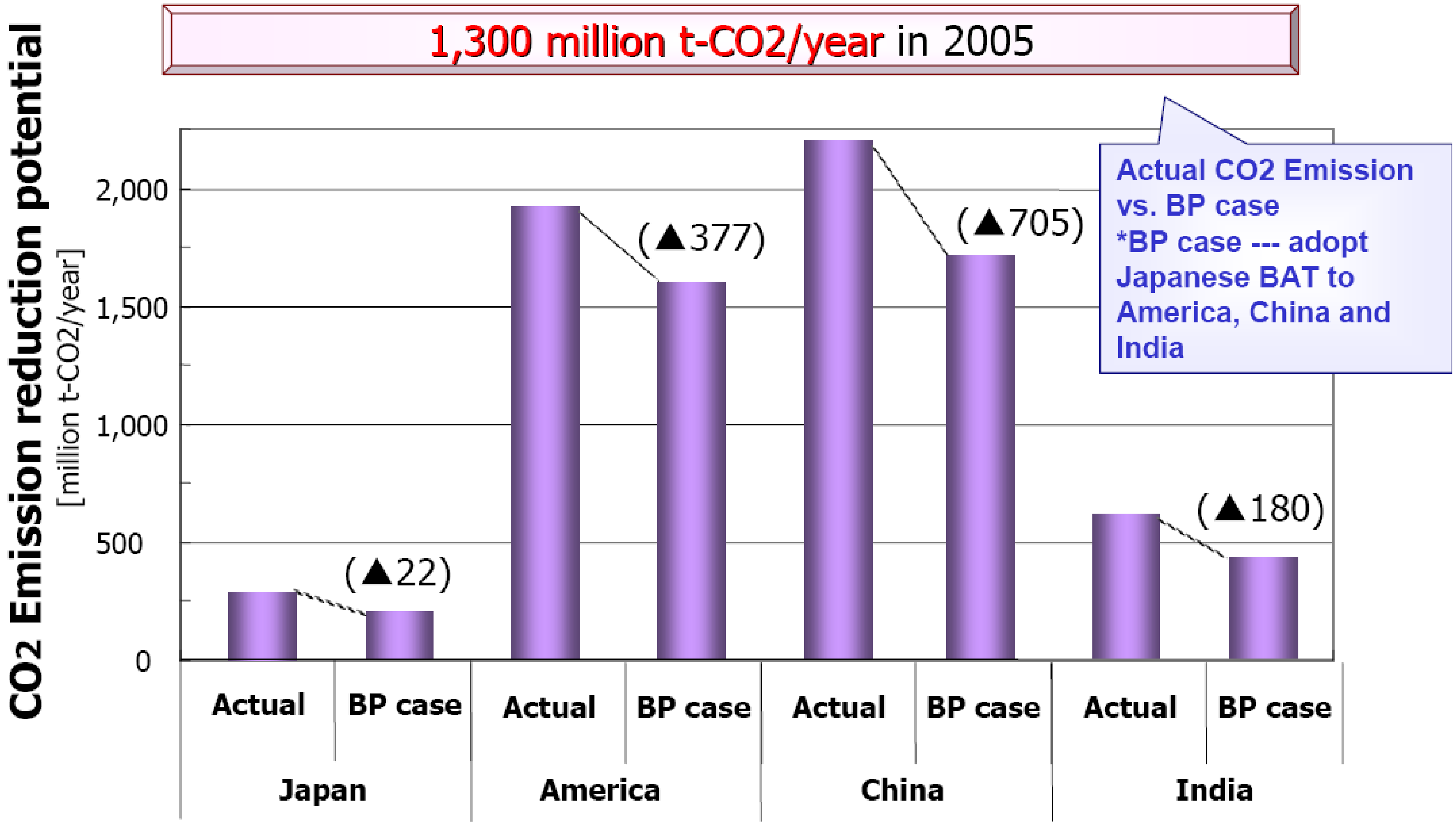
- **성능 Plant Integration 설계기술 및 출력증강의 핵심기술 확보**
- **개선 개념설계 및 비용 최적화 출력증강 Module 구축**

