Energy and Environmental Policy and Electric Utilities' Choice under Uncertain Global Warming

by

Masaki Takahashi

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Abstracts

The paper reviews and discusses uncertainty about global warming science, impact on society. It also discusses what assumptions have been made and how appropriate the assumptions in scenarios have been for estimating global warming and its impacts. It then reviews energy consumption and supply trends and past environmental issues and countermeasures, and discusses energy and environmental policy including: regulations, taxes and emission rights, as well as how global environmental policy should be formed and how technology transfer helps developing countries. Finally it discusses issues in energy resource and technologies for fossil fuels, nuclear energy, renewable energy, efficiency improvements and suggest the choice for utility industries under uncertain global warming. It concludes that global warming is not an issue of high priority and CO2 emission rate is not an appropriate index to form energy and environmental policy, and that an appropriate population and economic growth rate, energy consumption rate reduction should be sought through efficiency improvement and technology transfer.

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1. Introduction

It began with an unusually hot May and June in the United States in 1988. Since then fierce heat, droughts, forest fires, storms and all other unusual weather have been discussed in the news media in relationship to global warming. "Global warming" and "the greenhouse effect" have become popular phrases and CO2 has played the role of villain as the major cause of global warming.

An international conference had already started to review scientific studies in Villach, Austria in 1985, but did not attract much attention until June 1988, when the international convention titled "Changing Atmosphere" was held in Toronto, Canada, where "Time for Action" was agreed to and a declaration stating that "Developed countries will reduce 20% of CO2 emission by 2005" was adopted. (Kankyouhakusho, 1991)

The Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) in November 1988. The IPCC published three reports on scientific analysis, impact analysis and response strategies in 1990 and 1991. Recently the IPCC published a supplement report on scientific analysis. (IPCC, 1990, 1991, 1992)

Developed countries agreed on stabilizing greenhouse gas emission levels studied by the IPCC at the second World Climate Conference, at a ministerial meeting on air pollution and climate change in Noordwijk, Netherlands in November 1989 and International Negotiation Committee (INC) meeting started to set greenhouse gas emission targets.

After the World Climate Conference in November 1990 and many INC meetings in Washington D. C., Geneva, Nairobi, and New York in 1991 though 1992, the United Nations Conference on Environment and Development (UNCEO) or the "Earth Summit" was held in Rio de Janeiro, Brazil in June 1992. At UNCED global warming was signed, however, this convention did not set particular targets or timetables for reducing CO2 emissions. This was a reasonable choice. Why it was a reasonable choice will be discussed in this paper.

In the US, the EPA released a draft report to congress entitled "Policy Options for Stabilizing Global Climate" in February 1989. They used a set of energy and CO2 emission models called the Atmospheric Stabilization Framework (ASF) and scenarios used in their study. The ASF was also used by the IPCC to generate its scenarios.

In April 1990, White House held a meeting on the scientific and economic aspects of global change with participants from eighteen major countries. This meeting emphasized the need for further scientific study on global climate change, and agreed that scientific uncertainty should not prevent countries from taking countermeasures.

The Office of Technology Assessment (OTA) published a report in February 1991 titled "Changing by Degrees -- steps to reduce greenhouse gases" which used a bottom up approach to investigating the technical measures available for reducing greenhouse gases. (OTA, 1991)

National Research Council (NRC) took a similar approach in its study "Policy Implication of Greenhouse Warming." (NRC, 1991) Its adaptation and mitigation panels concluded that technical measures to adapt to and/or mitigate global warming will not cost very much in the US.

On the contrary the Department of Energy (DOE) used a top down approach in its report "Limiting Net Greenhouse Gas Emissions in the United States" in September 1991. The DOE compared the economic costs of the current policy cases with and without National Energy Strategy (NES), and Carbon Tax cases from $25/tC to $750/tC. The DOE concluded that a carbon tax would place a heavy burden on the US economy and that the NES action would be enough to reduce greenhouse gas emissions. (DOE, 1991)

In the process of INC meetings the US has been criticized by many environmentalist groups and the mass media for being unwilling to set CO2 emission targets and timetables. However, many of the studies of the economic impacts on society, available technical countermeasures and the science of global change have been done by the US. Thus international discussions on global warming are heavily dependent on research done in the United States.

