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Greenhouse Gas Mitigation Strategies and Energy Options in Korea

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Contents

Background Information of Korea

Research Aim

- To assess the prospects for different energy sources and technologies (among them prominently the prospects for nuclear energy),
  - with a view to their environmental effectiveness, economic efficiency and their compatibility with long-term sustainable objectives.

- To turn a view point about climate change from threat to opportunity in which we can make so much profit.

Objectives and Anticipated Outcomes

- To gather and organize relevant information about plausible designs for the future climate change agreements
  - with special emphasis on features concerning national energy policy issues, energy resources utilization and supply technology strategies among them and nuclear energy
- To survey policy & measure against climate change in the Republic of Korea and make a plan for electricity demand and supply.

Comparative Status of Climate Change

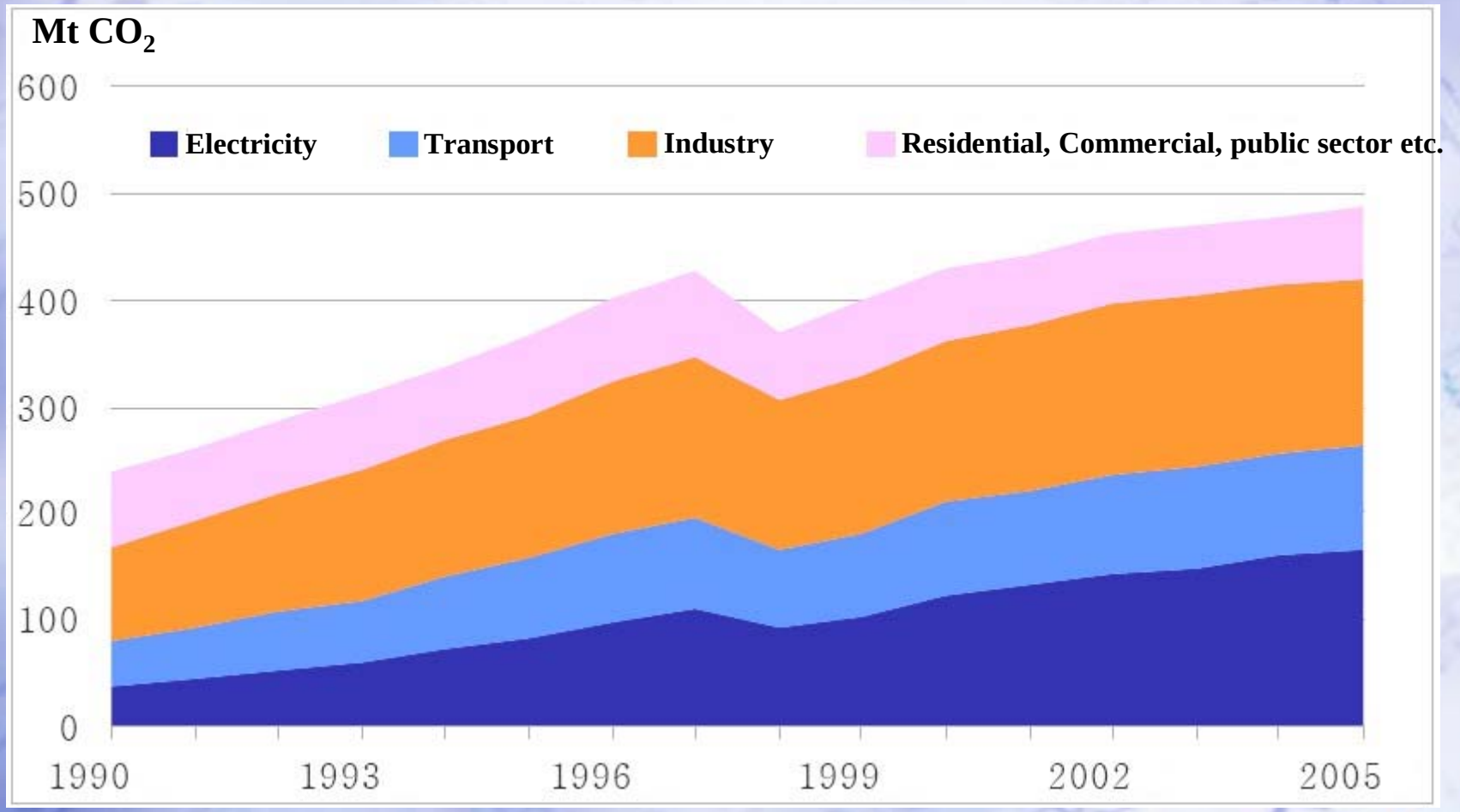
Division	Korea	USA	Japan	China	India	Australia
GDP ('04, U$)	6,656	117,280	46,721	16,008	6,774	6,176
Population ('04, Millions)	48.2	293.0	127.2	1299.8	1080.3	20.2
Per capita GDP ('04, U$)	13,803	40,023	36,693	1,232	627	30,623
Percentage of Emission in the world ('00)	1.6% 10th	20.6% 1st	4.0% 5th	14.8% 2nd	5.5% 4th	1.4% 16th
Per capita GHG Emission ('00/Carbon ton)	3.1 (32th)	606 (6th)	2.9 (37th)	1.1 (97th)	0.5 (140th)	6.8 (5th)
Carbon Intensity (TC/GDP, million$, Rate of change	185/2%	162/-14%	104/-2%	201/-47%	99/-4%	193/-11%
Accumulation of Emission	0.7% 23th	29.8% 1st	4.1% 7th	7.3% 5th	2.0% 12th	1.1% 15th
Future Emission	43-117%	20-52%	4-46%	50-181%	73-225%	

Source: Pew Center Climate change statistics data. 2004,12 etc

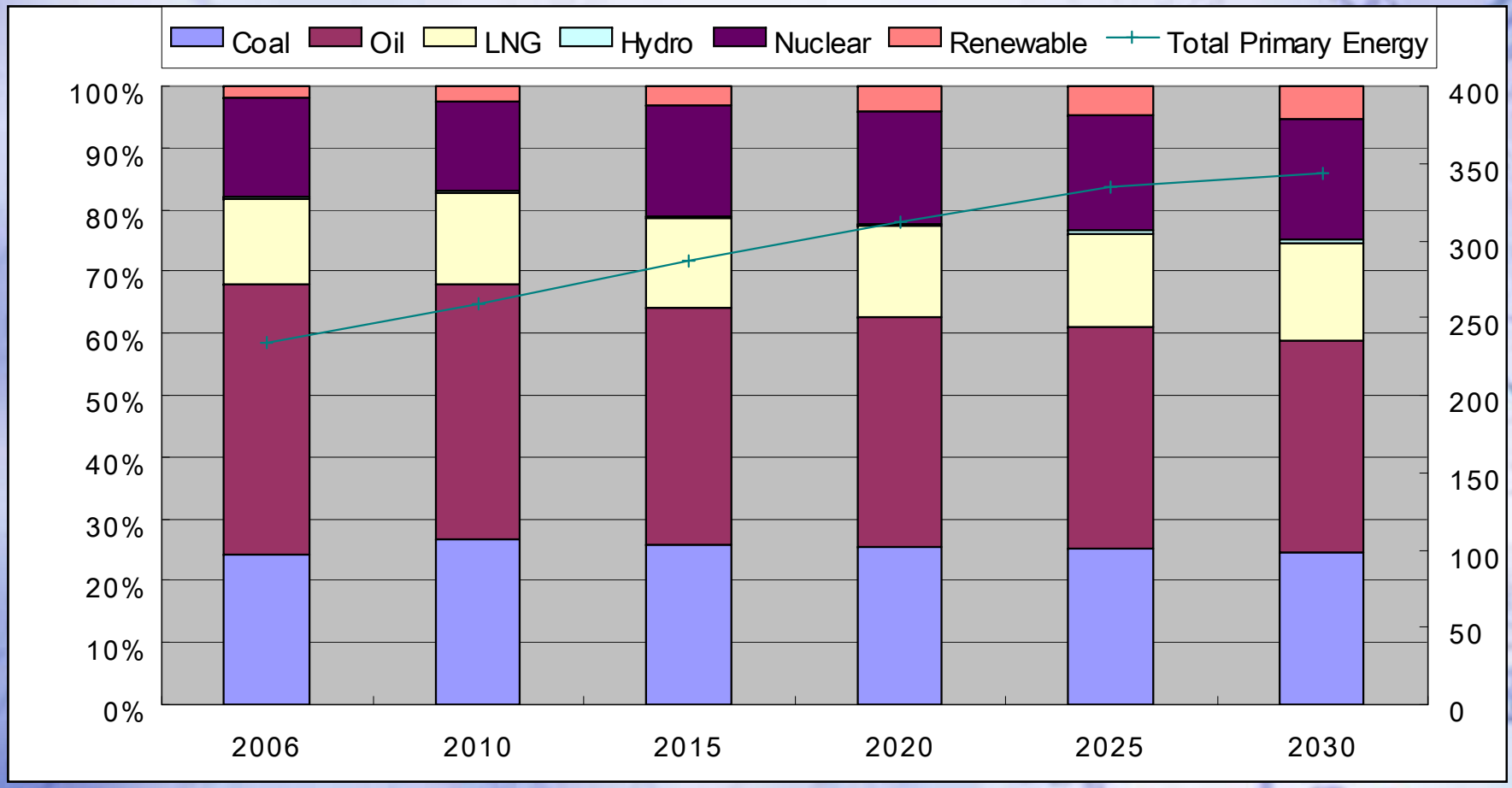
Background Information - Korea

- KOREA
  - → Non-Annex I country
  - → developing economy
  - → highly dependent on imported energy
    - 97.1% (in 2002), 31.2 billion US$
- More than 80% of GHG : CO_2 emission from fossil fuel combustion.
  - ➢ Industry energy use is the main factor.
- CO_2 emission (2005) from energy sector : 84.4%

CO_2 emission trend from energy combustion in Korea

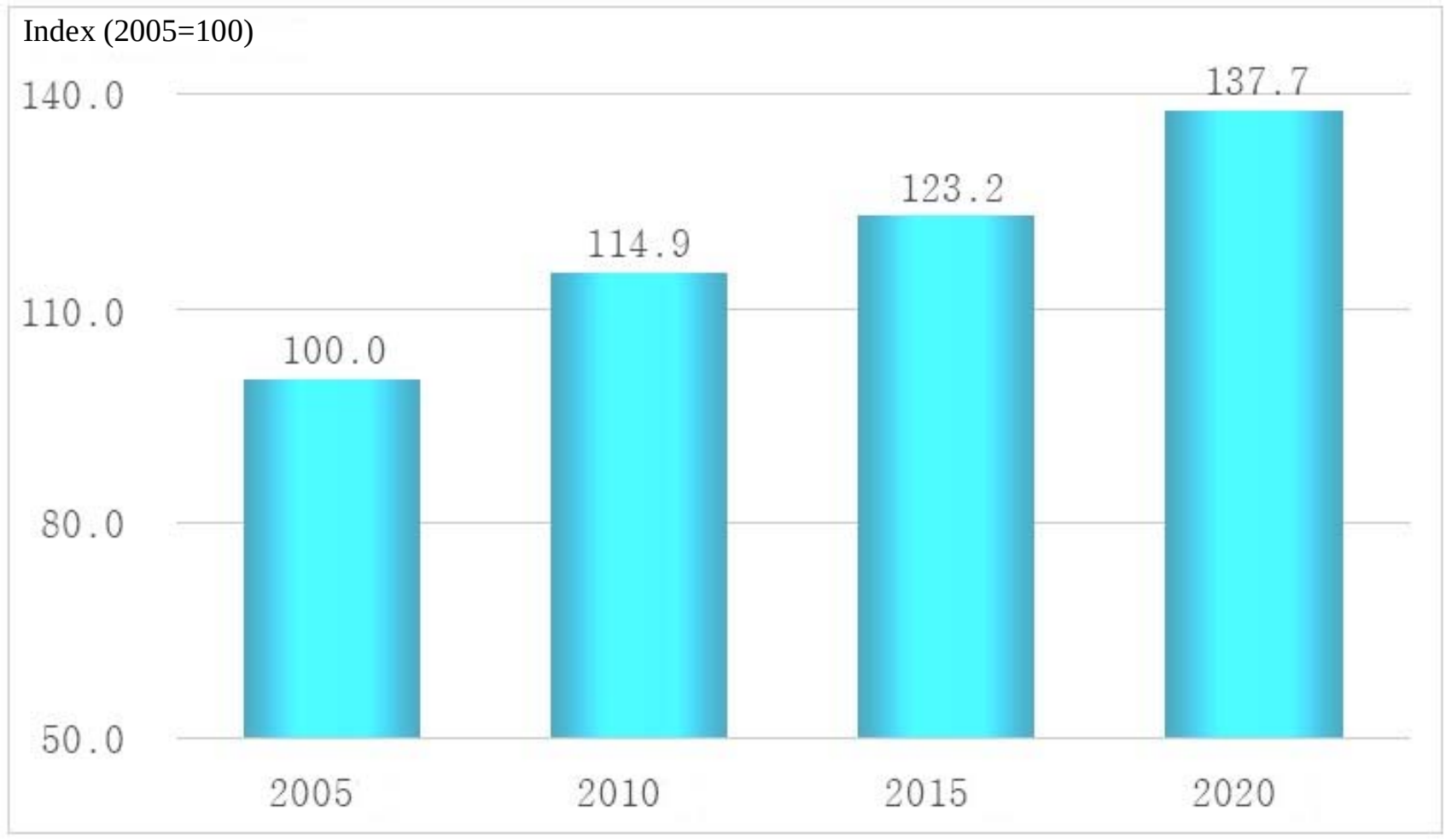


Primary Energy Demand in Korea (Mtoe)



Reference : Prime Minister Office, 2008, 1st National Energy Master Plan

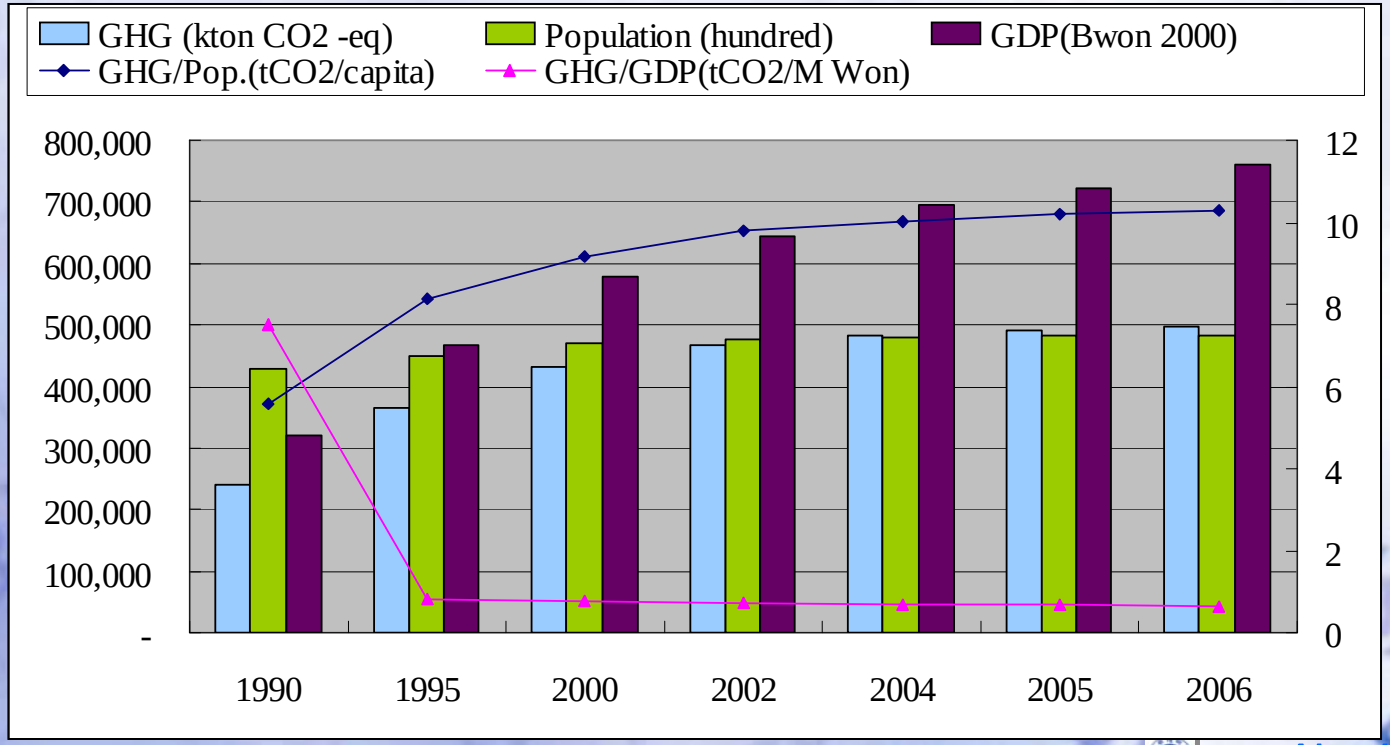
Future perspective for CO_2 emission (2005~2020)