2 단계

출력증강 상세설계 및 플랜트 적용검증

- 성능개선 주기기 및 보조설비 상세설계 및 성능검증
- 시제품 제작 및 현장설치 후 실증 검증

CO2 emission reduction potential



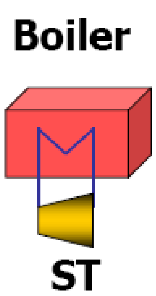
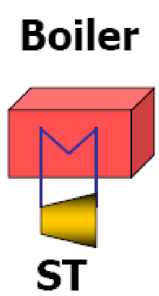
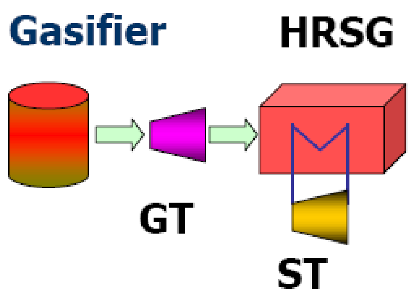
Source: IEA World Energy Outlook 2007, Ecofys International Comparison of Fossil Power Efficiency and CO2 Intensity 2008

Implementation of CCT in High Efficiency Power Generation

Clean Coal Technology in power generation sector

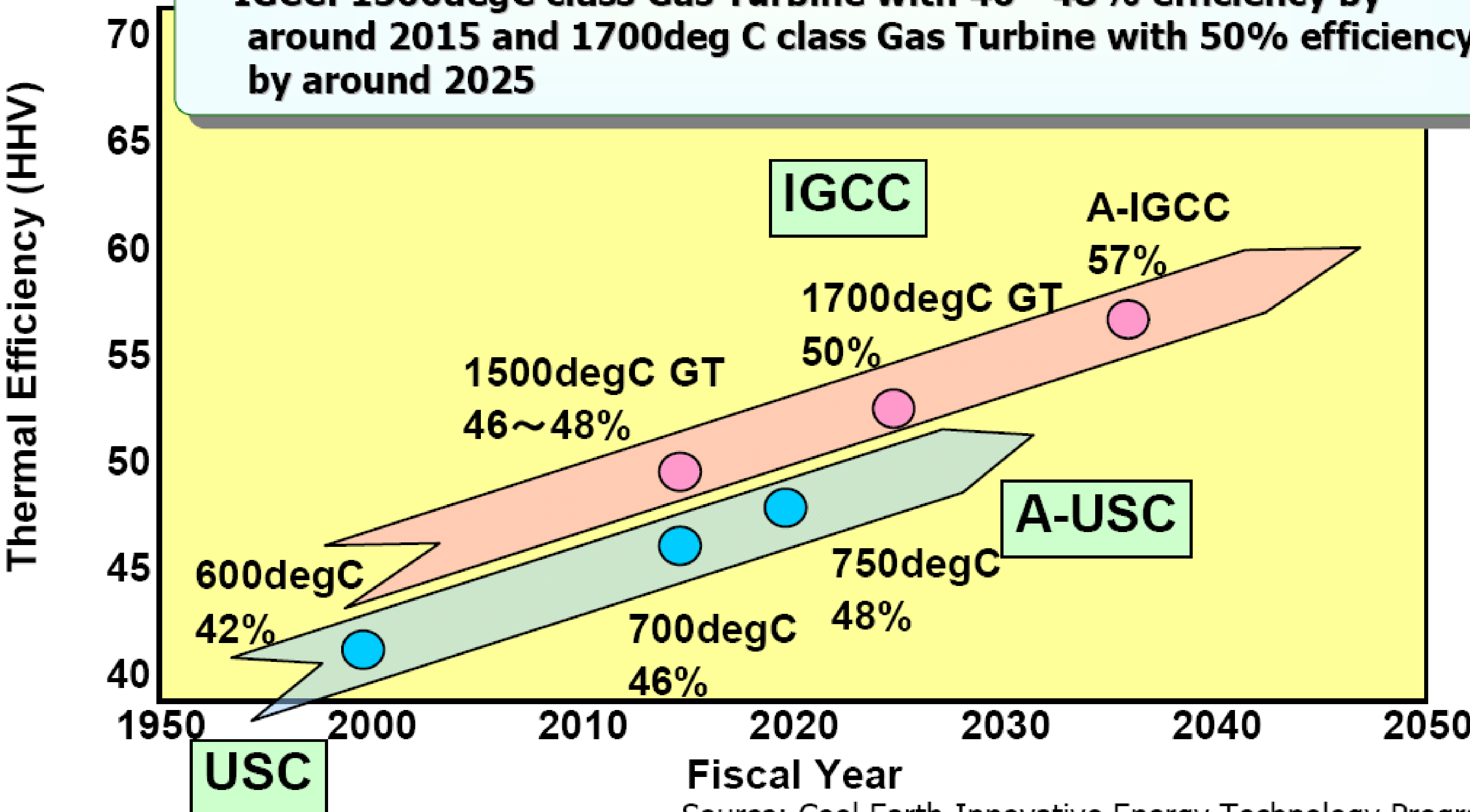
○ **Future development of the high-efficiency coal fired thermal power generation**