The primary reason the US government has been unwilling to set CO2 reduction targets is to protect its own economy and industries, however it is also true that it is better informed about scientific and economic study results on global warming than that of any other countries. "No-regret" policies, which identify and accelerate measures to be taken anyway by other reasons regardless of the global warming, are good policies for the global warming. It is probably better not to set a target for CO2 emissions because the CO2 emissions are not really good indicators of the genuine problems posed by interacting between energy and the environment.

Typically in European Countries, environmental issues become political ideology before any scientific studies or economic calculations are completed. Europeans are leading to form the opinion of and are independently setting CO2 emission targets and trying to implement a carbon tax. In October 1990, EC commissions adopted the "Luxembourg Agreement" which set a target of total EC CO2 emission to be stabilized at 1990 levels by the year 2000. In some European countries, carbon taxes have already been implemented, although we must understand that countries like Norway have almost totally depended on hydroelectric generation and are not thus a good model for other countries. In addition the EC is considering tax exemptions for specific industries. The EC Carbon/Energy Tax has naturally put as a condition for implementation that they will not lose competitiveness with the US and Japan.

In Japan the "Chikyuu ondanka boushi koudou keikaku" (Action plan for global warming prevention) was made public in October 1990. This plan set CO2 emission targets in two ways. The first target is to stabilizes per capita CO2 emissions at the 1990 levels by the year 2000, and the second target is to stabilizes the national total CO2 emission at the 1990 level by the year 2000. The second target assumes the fast development of advanced technologies such as photo voltaic, hydrogen energy and CO2 fixation. At the White House meeting in April 1990, and at the Houston Summit meeting in 1990, the Japanese government introduced the idea of "Chikyuu saisei keikaku" (Plan to regenerate the globe) which listed future technologies to be developed to cope with global warming.

These Japanese government policies and reactions from industries as well as the expectation of financial contribution on this issue gives the impression that Japan is highly technology driven or business oriented and does not pay much attention to the facts or causes of the global warming, but is using this issue as a business opportunity.

This paper reviews facts and assumptions about global warming science and scenarios in chapter 2. Then in chapter 3 it explores energy and environmental policies on global warming based on historical energy trends, and reviews past environmental measures. Finally in chapter 4 it explores the energy and environmental aspects of fossil fuels, nuclear energy and renewable technologies and efficiency improvements for electric utilities' choice.

2. Global Warming - Is it an issue?

We have seen expressions like "CO_2 which causes global warming" recently in newspaper and magazine articles. These articles often describe miserable futures resulting from global warming caused by the fossil fuel use. This chapter reviews what is known and what is unknown about the facts, causes and impacts of global warming.

The Intergovernmental Panel on Climate Change (IPCC) published a report by each of its working groups: Scientific, Impacts and Response Strategies, in 1990 and 1991. (IPCC, 1990 and 1991) The IPCC also published a supplement to the scientific analysis report recently.(IPCC, 1992)

The IPCC reports all included highly-simplified policymakers' summaries and executive summaries in each report. Often only these summaries attract attention. It is convenient to have these summaries, however sometimes they can be misleading and can cause misunderstandings. (see for example EPRI, May 1991) For example, in the summaries important assumptions which were used to get the results and the details of the results are often ignored.

Hundreds of scientists participated to the work of the IPCC. Many of the IPCC's important results were extracted from recent studies on climate change. But we should remind ourselves what was expected of the IPCC when we read these reports. The IPCC itself is careful in expressing the conditional nature of its results in the body of its reports, but when the results are extracted into the summaries, they are often translated into definitive language.

Among all the uncertainties of climate change discussion, it will be safer to say, "It is uncertain, but if we assume the worst case, this kind of bad results could happen, so some measures should be taken." rather than to say, "It is possible to think about the worst case, but it will probably not happen." IPCC was expected to report scientific analysis, impacts to the society and possible response to it, and organized as such from the beginning, and work was done almost parallel at each working group. If scientific analysis group conclude there will be no global warming, then the other groups work will be meaningless. Therefore scientific group was naturally expected to report visible global warming at least in once scenario.