Source: KEEI, a study for 3rd National Report for the UNFCCC, 2007.11

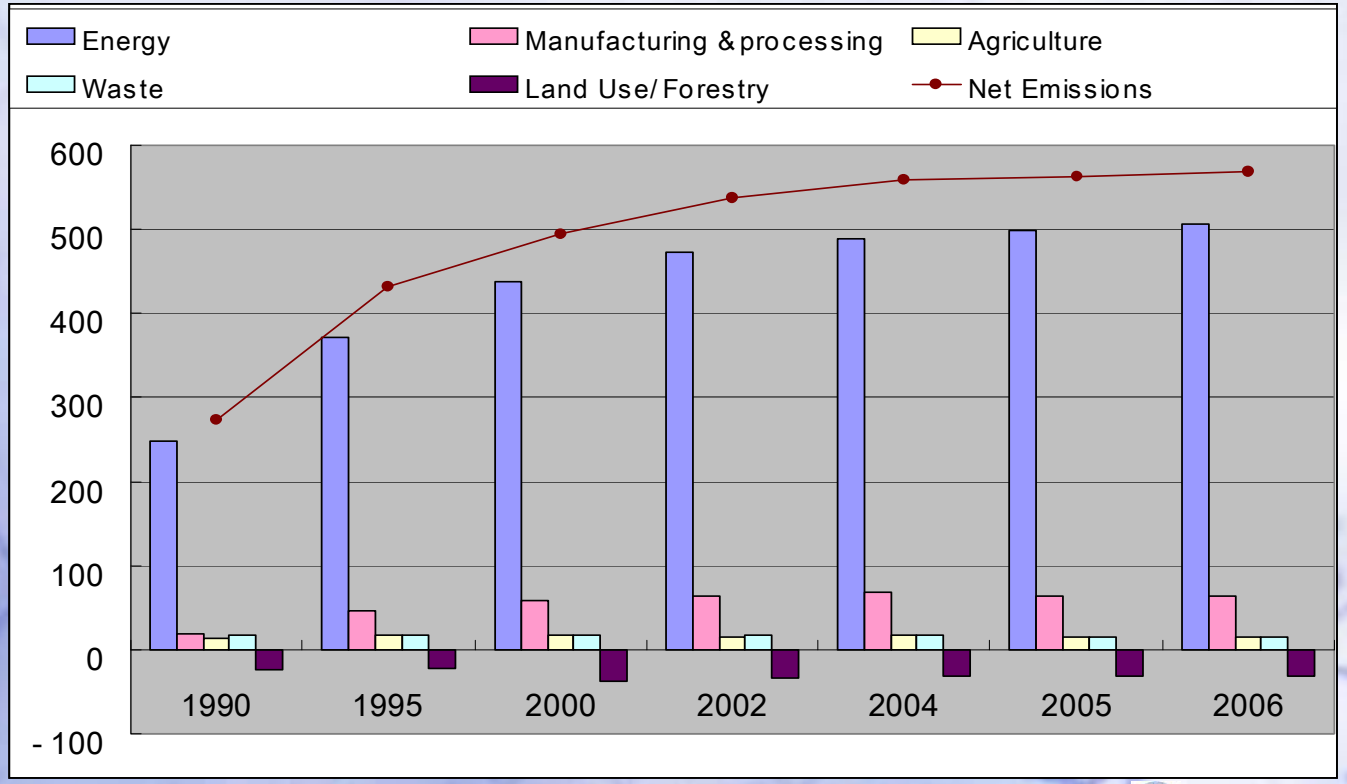
Greenhouse Gas Emissions

- The greenhouse gas increase rate between 1990 and 2006 was 4.68% per annum on average.
- GHG emissions increase rate per GDP have decreased by 0.89%, but GHG/Population have increased by 3.91%.
- Two deductions:
  ① The industrial structure is being gradually changed to less-energy consumptive and energy efficient use.
  ② Household have gradually used more energy.



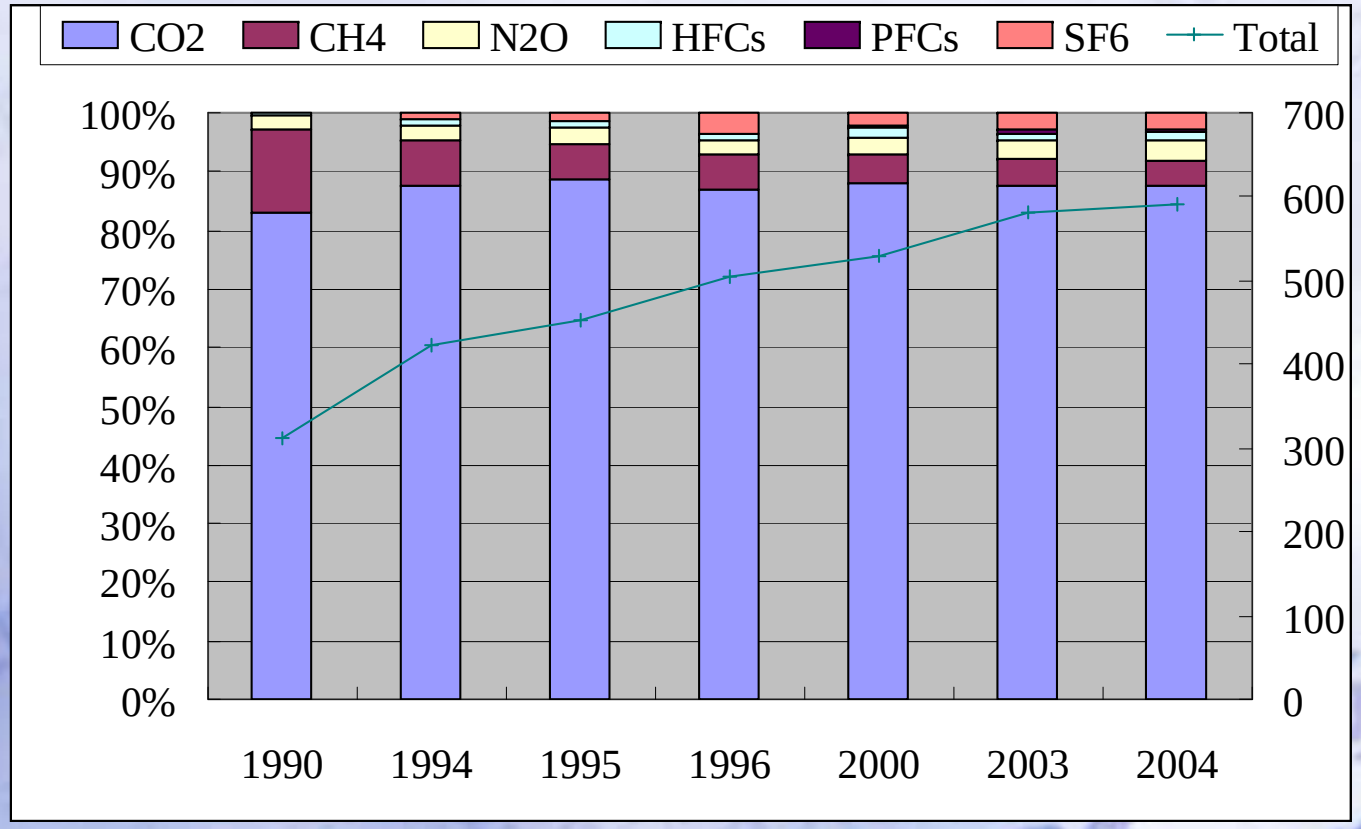
Greenhouse Gas Emissions from Each Sector

- Energy and manufacturing sectors account for 94.9% of the total emissions in 2006.
- The emission from power generation sector has continued to increase.
- In the waste sectors, the greenhouse gas emission has decreased by 0.62% between 1990 and 2006.
- The emission of GHG is reduced by the rate of 1.73% through land use and forestry.



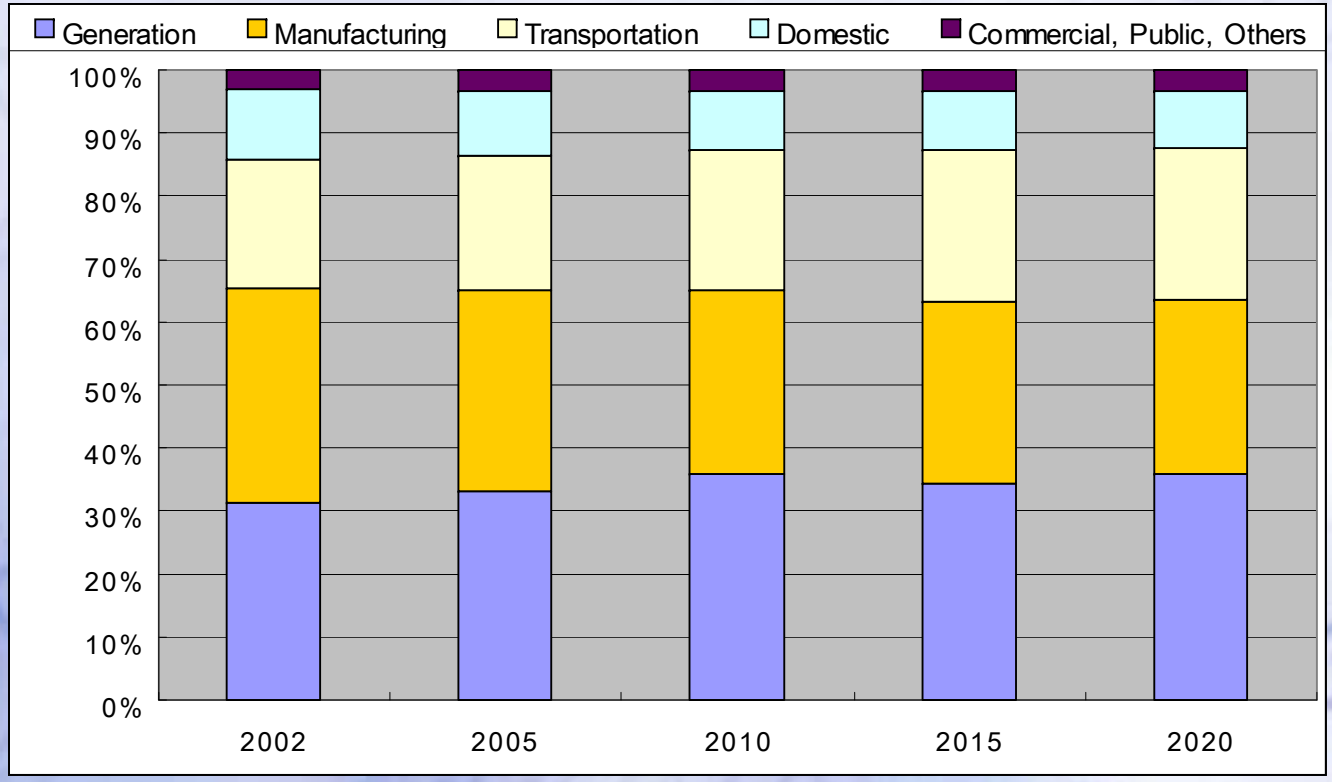
Trend of Greenhouse Gas Emissions

- CO_2 and methane account for 92.1% of total emissions.
- The percentage of CO_2 in greenhouse gas emissions increased from 83.2% in 1990 to 87.7% in 2004 (5.09% a year since 1990).
- Methane emission showed a decrease of 3.64% per year since 1990, reducing its percentage from 13.9% in 1990 to 4.4% in 2004.



Outlook for the Share of Greenhouse Gas Emissions from Energy Sector

- GHG emission is expected to increase 2.3%/year if no special efforts to mitigate greenhouse gases are made.
- Industrial sector: percentage of greenhouse gas emission is expected to reduce gradually because of a slowdown in the growth of consumer industry.
- Transportation sector: the highest increase of greenhouse gas emissions is expected and its percentage in the total emissions is expected to rise to 23.9% in 2020.



Outlook for Greenhouse Gas Emissions from Energy Sector

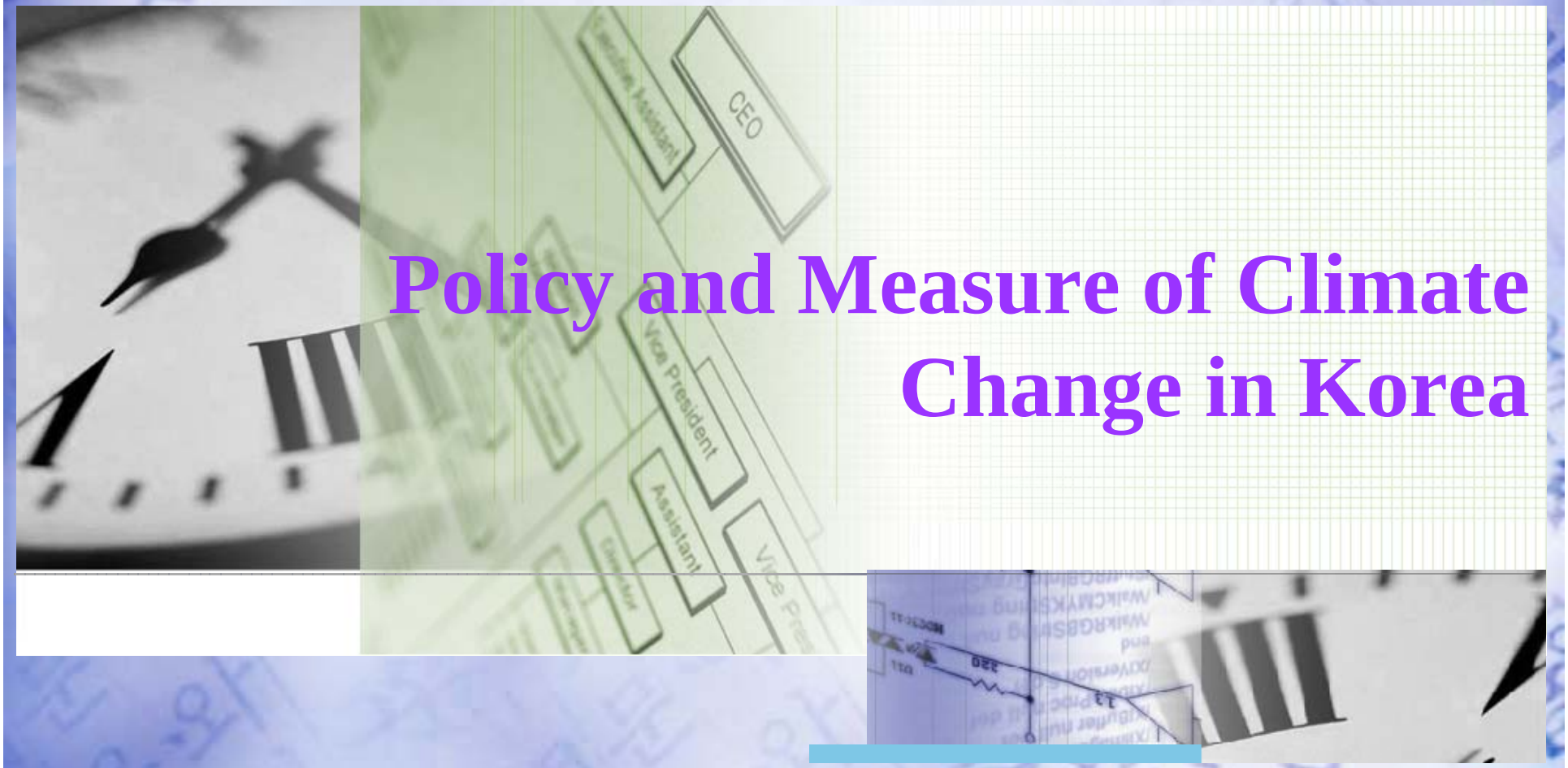
- CO_2 accounts for at least 99.5% of total emissions from the energy sector (expected to increase 2.3% a year on average).
- Methane and N_2O emissions are expected to increase 0.6% and 3.9% a year respectively.