- **A-USC: Advanced ultra super critical pressure power generation**
- **IGCC: Integrated Coal Gasification Combined Cycle**

	USC	A-USC	IGCC(1,500degC)
Configuration			
Thermal Efficiency	42%	46%	46~48%
CO2 Emission Reduction	Base	▲11%	▲13%

Roadmap for High-efficiency coal-fired power generation- Japan

- A-USC: 700deg C class Turbine with 46% efficiency by around 2015 and 48% efficiency by around 2020
- IGCC: 1500degC class Gas Turbine with 46～48% efficiency by around 2015 and 1700deg C class Gas Turbine with 50% efficiency by around 2025



Source: Cool Earth-Innovative Energy Technology Program, March 2008 Ministry of Economy, Trade and Industry

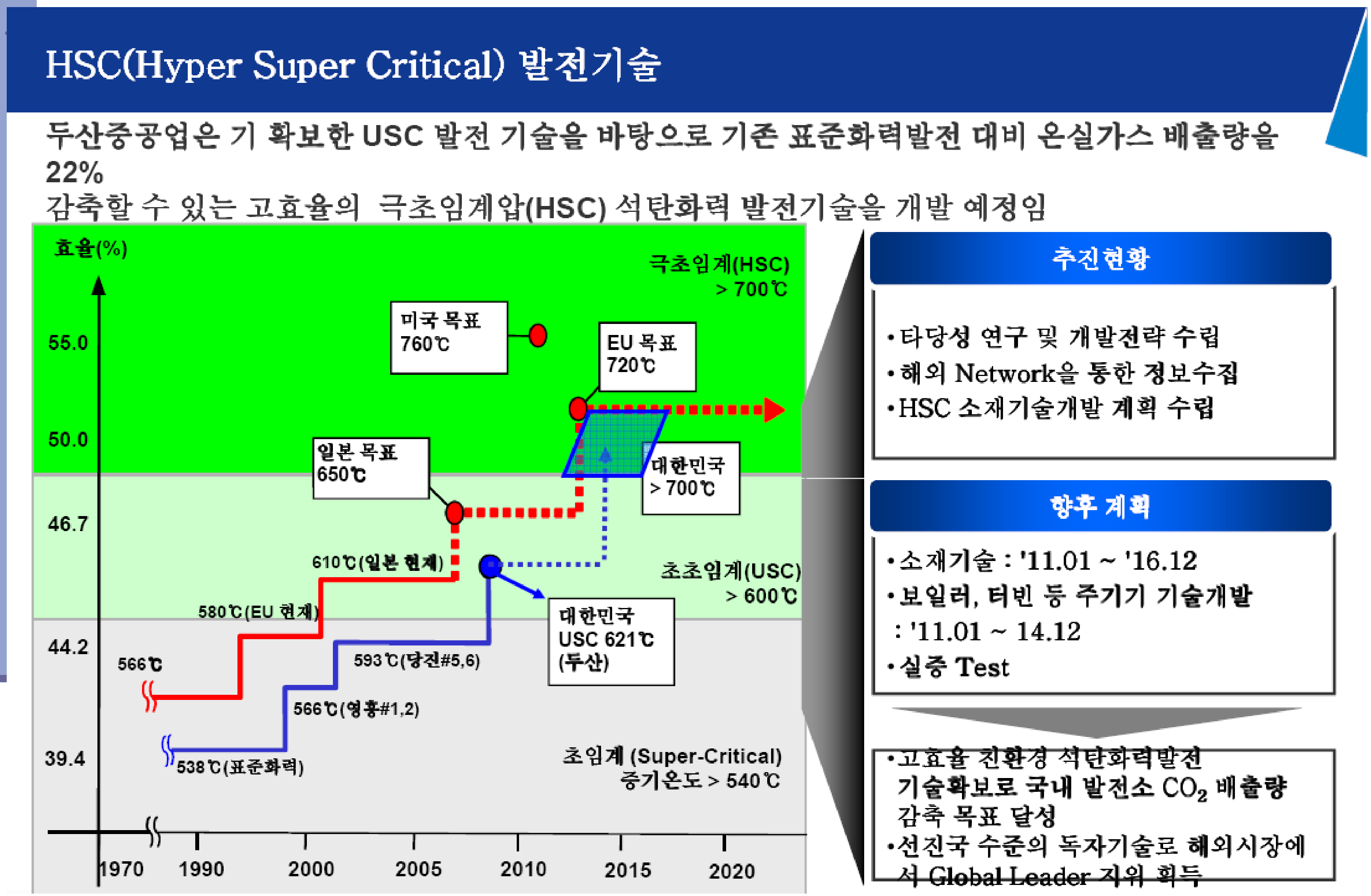
Roadmap for High-efficiency coal-fired power generation- EPRI