This chapter reviews following subjects:
- Is global warming occurring or will it occur in the future?
- Is CO_2 a major player of greenhouse effect?
- CO_2 emissions and concentrations in the atmosphere
- Effects of other minor greenhouse gases and aerosols
- Impacts of global warming to the society
- IPCC scenarios and Business as Usual

2.1 Is global warming occurring and/or will it occur in the future?

The IPCC concluded in its summary that "Global mean surface temperature has increase by 0.3 to 0.6C over last 100 years" (IPCC, 1992, p.4, "Our major conclusions")

This statement is true, supposing that the data and analysis collected by the IPCC is correct. But this simplified conclusion gives readers the impression that the average temperature has been increasing gradually since the industrial revolution started and human activities begun to grow. The fact is, according the body of the IPCC report, that global mean surface temperature increased until the 1940's. Since the 1940's there has been almost no change. In fact there was a slight decrease in the mean temperature between the 1940's and the 1970's (during this period global cooling was discussed). This was followed by an increase in 1980's. (Fig. 2-1-1) Important details have been ignored in the IPCC's simplified conclusion.

What we can conclude from the observation of global mean surface temperature is that the constant increase in atmospheric CO_2 concentrations (which is the only fact we can rely on in the global warming discussion) does not correspond to the global mean surface temperature on the order of decades. We cannot conclude that human activities caused the global warming by observing past temperature records. The IPCC's next conclusion was carefully described in this sense.

"The size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus the observed increase could be largely due to this natural variability; alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming" (IPCC, 1992, p.4, "Our major conclusions")

Chapter 8 "Detection of the Greenhouse Effect in the Observation" of IPCC scientific analysis report (IPCC, 1990, WG I) provides more details. The signal of global warming caused by greenhouse gases are small compared with the noise of natural variations including the variation of solar radiation, volcanic aerosol's cooling effect, ocean current change as well as anthropogenic causes like SO_2 emission from fossil firing. It could be concluded that all of the temperature variation has been caused by noise of natural origin, or it could be concluded that human induced global warming has already happened around 1-2 °C scale but has been offset by much greater natural noise. Which view one takes depends on the assumptions one makes about the of negative or positive effect of natural noises. (IPCC, 1990, WG I, p. 247)

When the IPCC applied the model to predict present temperatures from the past temperature record and CO2 concentrations increase, it overestimates (by 1°C) the temperature increase, although the actual increase was around half of that. Lindzen, professor of MIT earth, planet and ocean department, explains this as follows:

"Not only are there major reasons to believe that models are exaggerating the response to increasing CO2, but, perhaps even more significantly, the models' predictions for the past century incorrectly describe the pattern of warming and greatly overestimate its magnitude. Fig. 5 (Fig 11 in IPCC 1990, and Fig 2-1-1 in this paper) shows the global average temperature record for the past century or so. The record is irregular and not without problems. However, it does show an average increase in temperature of about 0.45 ± 0.15°C with most of the increase occurring before 1940, followed by some cooling through the early 70's, and a rapid but modest temperature increase in the late 70's. Now, as we have noted, we have already seen an increase in 'equivalent' CO2 of 50%. Thus, on the basis of models which predict a 4°C warming for doubling of CO2 we might expect to have seen 2°C already. However, if the delay imposed by the oceans' heat capacity is included, the expectation is reduced to about 1°C. This is still twice what has been seen. Moreover, most of what has been seen occurred before the bulk of the minor greenhouse gases were added to the atmosphere. Fig. 6 (Fig 8.1 in IPCC 1990, and Fig. 2-1-2 in this paper) shows what might have been expected for models with differing sensitivities to a doubling of CO2. What we see is that the past record is most consistent with an equilibrium response to a doubling of about 1.3°C - assuming that all the observed warming was due to increasing CO2. However, there is nothing in the record that can be distinguished from the natural variability of the climate." (Lindzen, 1992, p. 6, emphasis by the author)

IPCC's last conclusion is worthy of more attention. "The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more." (IPCC, 1992, p.5) This means that recent events such as droughts in the United States , floods in Bangladesh, storms in Europe, warmer winters in the east coast and Japan are not necessarily caused by nor evidence of global warming. It is usual to have unusual weather somewhere in the world.