(Unit: %)

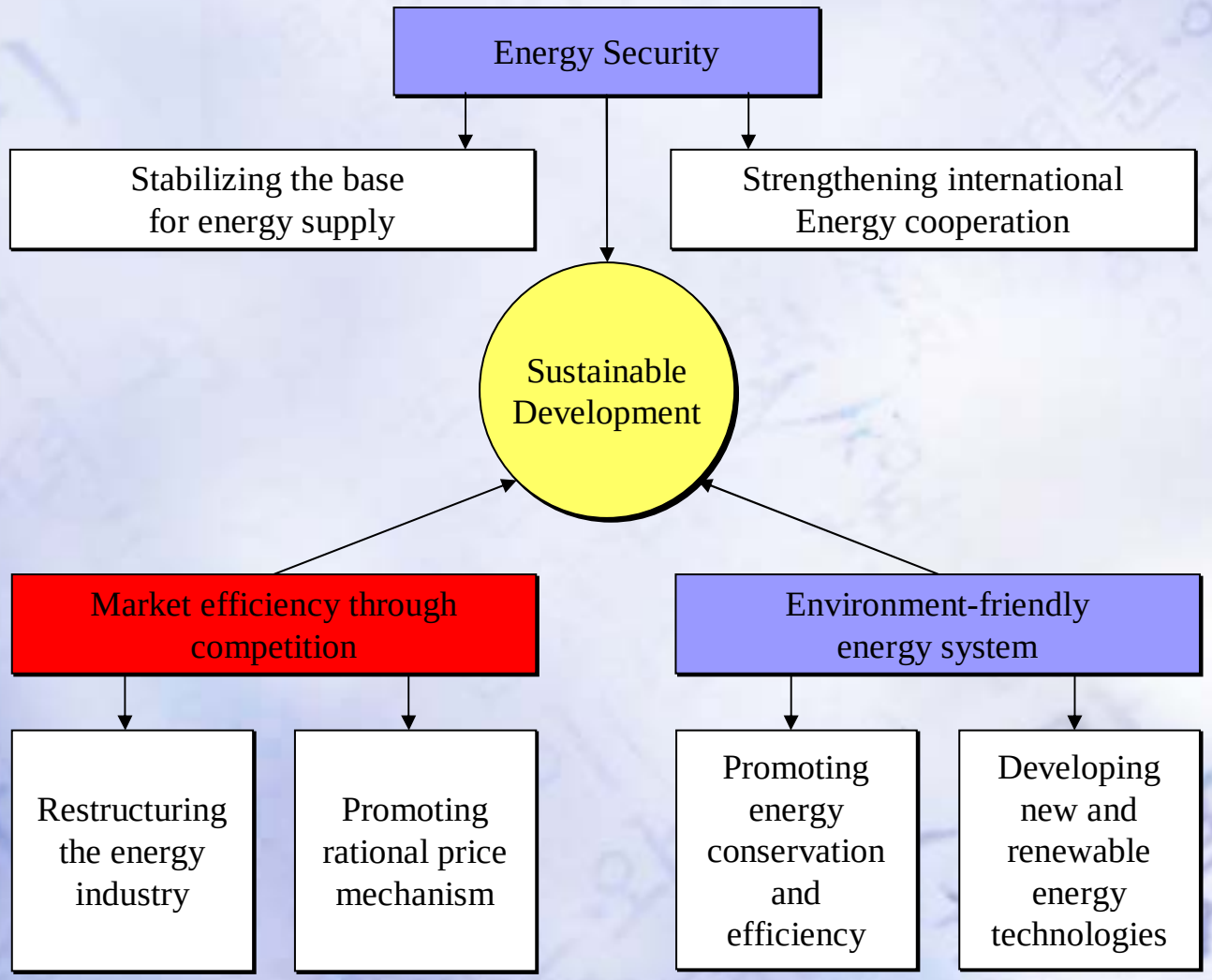
	2002	2005	2010	2015	2020	Annual Increase on Average ('02-'20)
CO_2	99.6	99.5	99.5	99.5	99.6	2.3
CH_4	0.2	0.2	0.2	0.2	0.1	0.6
N_2O	0.2	0.3	0.3	0.3	0.3	3.9
Total	100.0	100.0	100.0	100.0	100.0	2.3

※ *Source: Korea Energy Economics Institute (KEEI) (June 2004)*

Policy and Measure of Climate Change in Korea



Goal and Direction of Korea's Energy Policy



Implementation scheme

Strengthening GHG Emission Reduction Capability

Establishing Low Carbon Energy Demand & Supply system

Demand : Improve Energy Efficiency ["improving energy intensity"]

- Expand Voluntary Agreements
- Implement Automobile Average Fuel Economy Standards
- Promote Dissemination of Energy Efficient equipments

Industry : Induce revitalization of GHG Reduction Activities

- Recognize/compensate Early Action efforts
- Develop CDM Projects
- Support emission trading scheme utilization capacity building

Supply: Expand the Application of Clean Energy

- Develop & Disseminate New & Renewable Energy
- Maintain Appropriate Nuclear level in the Energy Mix
- Promotion of LNG and Community Energy Supply

Vision and Objectives

Vision

- 'Low Carbon, Green Growth'
  - contribute to the global efforts to combat climate change and achieve low-carbon society through green growth.

Objectives

- Develop climate industry as a new economic driving force
- Improve quality of life and the environment
- Contribute to the global efforts to combat climate change

Plan of Actions

Developing Climate Industry as a New Economic Driving Force

- Promote energy saving and energy efficiency improvement of industry
- More than double the R&D investment in climate change
- Develop climate-friendly industries and promote exports

Plan of Actions

Improving energy efficiency in the industrial sector

- 0.23 toe per 1,000 USD (2000$ PPP) in 2006 → 0.154 by 2020 → 0.123 by 2030
- Obligating large energy-intensive enterprises to receive **energy review**
- Developing energy service companies and expanding the application of **minimum energy efficiency standards**.
- Key industries will be encouraged to seek **higher added-value** through energy design innovation and quality management (QA), while **low energy consumption industries** will be newly developed.

Plan of Actions

Improving energy efficiency in the industrial sector

- To spur greenhouse gas mitigation of industry, voluntary agreements between the government and industry will be strengthened to **negotiated agreements.**
- **Various incentives** will be provided, including **financial and taxation support** on investments made in mitigation efforts.
- Specifically, mitigation activities of companies will be recognized in a way linked to the **Korea Certified Emission Reduction (KCER)** scheme.

Plan of Actions

Expanding R&D investment in green technologies

- Efforts will be concentrated in developing **innovative technologies.**
- About 5 trillion KRW will be injected in a five-year period from 2008 to 2012, **more than doubling the investment size** of 700 billion KRW (as of 2008).
- **Convergent "green" technology** will be developed using Korea's strength in IT, BT and NT.
- **IT and green technology will be converged** to **promote efficiency in buildings and transport sectors.**
  - Examples include construction of energy-saving building, efficiency improvement of electric power transmission/distribution efficiency and setting up "intelligent" transportation system.
- Strategic technology acquisition will be promoted alongside efforts to independently develop technologies and **professionals will be nurtured.**

Plan of Actions

Fostering climate industry – Renewable Energy

- Aggressive expansion of renewable energy supply through increased investment
  - The **share of renewable energy in total energy portfolio** will also be raised, from 2.24% in 2006 to 4% in 2012 to more than 11% by 2030 and over 20% by 2050.
- Creation of renewable energy markets and expansion of supply
  - By 2020, domestically produced **wind power generators of total 2,000 MW** will be supplied.
  - **marine energy** such as **tidal power generation** will be developed.
    - Sihwa-ho Lake by 2012(254MW), Garolim Bay, Inchon Bay and Ganghwa Island by 2020 (sum **3.024 MW**)
  - The **blending ratio of bio-diesel in diesel engine** will be increased from 0.5% in 2007 to 2.0% in 2010.
  - **"Waste Energy Towns" will be constructed** in four regions nationwide in order to promote **waste-to-energy** from food waste, sewage sludge and livestock waste.
- Strengthen support systems for promotion of renewable energy
- Promote export of solar and wind power industry

Plan of Actions

Fostering climate industry – Renewable Energy

- Strengthen support systems for promotion of renewable energy
  - **Renewable Portfolio Standard (RPS) – from 2012,** 50MW each year
  - **mandatory renewable energy installation** will be broadened, from the current standard that obligates newly built public buildings of 3,000㎡ or more to **include renovated buildings and school facilities.**
  - regulations on the site selection process of onshore and offshore wind farms will be eased.
- Promote export of solar and wind power industry
  - Korea aims to **secure a global market share** of 5% by 2012 which will translate into over 10 trillion KRW per annum.
  - By linking with its world-class IT and shipbuilding technology, the renewable industry of Korea is on track to becoming the nation's key industry.

Plan of Actions

Fostering climate industry – Energy Efficiency

- Advance technological level by expanding R&D investment
  - The specific amount of investment to be made in the five-year period from 2008 to 2012 is **500 billion KRW in electricity IT, 100 billion KRW in LED lighting and 110 billion KRW in energy storage**.
- Promote programs to foster energy efficiency industry
  - Regional **LED convergence specialized clusters.**
    - the **demand for LED will be created in the public sector**
  - **Hybrid cars and fuel cell cars**
    - By 2013, energy efficiency will be **improved by 30%** compared to existing vehicles.
    - Average fuel efficiency is to be increased from 11.04 ㎞/ℓ in 2007 to 14.35 ㎞/ℓ in 2013.
  - **Energy efficiency of major energy-intensive industries such as steel and petrochemicals will be improved.**

Plan of Actions

Fostering climate industry – Energy Efficiency

- Strengthen support systems for enhancement of energy efficiency
  - Growth of **energy service companies** (ESCOs) will be induced.
  - Support for energy audit costs will be increased from 70% in 2007 to 90% in 2009 to **encourage more small and medium sized companies to participate in energy audits.**
  - Furthermore, **public organizations will lead the initial efforts** to boost an emerging LED market, with an aim to increase the share of LED from below 1% in 2007 to 30% by 2015.
  - Public buildings will consider using LED lightings prior to other options, while traffic lights and street lamps will be replaced by LED units.
  - LED-use demonstration projects will be carried out on large post offices. Meanwhile, to drive low efficiency lighting systems out of the market, **minimum energy performance (efficiency) standard will** be strengthened.

Plan of Actions

Fostering climate industry – Nuclear Power Industry

- Korea is operating **20 nuclear reactors** in four sites(the sixth largest nuclear power producer in the world).
- Korean nuclear power plants boast **top level safety and operational efficiency** globally.
- Capitalizing on the accumulated **nuclear plant construction and operation expertise, export of nuclear facilities, technologies and manpower** will be promoted.
- Export of nuclear-power-related technology will be increased from **580 billion KRW in 2007** to **1,170 billion KRW in 2012.**
  - Export of **Korean-type nuclear reactors** (by securing core technologies)
- Exporting two reactors is expected to create 50,000 new jobs and approximately 5 trillion KRW.
- According to an IAEA forecast, some **309 new nuclear reactors are likely to be built by 2030 globally.**
  - The development of core technology is scheduled to be completed by 2012.

Plan of Actions

Fostering climate industry – Other Green Industries

- **Global water market** is growing at an average rate of 5.5% annually, with a projected **market size expansion** to 1,600 trillion KRW in 2015 (from 830 trillion KRW in 2003).
- Establishment of a **meteorology industry promotion act** will be pushed to lay the **legal framework** for developing the industry.
- Landfill-gas recovery and heat recovery systems will be reinforced. Turning 31% of usable waste into energy sources by 2012 is expected to lead to creation of **17,000 new jobs and 1.3 trillion KRW in economic profit.**
- A **CDM project support organization** will be operated to provide export-oriented services such as consulting on overseas market access, strategies and assistance for negotiation and contract processes.
  - As of August 2008, there are 19 Korean CDM projects registered in the UN, equivalent to 14.6 MtCo2eq / year.
  - The figure accounts for 6.6% of global CDM projects and places Korea at 4th in ranking after China, India and Brazil.

Plan of Actions

Improving quality of life and the environment - Enhancing quality of life [Transportation]

- Measures to **reduce passenger car use and promote public transit system** will be implemented such as imposing a greater **traffic congestion tax** and improving parking conditions.
- An environment favorable to **non-motor, green vehicle** users, such as bicycle riders, will be created.
- More investment will be made to expand **public transportation networks between cities in the metropolitan area** and **promote use of public transit** such as Light Rail Transit and subways.
- In designing newly developed towns, systematic **public transport infrastructure** will be made a priority in the **urban planning**.
- The **share of railway systems in total transport** will be doubled by 2019 and overall **competitiveness of railway systems** will be enhanced by introducing more multiple-lane, **electric and high-speed trains.**

Plan of Actions

Improving quality of life and the environment - Green life-style change

- **light vehicles, high-efficiency green cars, green homes & green buildings**
- Smart electricity measurement systems will be installed at households and the **supply of "integrated energy"** will be expanded.
- **Eco-friendly agricultural production bases** will be increased and **sea forests** will be created in coastal areas.
- Furthermore, to **reduce the generation of solid waste,** various measures including lighter packaging and waste wood recycling will be promoted.
- **Carbon sinks of forests** will be expanded and the **carbon cycle** will be facilitated.
- Efforts will be made to boost the carbon absorbing capacity of forests by implementing **optimal forest management** while minimizing carbon emissions through environmentally-friendly **mountainous land use and restoration** efforts.

Plan of Actions

Improving quality of life and the environment - Enhancing adaptation

Ecosystem	adaptation to effects on biodiversity and shifts in vegetation zones
Human health	improved climate-sensitive disease surveillance and control, health warning system
Agriculture/fishery	breeding new crop, developing new varieties, coping with changed fisheries resources
Forestry	adaptation to forest disasters including fire and pest
Marine environment	coastal disaster management in response to sea level rise
Urban area	prevention of urban stream erosion, strengthened safety standard for buildings
Finance	climate-related derivatives market development, natural disaster-related insurance scheme promotion

Plan of Actions

Improving quality of life and the environment – Awareness and changing patterns

- **"green culture"** and **"less carbon" life style** will be widely promoted.
- **Consumer responsibility** and **commitment to act** will be enhanced through campaigns.
- **Carbon labeling** system to achieve emission reduction of a product.
- A nationwide movement toward a low-carbon society will be pursued, using **private/public networks** such as the **Korean Council for Local Agenda 21.**
- All events held by government organizations will be **"carbon-neutral,"** while at the same time, encouraging the private sector to also organize **"zero-carbon"** events.
- Local governments will be encouraged to set voluntary mitigation targets that are **tailored to the needs of local environment.**
- Climate change issues will be more effectively integrated in the **primary and secondary school curriculum.**

Plan of Actions

Improving quality of life and the environment - Scientific monitoring and prediction

- Systems to **monitor the ongoing changes in the climate and Earth environment** will be established.
- **Climate change monitoring networks** will be reinforced and high level atmospheric monitoring will be strengthened.
- **National standard climate change scenario** will also be developed to guide designing adaptation measures.
- The **production of climate change prediction data** will be boosted and a **system to utilize such data** will also be created.
- Web-based climate scenario services will be provided.

Plan of Actions

Contributing to global efforts to combat climate change

- Set mid-term goal in 2009, become an “early mover” toward low-carbon society
- Propose Market-based climate regime and assume bridging role
- Advance to global climate industry and launch East-Asia Climate Partnership

Key Policy Tools

- **Financial and budgetary support**
- **Pricing structure reform**
- **Improve carbon intensity & eco-efficiency of major SOCs**
- **Legislative & institutional foundation**
- **Public Awareness and participation**

Key Policy Tools

FINANCIAL AND BUDGETARY SUPPORT

- Public Sector
  - **creation of a climate change fund -** about 31 trillion KRW is required for the next five years' public and private investments to address the effects of climate change in Korea.
    - ✓Investment in **R&D projects to develop "green technology" will be significantly expanded.**
  - As of 2008, climate change-related R&D investment accounted for 6.4% of total government R&D investment.
    - ✓The share is to be increased to about **8.5% by 2012.**
- Private Sector
  - A wide array of **financial and taxation incentives** will be introduced to encourage private investment in low-carbon, **"green management" and technology development.**
  - Financial institutions will be induced to provide **preferential financial schemes** to enterprises committed to corporate social responsibility (CSR) and carbon disclosure program (CDP).
  - **Tax credits will be expanded** for investments made in greenhouse gas mitigation facilities.