PC Plant Evolution to 2020 and Beyond

NOW	*NOW*	*NOW* *to 2010*	*FUTURE* *2010–20*	*FUTURE* *2020+*
• **Subcritical** • **Supercritical**	• **Subcritical** • **Supercritical**	• **USC** • **800 MW±**	• **USC** • **800 MW±**	• **USC** • **800 MW±**
Existing PC Plants w/ Changes 537°C–565°C →	**Current-Generation PC Plant Designs 537°C–582°C** →	**Advanced PC Plant 600°C/ 241 Barg** →	**Advanced PC Plant 650°C/ 276 Barg** →	**Advanced PC Plant 700°C/ 310 Barg+**
• CO_2 Capture Issue • Emissions Issue	• SOA Design • CO_2 Capture Accommodation • Future Emissions Reductions	• Advanced Ferritic Materials • CO_2 Capture Accommodation • Future Emissions Reductions	• Nickel / Austenitic Materials • CO_2 Capture Ready • Advanced Emission Controls	• Nickel Alloys • CO_2 Capture Capable • Near-Zero Emissions

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Roadmap for High-efficiency coal-fired power generation- Korea



Source : 두산중공업 동남권 기업간담회 발표자료, 김정태 상무

Roadmap for High-efficiency coal-fired power generation- Korea

USC(Ultra Super Critical) 발전기술

두산중공업은 국책과제를 통해 세계 최고수준의 친환경, 고효율, 대용량 1000MW급 초초임계압(USC) 석탄화력발전 주기기 설계 및 제작 기술의 독자 개발에 성공하여 상용화 준비 중임