2.2 Is CO2 a major contributor to the greenhouse effect?

According to Lindzen, 98% of current greenhouse effect is due to water vapor and clouds. (Linzen, 1992, p.3) CO2's contribution to the greenhouse effect is only half of the rest of 2%. Therefore CO2 deserves the name "minor greenhouse gas" as Linzen used this term in his paper rather than "major". The IPCC expresses this fact by using the term "enhanced", and Figure 2-2-1 is explained as "the contribution from each of the human-made greenhouse gases to the change in radiative forcing from 1980 to 1990. " as the title of the figure. This long title tends to be shortened when it is cited or recognized, first omitting the time period considered as "contribution of human-made green house gases" and then further shortened to "contributions to greenhouse effect" which is apparently wrong. To avoid this kind of confusion, I would suggest, this figure should always be shown together with the absolute contribution to the greenhouse gas effect for the same time period, (Fig. 2-2-2) and put a note saying that water is not only the major greenhouse gas but can also vary itself.

Water is the major contributor to the greenhouse effect, and also play the major role in global warming. Without water vapors positive feedback, we cannot have significant warming, and the sign of this feedback is still controversial. This will be discussed below.

Water plays a major role in the form of water vapor, clouds and snow-ice albedo in the process of determining the atmospheric temperature. The present climate models used to predict global warming in response to the atmospheric CO2 concentration increase, takes into account these water feedbacks and the results are heavily dependent on them. (Table 2-2-1) The IPCC itself admits uncertainties and listed them in items of "key uncertainties and further work required", as "clouds (particularly their feedback effect on greenhouse-gas-induced global warming, also the effect of aerosols on clouds and their radiative properties) and other elements of the atmospheric water budget, including the processes controlling upper-level water vapor". (IPCC, 1992, p. 19)

Nevertheless IPCC's single most frequently cited conclusion of "global mean temperature of 3°C before the end of the next century" (IPCC, 1990, WG I, p. xi) or "the sensitivity of global mean surface temperature to doubling CO2 is unlikely to lie outside the range 1.5 to 4.5°C" is heavily dependent on these water positive feedbacks. According to Lindzen, "The way these factors (like clouds and water vapor) are handled in present models is <u>disturbingly arbitrary</u>." (Lindzen, 1992, p.5, emphasis by the author)

The IPCC describes water vapor feedback as "best understood" and "intuitively easy to comprehend", gave some simple numerical calculations and concluded, "water vapor feedback has amplified the initial global warming of 1.2C to 1.9°C, i.e., an amplification factor of 1.6". (IPCC, 1990, WG I, P. 78) However, according to Lindzen, it is not so simple.

"In many instances the underlying physics is simply not known. In other instances there are identifiable errors. Even computational errors play a major role. For example, existing models have only 10 - 20 levels in the vertical, which is inadequate for predicting the behavior of a substance like water vapor which varies immensely with height. The difficulty leads to model predictions of negative water vapor in some parts of the atmosphere. The arbitrary filling routines used to correct this obviously unrealistic behavior play a major role in the model water vapor budgets. In fact, there is compelling evidence for all the known destabilizing feedbacks in the models to actually be stabilizing (negative) feedbacks. In that case, we would expect the response to CO_2 doubling alone to be diminished." (Lindzen, 1992, p. 5)

For the cloud feedback, the IPCC is more careful in choosing its words. After a hypothetical calculation of positive feedback, it says, "It is emphasized that this is a hypothetical example, and there is no a priori means of determining the sign of could feedback." (IPCC, 1990, WG I, p. 79) "In that both cloud and snow-ice albedo feedbacks are geographical in nature, then these feedback mechanisms can be addressed through the use of three-dimensional numerical circulation models. (ditto)

However, sophisticated three-dimensional general circulation models can only make things more complicated, and they cannot answer the basic problem of whether the feed back is positive or negative. They are simply adjusted to get an acceptable positive feed back result.