Key Policy Tools

PRICING STRUCTURE REFORM

- Low-carbon tax scheme
  - **A "climate-friendly" aspect** will be incorporated into the existing tax scheme while the **adoption of a carbon tax** will be considered.
  - In such case, the carbon tax will be imposed in a **"revenue-neutral"** manner in order to prevent an increase in the taxpayers' burden.
  - Tax benefits for **investments in emission mitigation facilities** will also be enhanced.
- Life style change
  - The **"polluter-pay-principle"** will be promoted to encourage consumers to adopt **"green consumption"** patterns, opting for **eco-friendly products.**
  - Overall, low-carbon oriented **life styles** will be promoted by managing the energy demand side, such as imposing **regulations on CO2 emissions of vehicles** or levying **traffic congestion charges.**

Key Policy Tools

Improve carbon intensity & eco-efficiency of major SOCs

- Transport sector : Reduced traffic congestion cost, increased sustainability
  - **railways** will be significantly expanded and investments will be made to expand public transportation, especially focusing on **subways and light rail transit (LRT).**
  - At the same time, environment favorable for bicycle riders will be created to promote **bicycle use.**
  - To encourage the **use of public transit** instead of passenger vehicles, the **accessibility of public transportation** will be enhanced.
- Buildings sector : Energy-saving, sustainable construction
  - **Building energy design standards** will be strengthened while energy-saving buildings will be developed and widely used.
  - Eco-friendly features of buildings include enhanced thermal insulation capacity, installation of high-efficiency equipment and achieving a "**carbon-neutral**" status.

Key Policy Tools

Improve carbon intensity & eco-efficiency of major SOCs

- Resources-recycling infrastructure
  - **Social overhead capital** facilities designed to **reduce waste** and/or **promote recycling of resources** will be expanded while relevant **legal and institutional framework will be introduced.**
- Building the foundation for climate change response
  - **Legal framework for "low-carbon, green growth"** will be prepared to promote efficient and systematic response to the issue of climate change.
  - The public sector will be subject to systematic **review and evaluation of climate change actions** carried out.
  - For the private sector, incorporating the concepts of carbon intensity and eco-efficiency into **environmental impact assessments** will be considered.

Key Policy Tools

Improve carbon intensity & eco-efficiency of major SOCs

- Setting up national inventory system
  - Korea's own greenhouse gas **emission and removal coefficients** will be developed.
- Rationalizing renewable energy regulations
  - **Regulations on renewable energy sites** and other relevant areas will be **significantly revised** to foster renewable energy development.
- Considering introduction of emissions trading scheme
  - For **efficient greenhouse gas mitigation,** the possibility of establishing an emission trading system will be examined.
  - A **basic plan for emission trading system** will be drafted by 2009.
  - **Trading and cooperation with global carbon markets** will be considered.

Key Policy Tools

PUBLIC AWARENESS AND PARTICIPATION

- Public awareness
  - It is critical for the government to **enhance public awareness and encourage positive reception and active participation** on the new national development paradigm of “low-carbon, green growth.”
  - Active awareness campaign will be launched using various means including **mass media, television and the Internet.**
  - Other promotional campaigns will be organized to raise awareness on **consumer responsibility towards the environment.**
- Education
  - The concept of “low-carbon, green growth” will be reflected in the **primary and secondary school curriculum** to help future generations **understand and act** upon the new paradigm.

Reduction targets by Government

(Unit: Million ton)

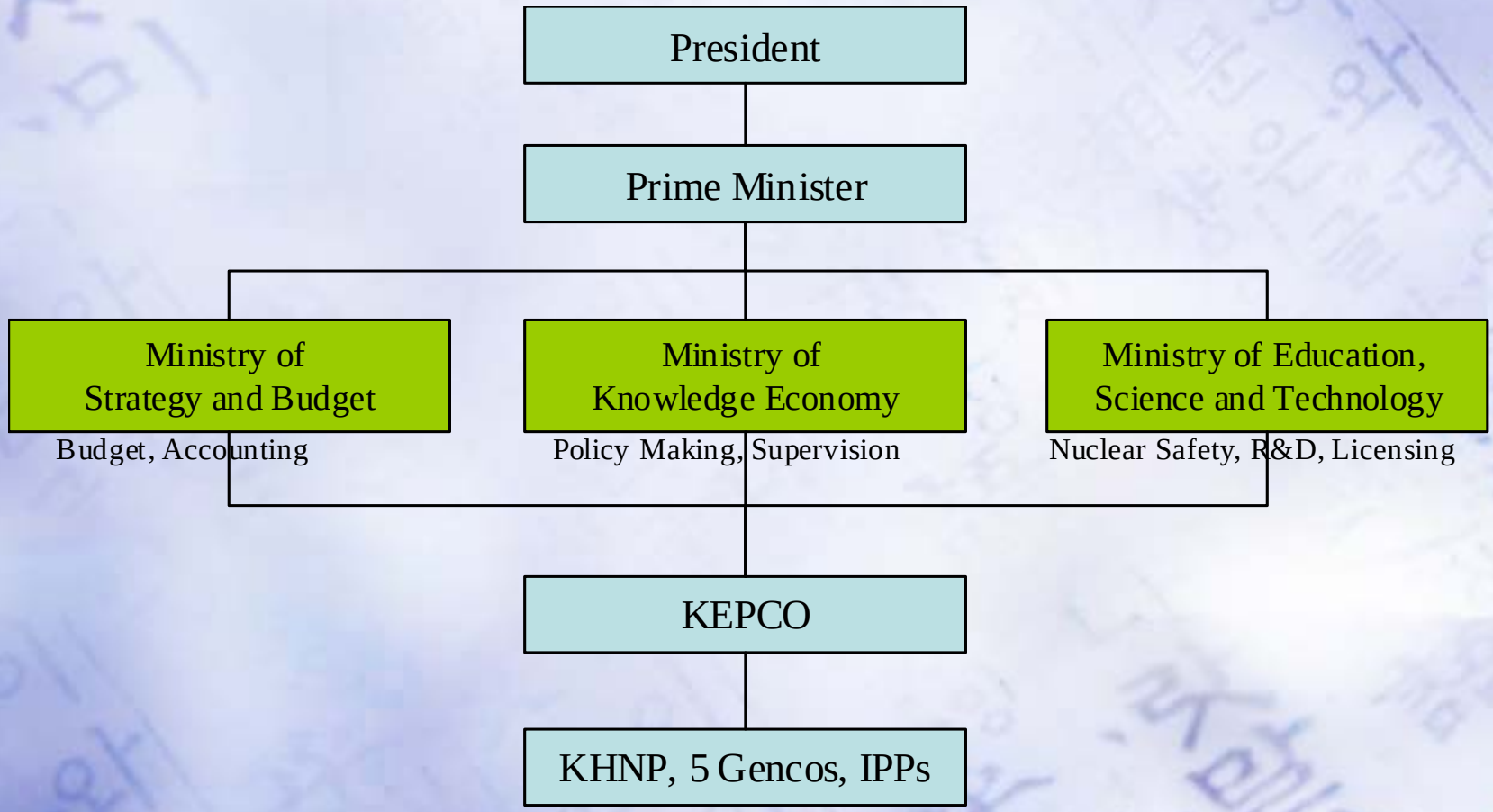
1990	2005	2020			
		Prospects	Target	Reduction rate	
298.1	594.4	813.0	642.0	-21%	Scenario-1
			594.0	-27%	Scenario-2
			569.0	-30%	Scenario-3

Means of Achieving the Goal

Scenario -1	Green Home, Green Building
	Use of High Efficiency Lighting Equipment such as LED
	Low Carbon/High Efficiency Transportation System
Scenario-2	Hybrid Car
	Expanded Use of Bio Fuel
	CCS(carbon capture & sequestering) Technology
Scenario-3	Next generation car(Electric Vehicle, Fuel cell car etc.)
	High-tech/High Efficiency Equipment
	Expanded use of CCS

Power Development Plan

Electric Power Sector

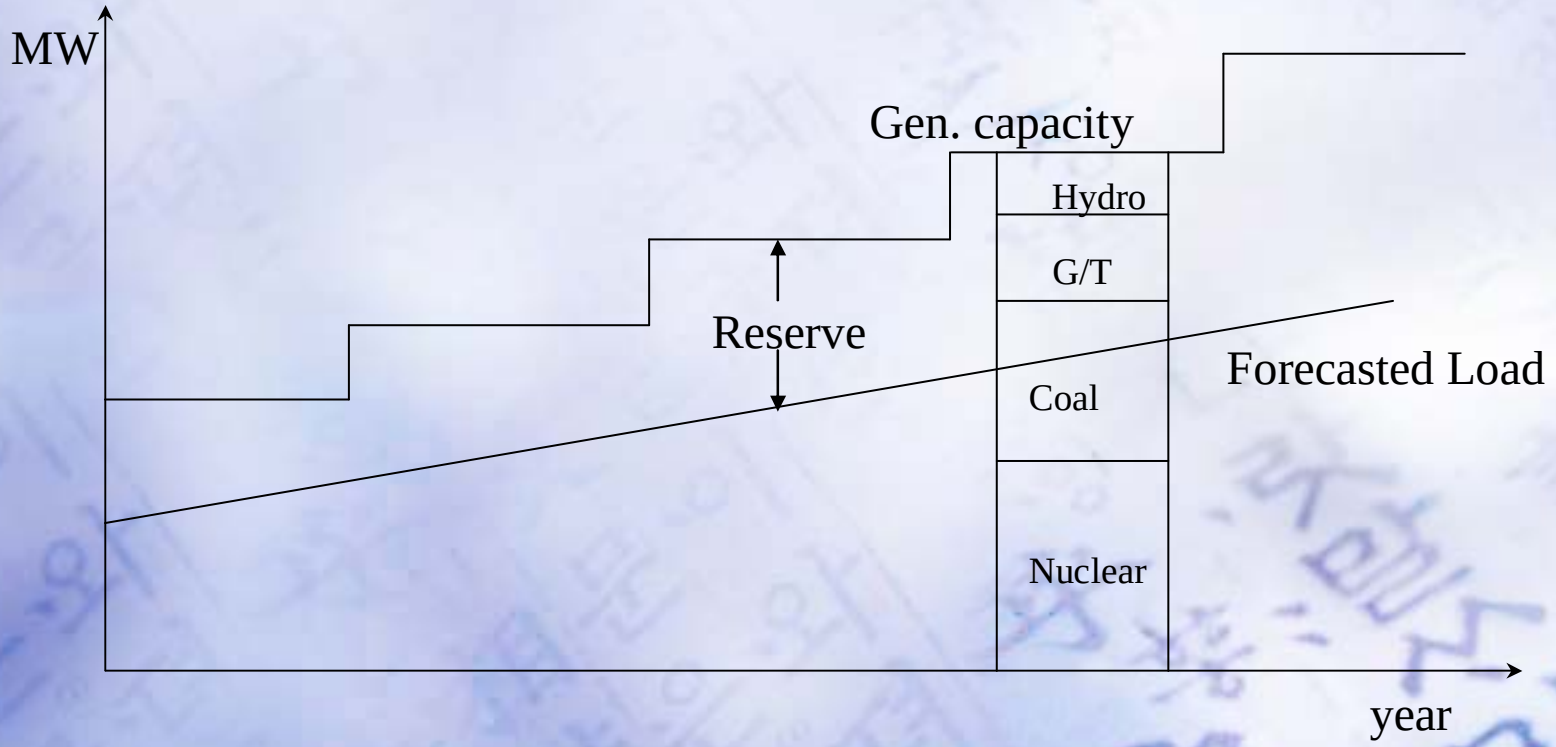


Demand/Supply Plan procedure

Establish directions for Master Plan	○ Government
⇩	
Submit materials covering each field (Including the letter of intent for construction submitted by the electricity business operators)	○ Electricity business operator/Korea Power Exchange
⇩	
Review and prepare working drafts	○ Practical work by the 6 working subcommittees
⇩	
Collect opinions related to Master Plan(Tentative plan)	○ Hold a hearing
⇩	
Examine Master Plan(Draft)	○ Electricity Policy Examination Council
⇩	
Finalize and announce Master Plan	○ Government

Generation Expansion Planning

- Determine least cost capacity addition plan under reliability criteria.
- Sum of present worth of yearly operation cost and investment cost is minimized.



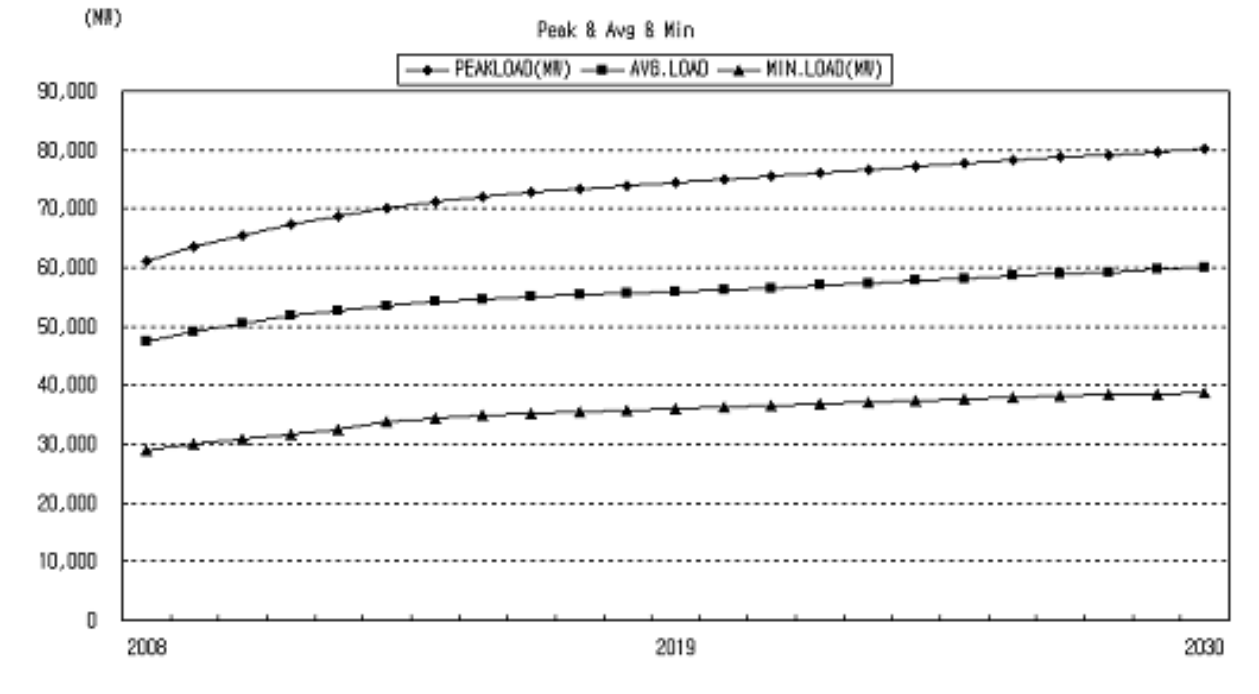
Greenhouse Gas Mitigation in the Electric Sector

- Generation Sector contributes to emission of CO_2.
  - Change of capacity mix in the planning stage
  - Control is possible by central decision-making and dispatch
  - Environmental dispatch in the operation stage
- Use of IGCC (clean coal technology), Use of CO_2-reducing Thermal Power Plants
- Renewed addition of Nuclear Power Plants
  - Resistance from NGOs to the construction of a nuclear power plant
  - But International turning-back to a nuclear power (solution to GHG problem)
- Expanded use of new and renewable sources
- R/D for Energy storage, Fuel Cell Technology, and CO_2 sequestering
- Active implementation of Demand Side Management

Input Data

Load Data

- Electricity Demand
  - Input data for 3rd Long-term Power Development Plan
- Transmission Loss and Aux. use
  - T/D loss 4.5%,
  - Aux. Use 4.56%
  - 109 % of Energy Sales : Energy Generation
- Renewable Energy and CES (Community Energy System)
  - Generation: 0.9% of total Generation (2007)
  - 1.0 % in the year 2008
- Forecasted Energy (without energy from decentralized generation)



Candidate Power Plants

- Base Scenario

	Capacity (MW)	type	Fuel Cost (c/10^6 kcal)	FOR (%)	Fixed O&M cost ($/kW-month)	Heat value of fuel (kcal/kg)	CO2 emission (% wt. of fuel)	Capital cost ($/kW)	Plant life (yr)	Construction time (yr)
CC5H	500	LNG	3,535	6.6	3.09	12,996	305	680	20	2.5
CC7H	700	LNG	3,535	6.6	2.66	12,996	305	665	20	2.5
C500	500	Thermal	953	4.8	3.11	5,911	234	1,161	30	3.7
C800	800	Thermal	953	4.8	2.52	5,911	234	1,064	30	4.3
C10H	1,000	Thermal	953	4.8	2.28	5,911	234	962	30	4.3
N10H	1,000	Thermal	138	5.1	8.01	N/A	N/A	1,853	40	5.3
N14H	1,400	Thermal	138	5.1	6.77	N/A	N/A	1,731	40	5.7

- IGCC/MEA Scenario

	Capacity (MW)	type	Fuel cost (¢/10^6 kcal)	FOR (%)	Fixed O&M cost ($/kW-month)	Heat value of fuel (kcal/kg)	CO_2emisison (% wt. of fuel)	Capital cost ($/kW)	Plant life (yr)	Construction time (yr)
CC5H	500	LNG	3,535	6.6	3.09	12,996	305	680	20	2.5
CC7H	700	LNG	3,535	6.6	2.66	12,996	305	665	20	2.5
C800	800	Thermal	953	4.8	2.52	5,911	234	1,064	30	4.3
C80A	800	CO2-reduction	953	5.5	4.10	5,911	23.4	1,808	30	4.3
IGCC	500	IGCC	953	20.0	3.68	5,911	93.648	2,308	30	4.8
N10H	1,000	Nuclear	138	5.1	8.01	N/A	N/A	1,853	40	5.3
N14H	1,400	nuclear	138	5.1	6.77	N/A	N/A	1,731	40	5.7

Simulation

Changes in Capacity Additions

- **Base and IGCC/MEA scenarios**
  - Concentration on coal-fired units: if there is no carbon tax or that of 10 US $ /ton.
  - For the first 4 years, coal-fired units cannot be chosen.
  - Therefore construction of LNG combined cycle is inevitable.
  - IGCC and nuclear power plants were allowed to appear in 8 years.