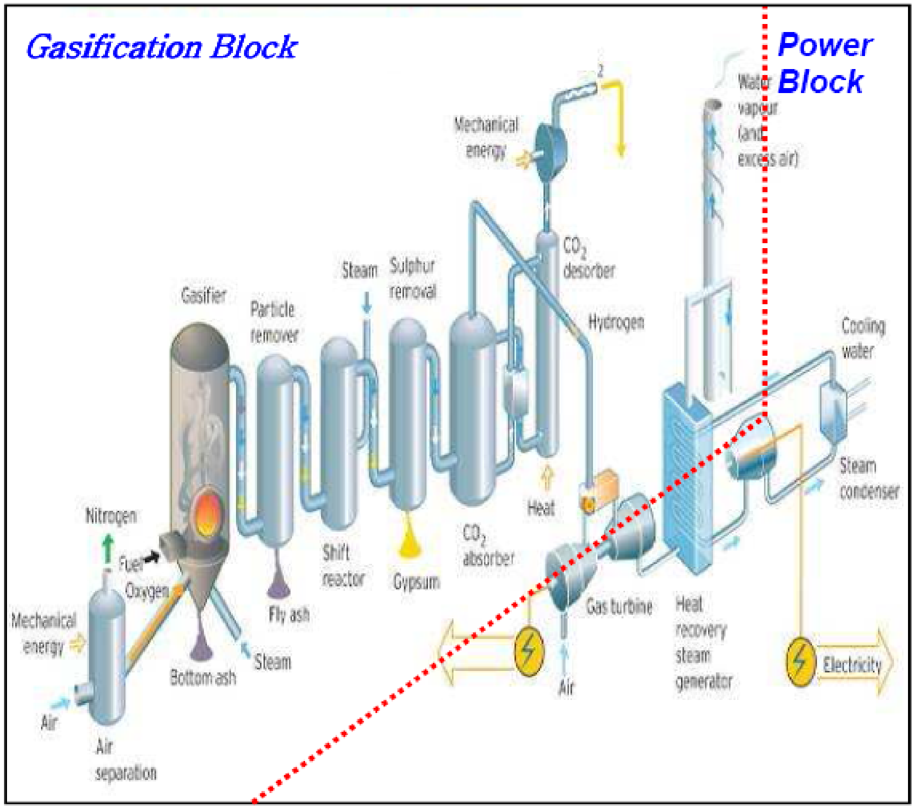
경쟁사 비교	발전용량 (MW)	증기조건[1] (kg/cm2/℃/℃/℃)	발전효율[2] (%)	CO2 배출량[3] (만톤/yr)
국내 개발 기술	1,000	265/610/621	Min. 44.4	Base
MHI	1,050	256/600/610	42.1	+32
ALSTOM	1,000	278/580/600	42~43	+16

- 일본과 유럽에서 가동중인 600°C급 USC 석탄화력발전에 비해 효율이 높아, 연간 32만 톤의 CO_2 배출량 감소가 예상됨

Roadmap for High-efficiency coal-fired power generation- Korea

IGCC(Integrated Gasification Combined Cycle)

두산중공업은 발전플랜트 EPC 사업을 통하여 확보된 기술과 연계 및 시너지를 통하여 IGCC 가스화
플랜트 기술을 개발 중이며, 서부발전과 협력하여 태안 발전소 실증 플랜트 건설에 참여할 계획임



기술개발 방향

- 300MW 가스화 플랜트 설계, 제작, 건설 및 시운전
  - 300MW 출력용 합성가스 생산, (탈황성능 99%, 엔지니어링 자립 90%)

실증 및 상용화 계획

- 서부발전은 2011년부터 태안화력에 실증 플랜트 건설을 계획 중이며, 두산중공업은 실증 가스화 플랜트 건설에 참여 예정임

- 두산중공업이 기 보유한 Power Block 역량과 Synergy를 통한 기술개발 및 세계 시장 진출 등 사업화 파급효과가 큰 발전 기술임

Roadmap for High-efficiency coal-fired power generation- Korea

Characteristics of IGCC Demonstration Plant

- ○ **Upgrade of Thermal Efficiency: 48 to 50% (HHV) is expected and CO2 Emissions Intensity is improved up to Oil fired Power Plants Level.**
- ○ **Improvement of Air Pollution: SOx, NOx and Dust Intensity is reduced.**
- ○ **Expansion of Coal Quality for Use: Low Rank Coal is usable.**
- ○ **Effective Use of Coal-slug: Ash is exhausted as Coal-slug condition and Ash volume is reduced. Coal-slug is re-used as Cement Alternatives.**

Challenges for Commercial Operation

- ○ **Stability of Plant control system: Stable Shut down and Start up, Stable Operation of Gasifier is tested.**
- ○ **Establishment of Plant Reliability: 200hrs continuous operations was successful.**
- ○ **Expansion of Usable Coal Quality: Some Coal Quality is tested.**
- ○ **Performance Test: Designed value achievement is verified.**
- ○ **Plant Durability : Long-term operation is tested and overhaul is planned.**
- ○ **Economical Efficiency: Potential of Commercial Operation is verified.**

Roadmap for High-efficiency coal-fired power generation- Korea