"Cloud cover in models is poorly treated and inaccurately predicted. Yet clouds reflect about 75 watts per square meter. Given that a doubling CO_2 will change the surface flux by only 2 watts per square meter, it is evident that a small change in cloud cover can strongly effect the response to CO_2. The situation is complicated by the fact that clouds at high altitudes can also supplement the greenhouse effect. Indeed, the effects of clouds in reflecting light and in enhancing the greenhouse effect are roughly in balance. Their actual effect on climate depends both on the response of clouds to warming, and on the possible imbalance of their cooling and heating effects." (Lindzen, 1992, p. 5)

"An additional well-known positive feedback mechanism" (IPCC, 1990, WG I, p. 78) of snow-ice feedback sounds simple and reasonable. "A warmer Earth has less snow and ice cover, resulting in a less reflective planet which in turn absorbs more solar radiation." (ditto) However, reality is not so simple, as the IPCC itself admits. In warmer climates more water will be transferred to the polar regions from the tropical regions by cloud motion. This will result in more snow fall and accumulation during winter time, so it depends on how much snow falls and how fast it melts or evaporates. "There is a need to diagnose the interactive nature of this feedback mechanism more fully." (ditto) But in summarizing the process these cautions are ignored and the results are heavily dependent on the assumption of positive feedbacks.

Why did the IPCC explore only positive feedbacks of water vapor, clouds, and snow-ice albedo and not negative ones? Lindzen argues that, "It is commonly suggested that society should not depend on negative feedbacks to spare us from a 'greenhouse catastrophe'. What is omitted from such suggestions is that current models depend heavily on artificial positive feedbacks to predict high levels of warming." (Lindzen, 1992, p. 5) One simple answer to the question is that if they explored negative feedbacks, the results wuold be apparent: No warming would occur by doubling CO2 concentration. Thus their would be no impacts to society and no need for a response strategy. It would mean that there is no need for the working group II and III reports. They cannot deny their own reason for existing.

Ending this section, I want to cite Lindzen's paper again, and introduce his idea on what is really happening in the greenhouse effect mechanism.

"Fig 3 (Fig 2-2-3 in this paper) shows the common popular presentation of the greenhouse effect. The crude idea is that the atmosphere is transparent to sunlight (apart from the very significant reflectivity of both clouds and the surface) which heats the Earth's surface. The surface attempts to balance this heating by radiating in the infrared. The infrared radiation increases with increasing surface temperature, and the temperature adjusts until balance is achieved. If the atmosphere were also transparent to infrared radiation, then the infrared radiation produced by an average surface temperature of -18°C would balance the incoming solar radiation (less that amount reflected back to space by clouds, etc.). However, the atmosphere is not transparent in the infrared, and so the Earth must heat up somewhat more in order to deliver the same flux of infrared radiation to space. This is what is called the greenhouse effect. The fact that the Earth's average surface temperature is 15°C rather than -18°C is attributed to this effect...it is worth noting that the simple picture of the greenhouse mechanism is <u>seriously oversimplified</u>. Many of us were taught in elementary school that heat is transported by <u>radiation, convection, and conduction</u>. The above picture <u>only refers to radiative transfer</u>. As it turns out, if there were only radiative heat transfer, the greenhouse effect would warm the Earth to about 77°C rather than to 15°C. In fact, the greenhouse effect is only about 25% of what it would be in a pure radiative situation. The reason for this is the presence of convection (heat transport by air motions), which bypasses much of the radiative absorption. What is really going on is schematically illustrated in Fig. 4. (Fig. 2-2-4 in this paper) The surface of the Earth is cooled in large measure by air currents (in various forms including deep clouds) which carry heat upward and pole ward. One consequence of this picture is that it is the greenhouse gases well above the Earth's surface that are of primary importance in determining the temperature of the Earth. This is especially important for water vapor whose density decreases by about a factor of 1000 between the surface and 10km. Another consequence is that one cannot even calculate the temperature of the Earth without models that accurately reproduce the motions of the atmosphere. Indeed, present models have large errors here (order 50%), and not surprisingly, these models are unable to correctly calculate either the present average temperature of the Earth or the equator-pole temperature distribution. Rather, the models are adjusted (or 'tuned') to get these quantities approximately right." (Lindzen, 1992, p.3, emphasis by the author)