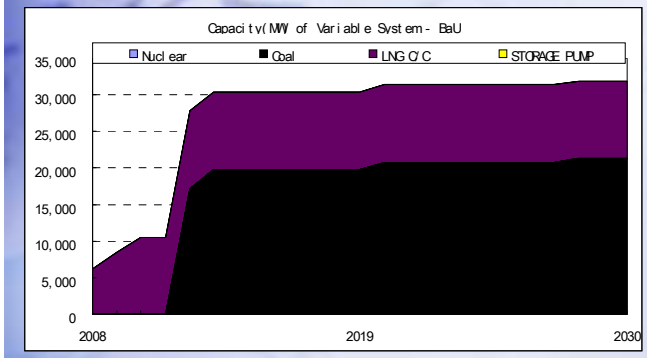
- **Increasing carbon tax**
  - Share of coal-fired units are reduced and nuclear units begin to appear under the carbon tax of 20 US $/ton.
  - Nuclear unit's share does not increase and only keeps certain share
  - The vacuum created by reduction of coal-fired units is replaced with LNG-fired combined cycle units.
  - In the case of IGCC/MEA scenario, nuclear units appear from year 2015 and IGCC units become competitive from the year 2020.

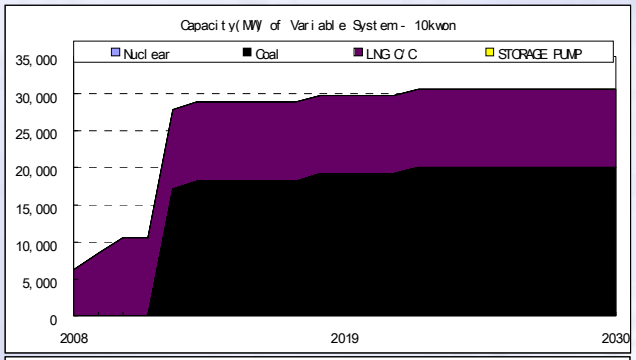
- **Increase of carbon tax from above 20 US $ in the IGCC/MEA scenario,**
  - Nuclear units does not appear, nor coal-fired units.
  - Instead, LNG-fired combined cycle units appear.
  - It should be noted that, under the base scenario, addition of coal-fired units remain unchanged but in the IGCC/scenario, coal-fired units are not chosen as the amount of carbon tax is increased.

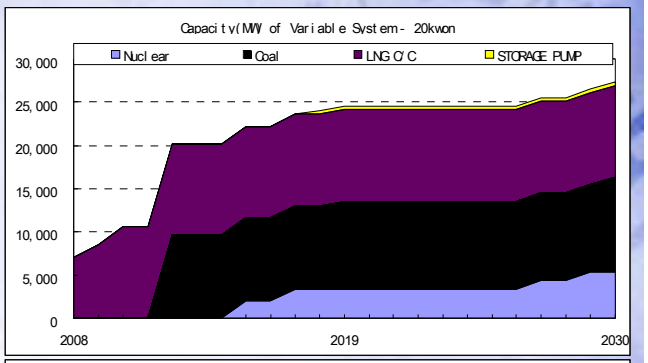
- **In the range of 20~25 $ of carbon tax.**
  - Nuclear power plants are favored, pumped storage power plants are selected.

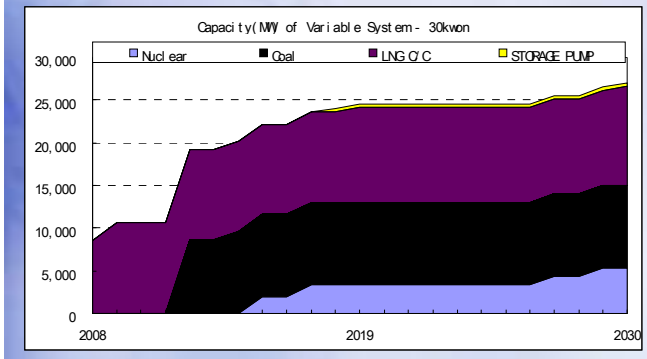
- **If we increase carbon tax above 60$/ton,**
  - Nuclear power plants are diminished, LNG-fired combined cycle units are added.
  - IGCC/MEA scenario, as the capacity of IGCC and thermal power plants with CO2-absorbing equipment increases, and share of base-load units increases.
  - Pumped storage take the role of serving peak load.

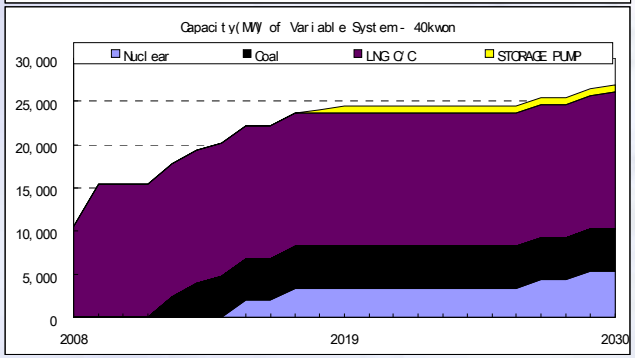
Future Capacity Addition- Base Scenario

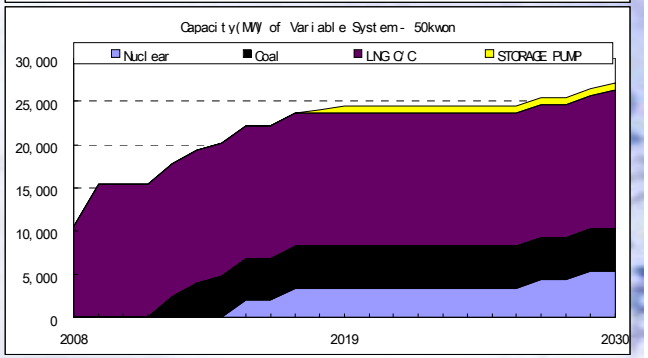


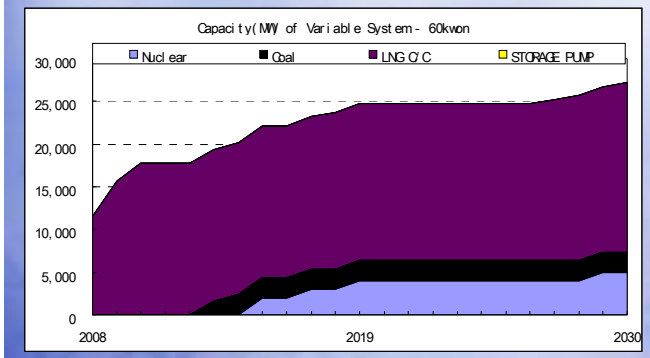


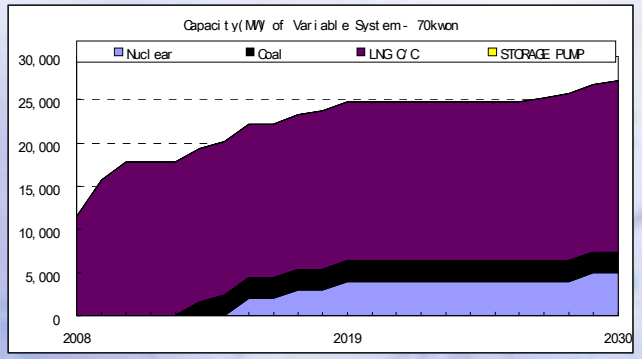


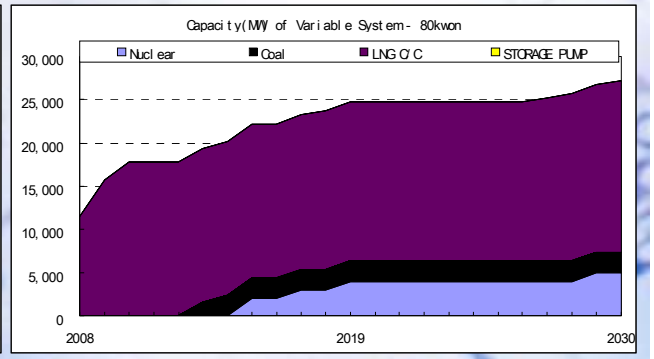




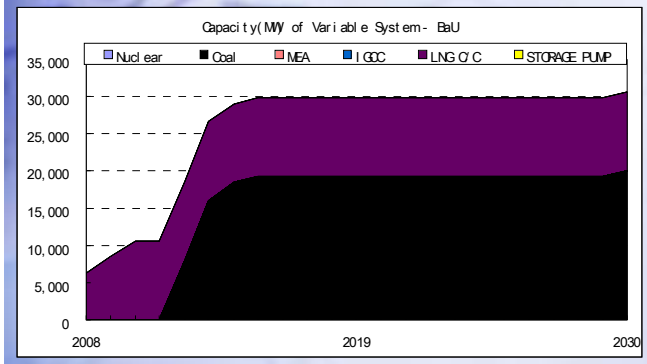


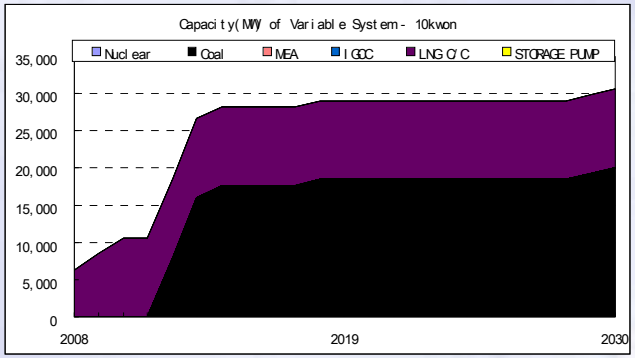


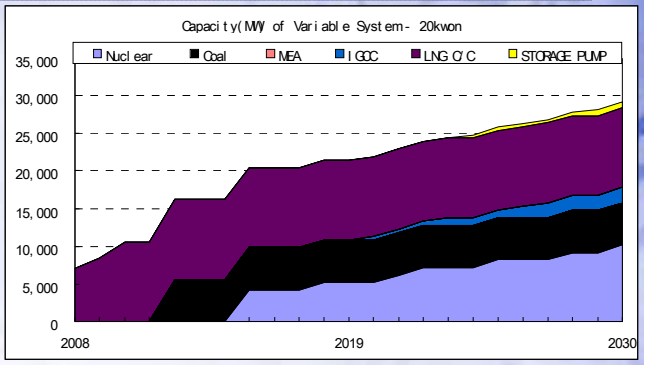


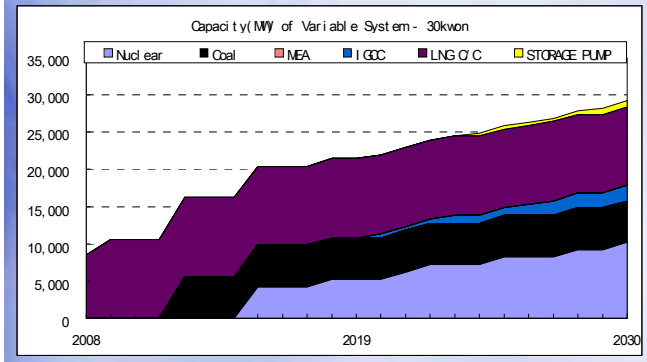


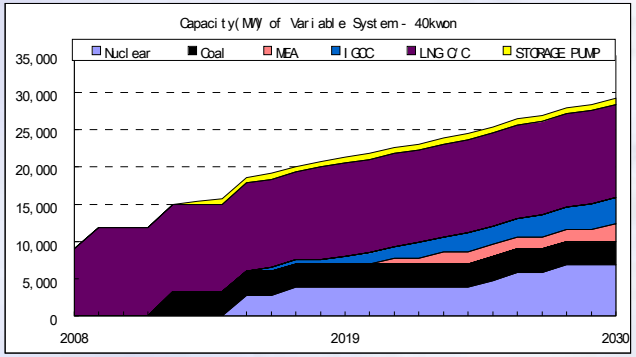
Future Capacity Addition- IGCC/MEA Scenario