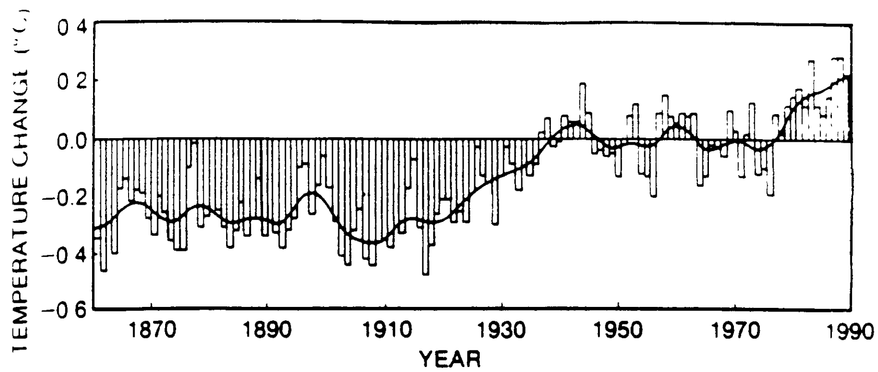


Fig. 2-1-1: Global mean combined land-air and sea surface temperatures

Sources: IPCC, 1990, WG I, Policy Makers Summary, p. xxix

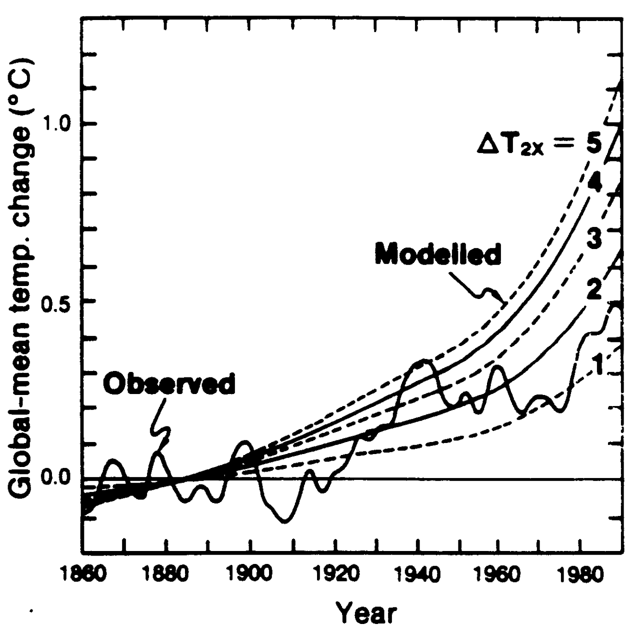
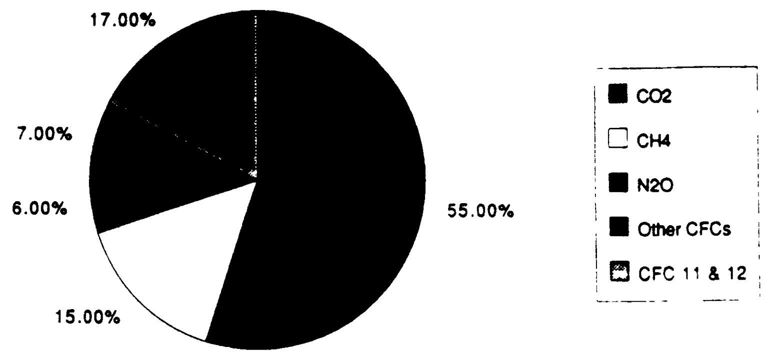


Fig. 2-1-2: Observed and modeled global mean temperature change

Sources: IPCC, 1990, WG I, p. 246

Fig. 2-2-1: The contribution from each of the human-made greenhouse gases to the change in radiative forcing from 1980 to 1990



Source. IPCC, 1990, WG I, p. xx

Fig. 2-2-2: Contribution to the Greenhouse Effect in 1980's

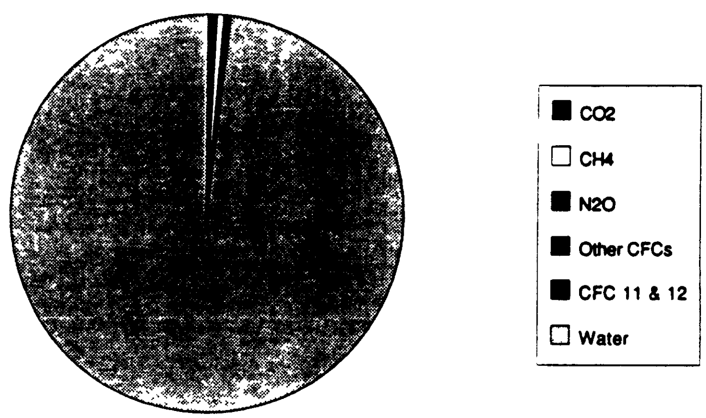


Table 2-2-1: Positive Feed Back Assumed (ΔTs: °C)

Feedbacks	GFDL	GISS
No cloud or snow-ice	1.7	2.0
Plus cloud	2.0	3.2
Plus snow-ice	4.0	4.2

Source: IPCC, 1990, WG I, p. 89

Fig. 2-2-3: Greenhouse Effects in Radiative Balance

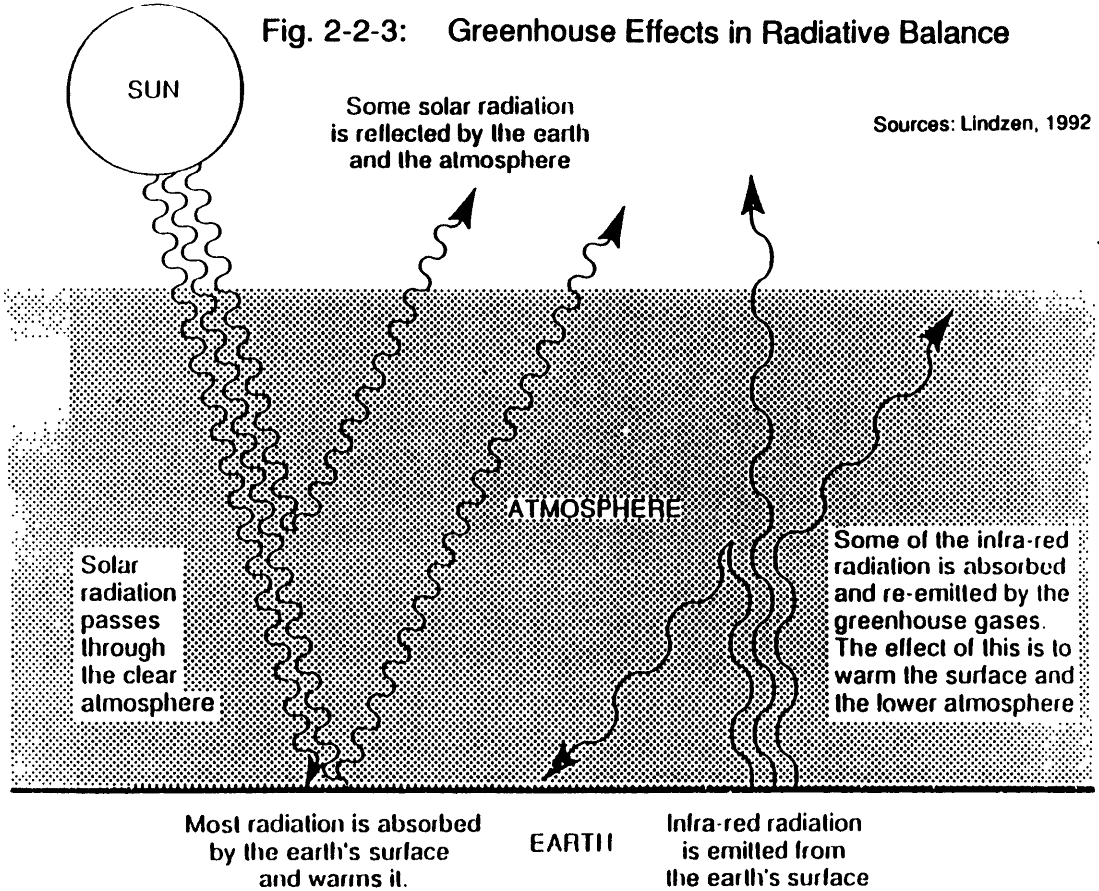
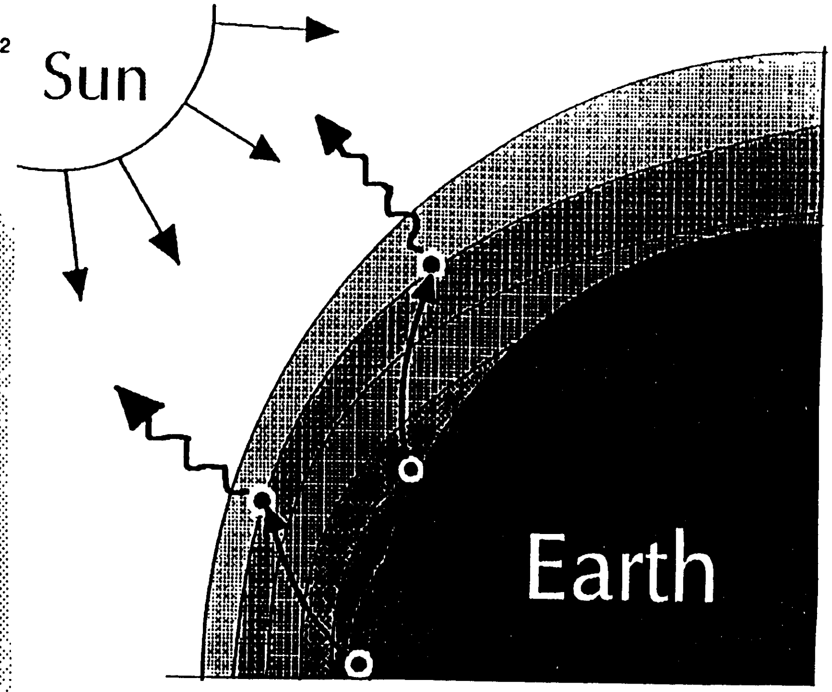