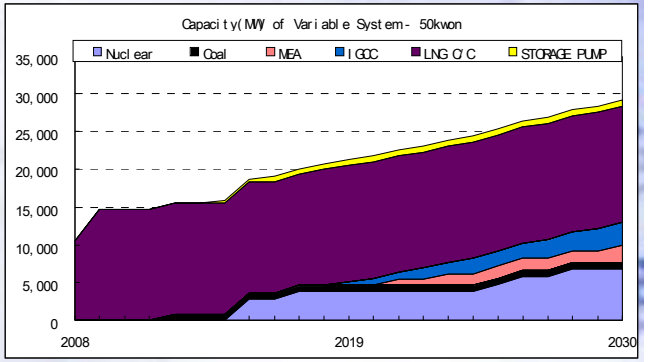


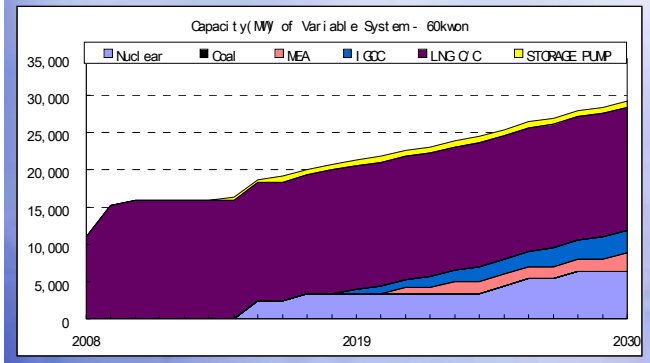


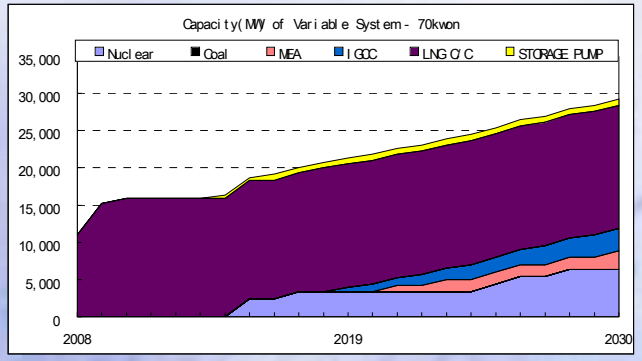


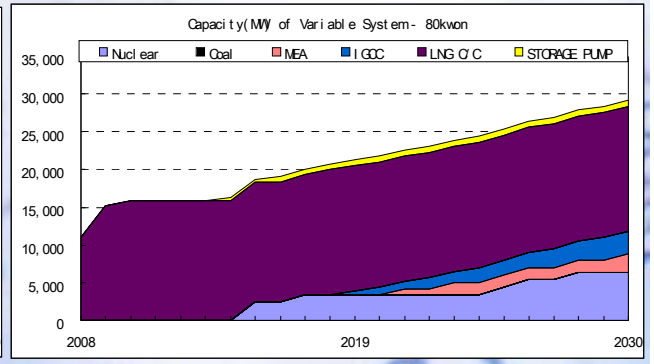








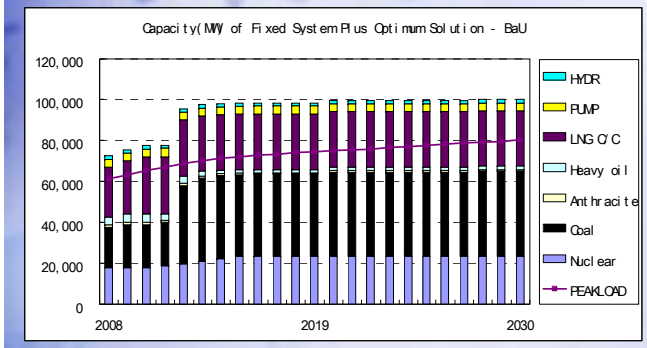


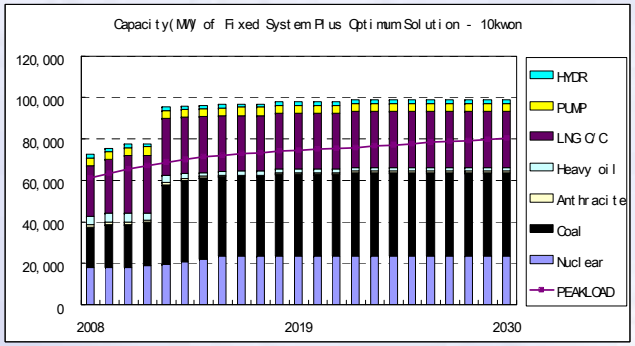


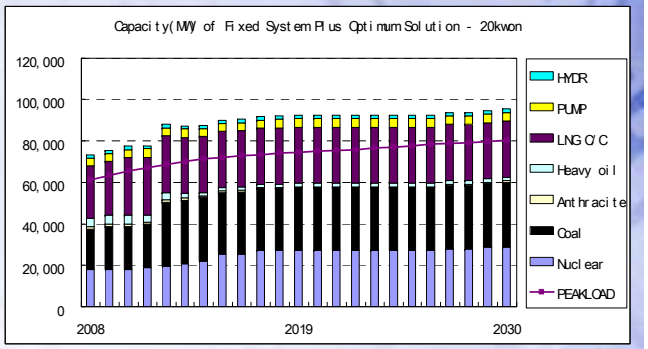
Capacity mix by fuel types

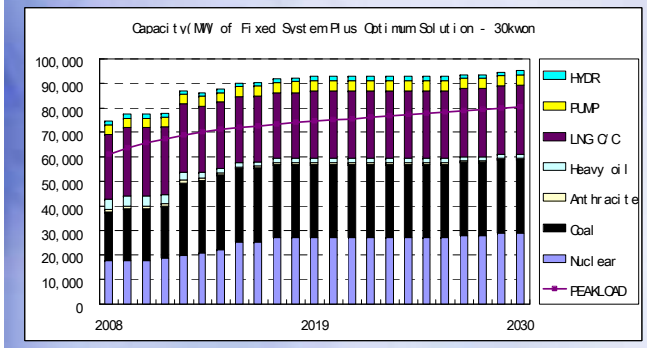
- Coal-fired power plants are competitive under low carbon tax, but due to construction lead time, coal-fired units cannot be added.
- But after 2012, installed reserve capacity rapidly increases due to construction of coal-fired units with LOLP below 1.0 days/year.
- As carbon tax is increased, addition of coal-fired units are slowed down and LNG-fired combined cycle units are chosen.
- Share of IGCC and CO2-reducing units are not significant among total capacity and the change of their share are not noticeable.
  - In the later years, existing power plants will retire and accordingly, the vacuum will be filled with IGCC and CO2-reducing power plants.

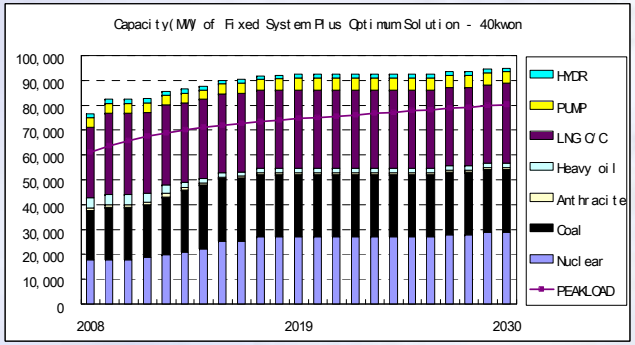
Capacity Mix – Baseline scenario

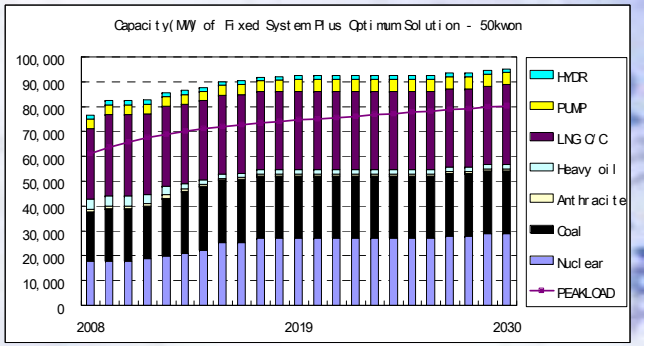


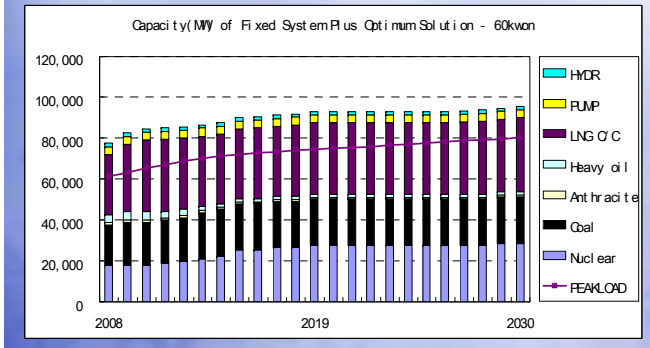


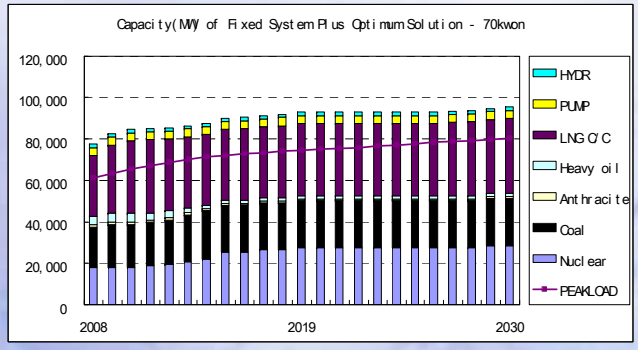


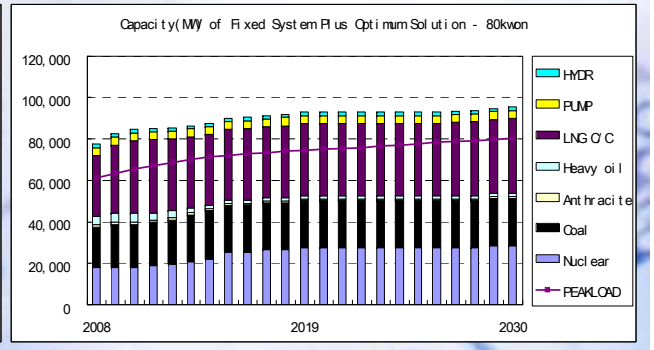




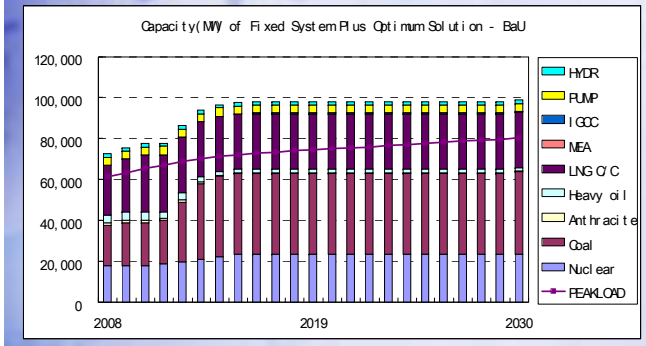


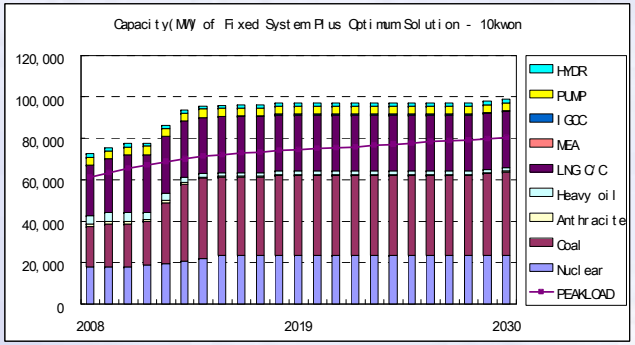


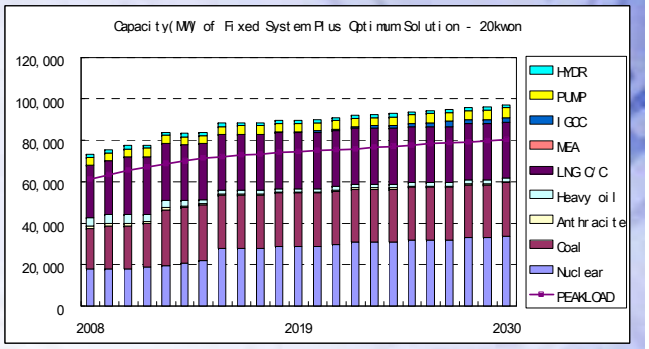


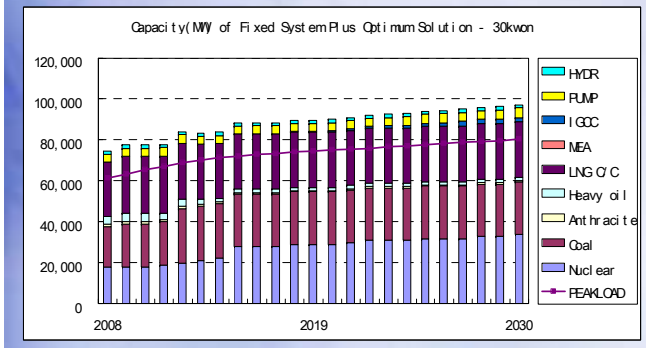


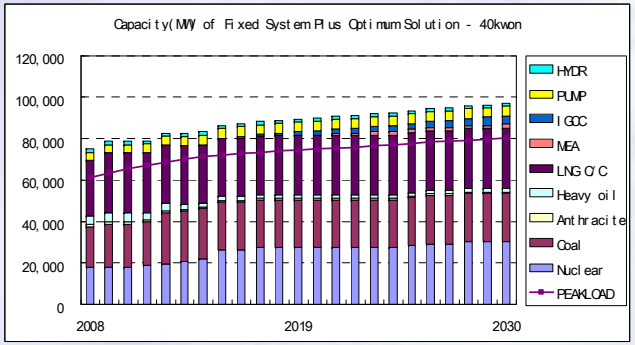
Capacity Mix – IGCC/MEA scenario

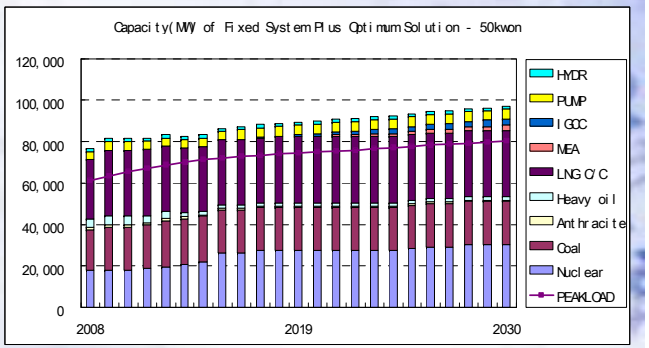


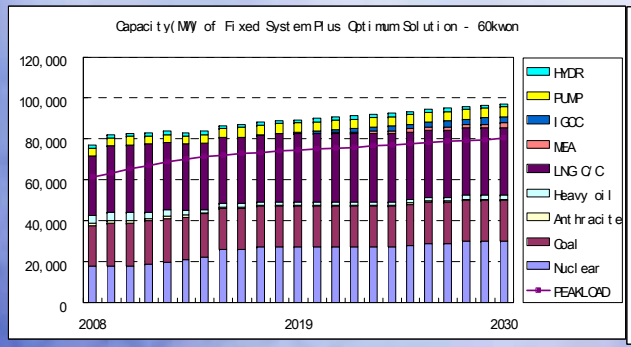


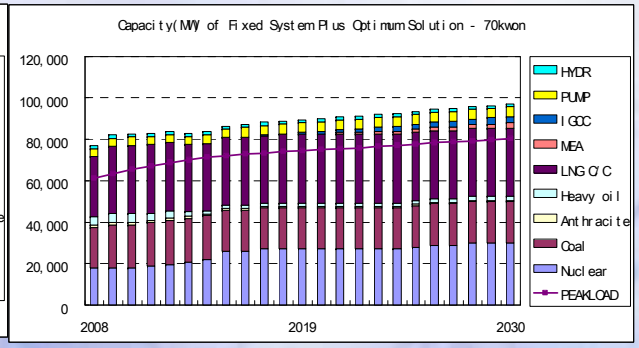


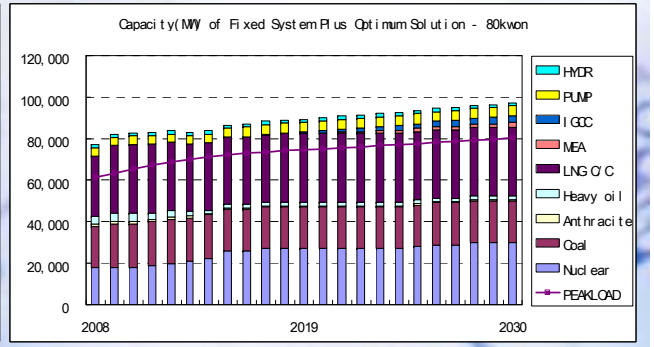








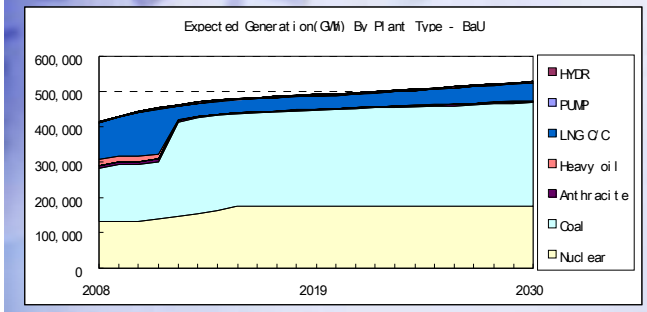


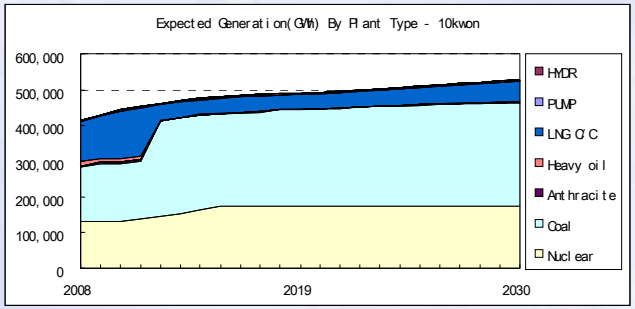


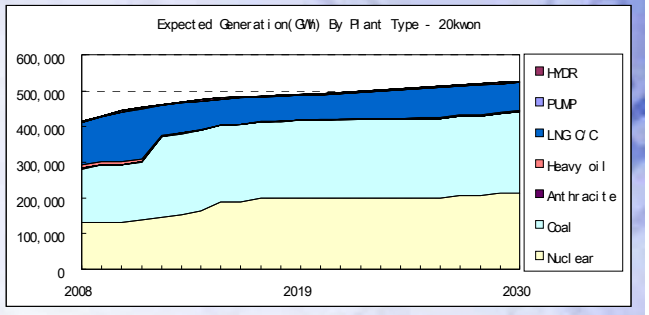
Energy Generation by Fuel Types

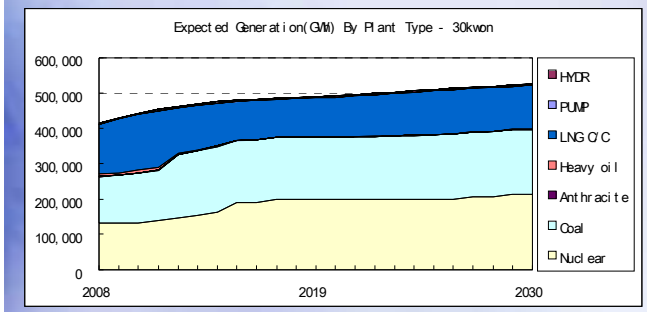
- Carbon tax's effect on fuel cost which dominates generating system's operation cost.
  - Increase of carbon tax influences merit order and system's fuel cost.
  - In the case of no carbon tax or 10 $ carbon tax, generation from coal-fired units rapidly increases.
- For the LNG-fired combined cycle units, their share among total generation was around 30%.
  - As Coal-fired units are added, LNG-fired combined cycle units behaves as peak-load generators.
  - As we increase carbon tax, LNG-fired combined cycle replaces some share of mid-load power plants.
- In the case of nuclear power plants, these units share the positions with coal-fired units up to the shoulder of load duration curve.
  - As carbon tax is increased, they supply the load up to minimum level.
  - Since capital cost of nuclear power plants are big, they cannot expand their position if their capacity factor is below a certain level.
  - Nuclear power plants take the role of base–load units.
- IGCC units have high competitiveness because of high efficiency and
  - CO_2-reducing power plants are cost-competitive because of CO_2-reduction capability and have more generation amount compared to their capacity.

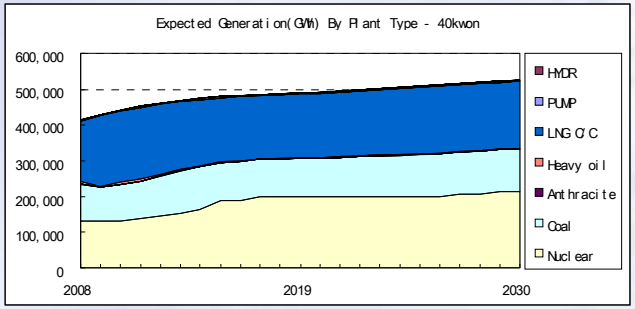
Generation by Fuel Type - Base Scenario

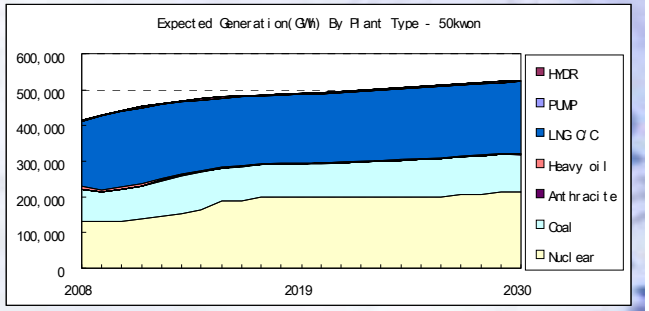


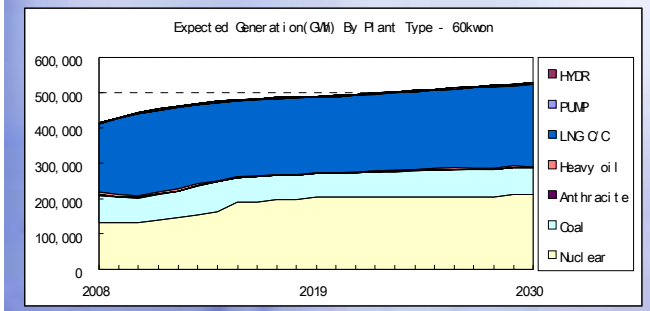


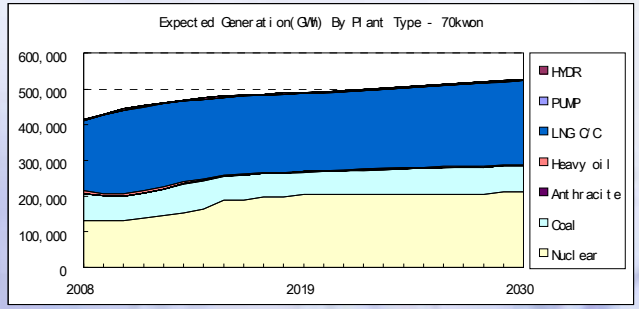


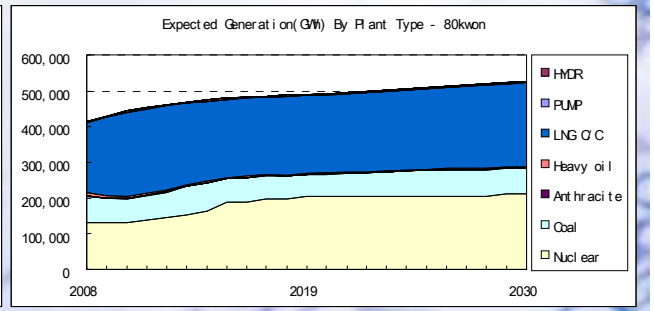




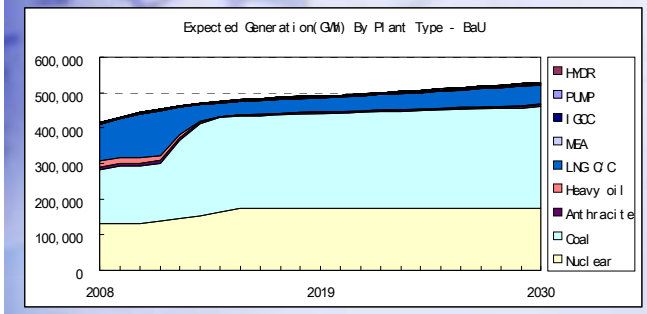


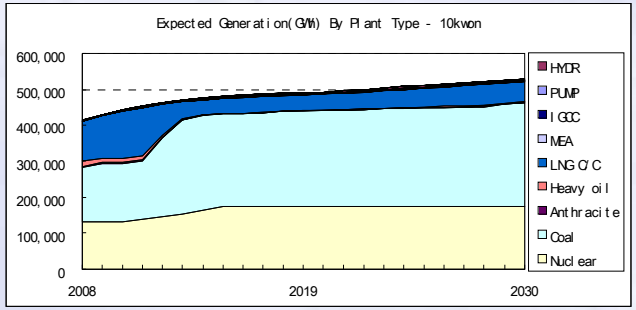


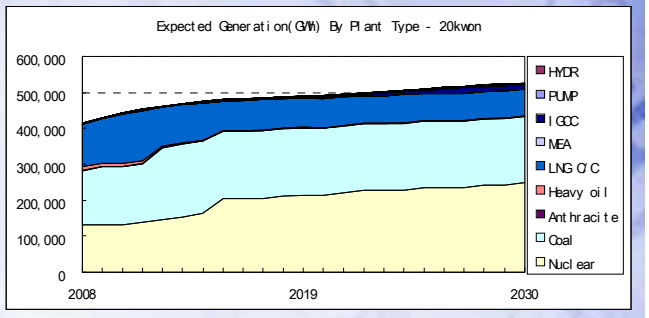


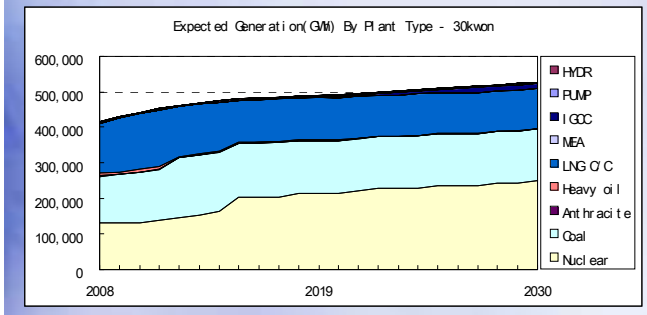


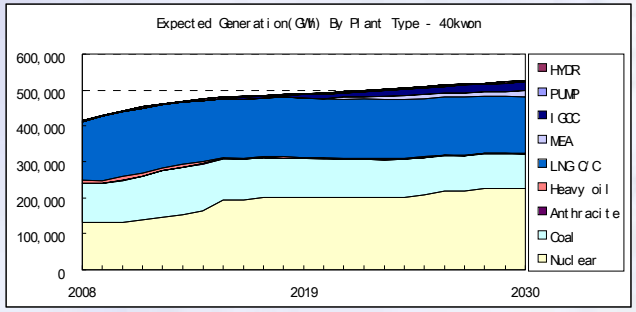
Geberation by Fuel type – IGCC/MEA Scenario

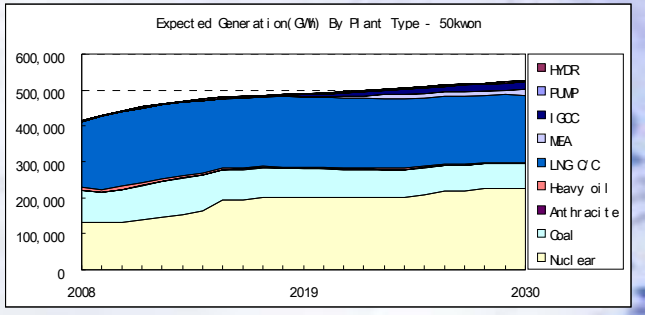


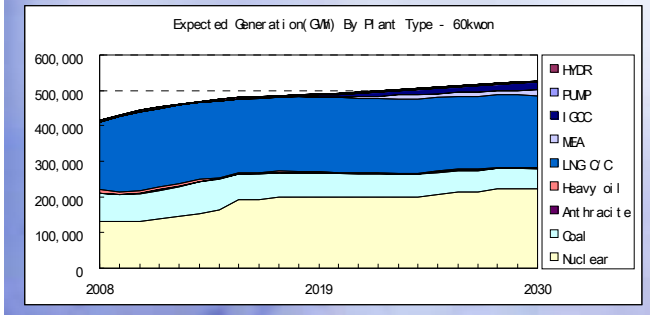


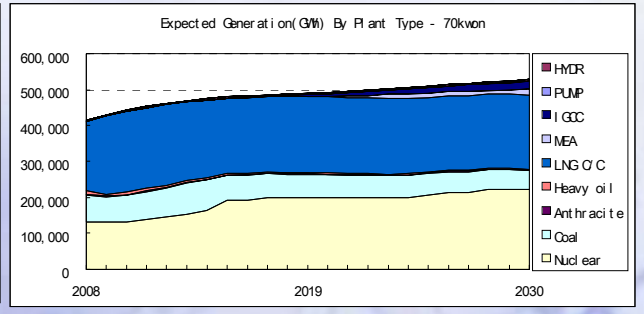


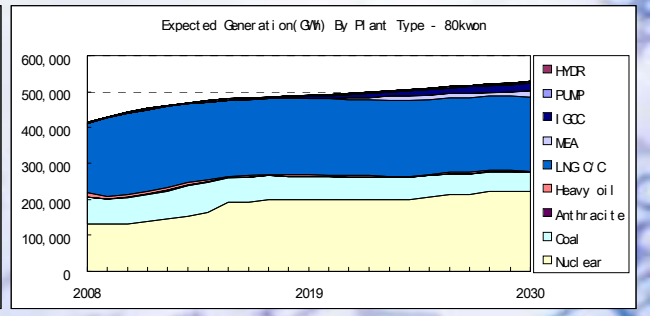










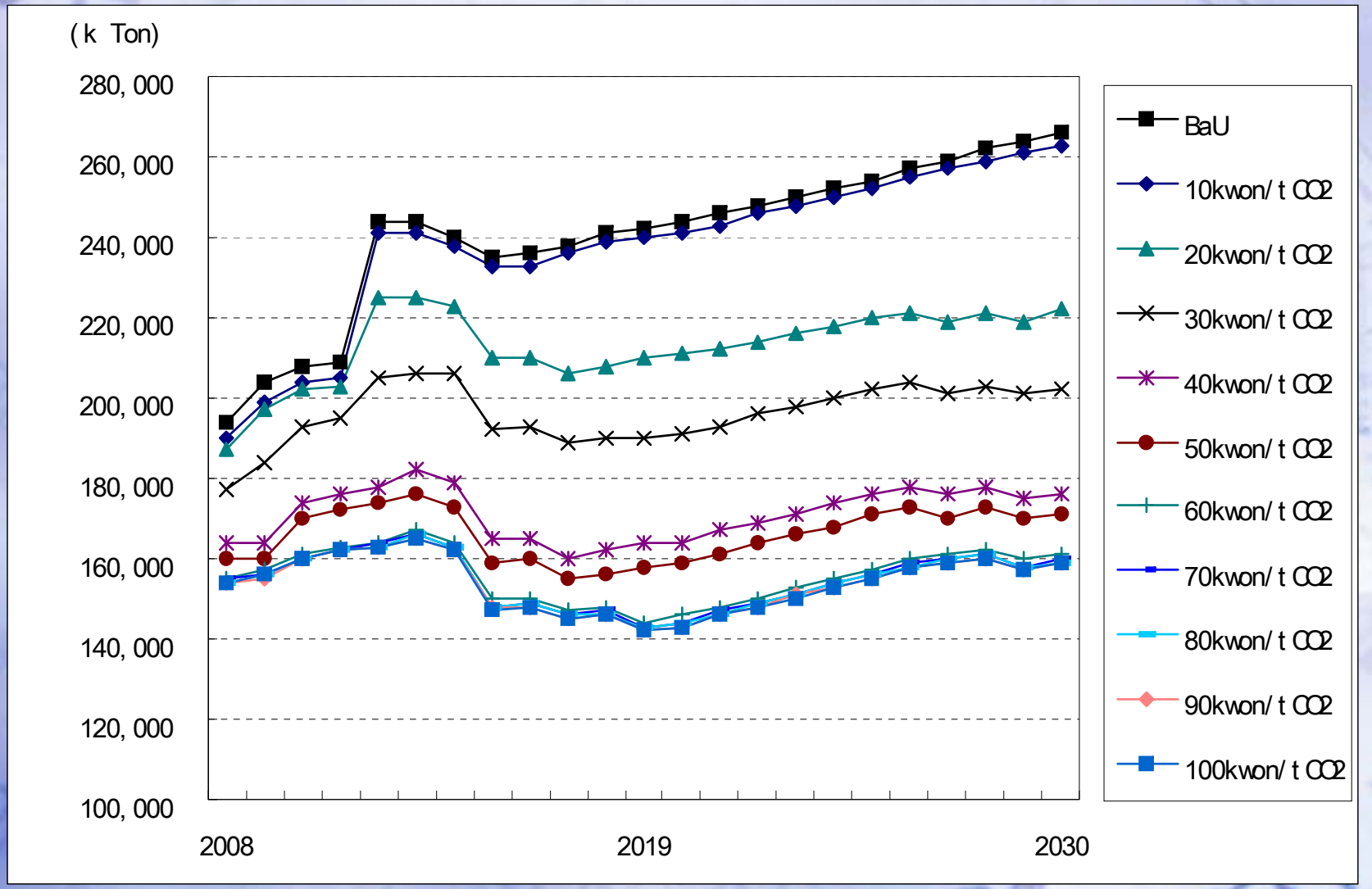


Emission of CO_2

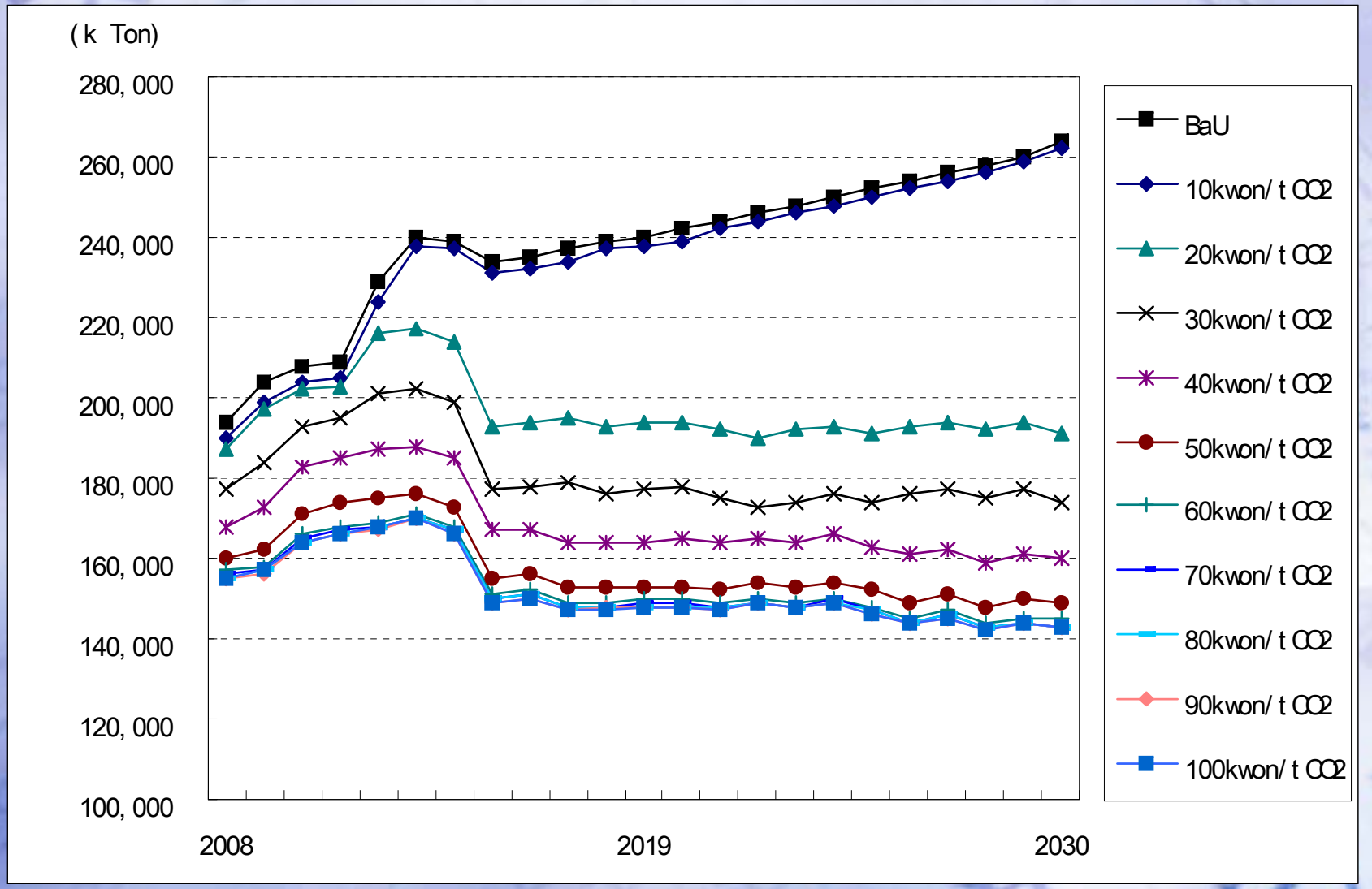
- In BaU case, the amount of emission increases monotonously, and this is notable in the year 2012.
  - As we increase carbon tax, CO_2 emission quantity is decreased.
  - If nuclear power plants are added, the quantity is reduced and it is decreased further due to carbon tax.
  - If carbon tax is 10$/ton, the quantity remains unchanged but if we increase it above 10$, emission is rapidly reduced.

- If we increase the number above 60$/ton, the effect is saturated.
  - This is due to the fact that the increase of variable cost with their investment cost is not competitive with other types of generating units capacity mix does not change with the tax above 60$/ton.
  - Emission quantity may not be reduced further.
  - Under the same carbon tax, IGCC/MEA scenario has less CO_2 emission quantity and particularly, reduction quantity is reduced rapidly with 20~30$ /ton but two scenarios show similar emission quantity with carbon tax above 60$/ton.

Emission of CO_2 – Base Scenario



Emission of CO_2 – IGCC/MEA Scenario



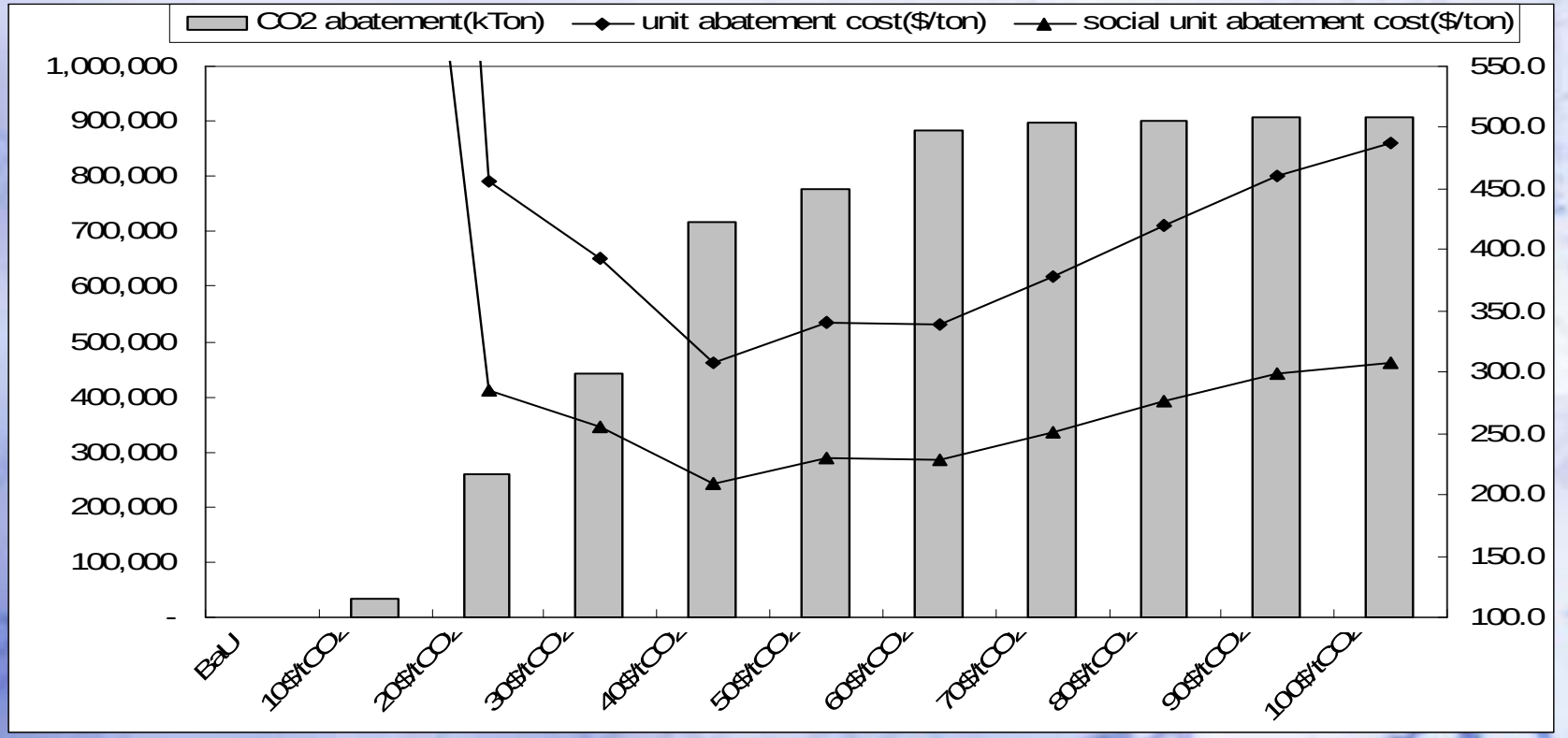
Cost of CO_2 Reduction

- We subtracted respective CO_2 emission quantity with different carbon taxes from CO_2 emission quantity of BAU case (carbon tax =0).
  - We showed CO_2 reduction cost by subtracting total cost of BAU case (carbon tax =0) from that of cost under different CO_2 taxes.
  - Future cost and reduction quantities are also present-worthed to the year 2007.

- Emission quantity of CO_2 is not reduced although we set 60$ carbon tax and the unit cost of CO_2 reduction increases in proportion to carbon tax.
  - Carbon tax higher than 60$/ton will not help to reduce CO_2 emission target.
  - Unit reduction cost of 308.5$/ton was obtained for the carbon tax of 40$/ton and reduction quantity is 718,821 kton-CO_2.
  - In the IGCC/MEA scenario, unit reduction cost is 304.2$/ton and reduction quantity is 370.817 kton-CO_2.
  - Carbon tax is included in the reduction cost and generating company pays the cost.
  - In order to estimate optimal level of carbon tax, we calculated social cost of CO_2 reduction under the assumption that the tax levied on carbon tax is used for raising social benefit.
- Both scenario has socially optimum marginal abatement cost of near 200$/ton-$CO_2$.
  - In the IGCC/MEA scenario, the optimal carbon tax is lower than Base Scenario.
  - The assumption that carbon tax is contributed to social welfare is not perfect. Maybe there is any deficit to transfer from taxation to social welfare. So we can guess IGCC scenario has small deficit

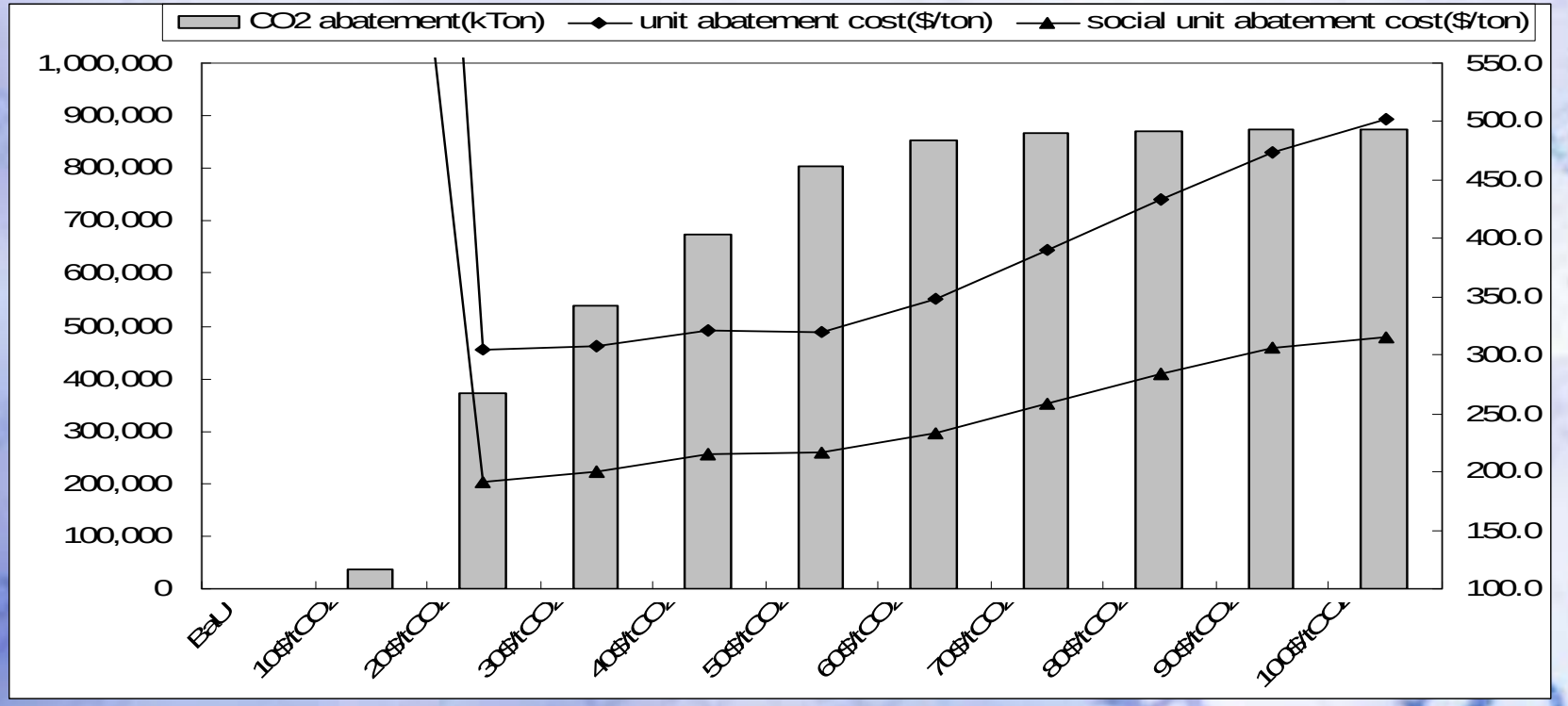
CO_2 Reduction Cost – Base Scenario

	BaU	10$ /tCO_2	20$ /tCO_2	30$ /tCO_2	40$ /tCO_2	50$ /tCO_2	60$ /tCO_2	70$ /tCO_2	80$ /tCO_2	90$ /tCO_2	100$ /tCO_2
CO_2 abatement (kTon)	-	34,840	258,799	442,152	718,821	776,400	885,044	896,492	899,593	905,498	905,509
unit abatement cost ($/ton)		1,765.8	456.4	393.5	308.5	340.7	338.8	378.3	420.4	459.7	487.3
social unit abatement cost ($/ton)		1,066.7	285.1	255.1	209.8	229.6	228.4	251.6	275.9	298.4	307.2



CO_2 Reduction Cost – IGCC/MEA Scenario

	BaU	10$ /tCO_2	20$ /tCO_2	30$ /tCO_2	40$ /tCO_2	50$ /tCO_2	60$ /tCO_2	70$ /tCO_2	80$ /tCO_2	90$ /tCO_2	100$ /tCO_2
CO_2 abatement (kTon)	-	35,498	370,817	537,467	674,819	804,566	854,309	865,816	869,672	874,855	873,661
unit abatement cost ($/ton)		1,716.3	304.2	307.8	321.7	320.2	348.1	389.6	433.2	474.4	502.3
social unit abatement cost ($/ton)		1,036.8	191.4	200.0	215.2	215.9	233.3	257.9	283.3	306.9	314.9



Conclusion

Findings and Conclusion

- Increase of CO_2 Tax → Reduced Share of Coal fired Units → Increase of Nuclear Power (partially replaced)→ IGCC and CO_2-reducing Power plants replace coal fired power plants of base-load units → Remaining share is taken by LNG-fired combined cycle
- Because of share of existing power plants, share of IGCC and CO_2-reducing power plants seems negligible → Existing power plants will be replaced by IGC and CO_2-reducing power plants
- Nuclear power as a base-load is one of the best candidates for mitigation of GHG → Because of high investment cost and heat rate, these are not competitive with low capacity factor
- IGCC forms another alternative for mitigating GHG, with high efficiency, and is competitive but reliability & availability must be enhanced by R/D activities.
- Limitation of Case Study
  - Deterministic approach is used for capital and O/M cost, cost reduction by technology innovation is not considered.
  - Techno-economic data for IGCC plants are very uncertain and differs by literature.
  - Reducing the uncertainty of input data is most important task.
- Role of Nuclear Power plants under yearly emission constraint needs to be studied.

Findings and Conclusion

- Nuclear Power with Emission Constraint is a superior option with less distortion in economic dispatch.
- Reduction of CO_2 emission by constructing nuclear power plants must have priority. (NGOs)
- Contribution by decentralized generation using renewable energy sources are limited and not economically competitive in the foreseeable future.
- If regulation by total emission quantity is announed by the government, generation expansion plan needs to be reviewed with constraint in the emission quantities from fossil-fired generating units.
- Techno-economic data for thermal power plants with CO2 reduction equipment must be readjusted.

Thanks for your attention