Fig. 2-2-4: Greenhouse Effects in Radiative and Convection Balance



Infrared Opacity is greatest at the ground over the tropics, and diminishes as one goes poleward and upward. Air currents bodily carry heat to regions of diminished infrared opacity where the heat is radiated to space -- balancing absorbed sunlight. Lighter shading schematically represents reduced opacity due to diminishing water vapor density.

Sources: Lindzen, 1992

2.3 CO_2 emissions and concentrations in the atmosphere

In spite of the effort to collect data and analyze CO_2 sources and sinks, the IPCC science report was issued in 1990 through its supplement was issued recently. The IPCC could not find strong reasons to revise its 1990 values of deforestation and land use, accumulation in the atmosphere and ocean uptake. (IPCC, 1992, p. 29, 33) Only the fossil fuels emissions were revised from 5.7 ± 0.5 GtC in 1987 to 6.0 ± 0.5 GtC in 1990, because they are the single most accurately measured source. (Table 2-3-1)

This leaves us an increased net imbalance (missing sink) of CO_2 on the scale of 2.2 GtC. This is around a quarter of anthropogenic CO_2 emission and looks big, but when we compare it to the naturally occurring CO_2 emission (90 GtC from Ocean plus 100 GtC from Land, IPCC, 1990, WG I, p.8), it is 1% of the total. This is not so big considering its measurement accuracy. Anthropogenic CO_2 emissions themselves are still around 4% of the total and are rather small when compared with other anthropogenic gases discussed in the next section.

2.4 Effects of other minor greenhouse gases and aerosols

The US comprehensive approach heavily depends on the reduction of CFCs. (DOE, Sep. 1991, Vol. II, p. 5.74) Since the fall of 1991 there were many arguments that the indirect effect of CFCs through ozone depletion has a negative effect (cooling) which might be as large as its direct effect. It has not been concluded how much the indirect effect is because of complicated contributions of ozone to global warming at various elevations and a lack of ozone data at all elevations of the atmosphere except the lower stratosphere.

"Depletion of ozone in the lower stratosphere, in the middle and high latitudes, results in a decrease in radiative forcing which is believed to be comparable in magnitude to the radiative forcing contribution of chlorofluorocarbons (CFCs) (globally averaged) over the last decade or so." (IPCC, 1992, p.5) If the negative indirect effect is as large as direct effect, the US comprehensive approach cannot depend on CFC reduction to mitigate greenhouse gas emissions.

Methane will naturally be the next target of a comprehensive approach. There are good reasons to focus on it after CFCs, because of its high anthropogenic emission ratio and the increased ratio in the atmosphere.

Table 2-4-1 compares several gases in terms of their anthropogenic ratio to total emission of natural and anthropogenic sources, and rate of increase in the atmosphere. CFCs are the highest in both values (100% of anthropogenic ratio and 4% of rate of increase), and methane is the next highest in both values (76% and 0.9% respectively) compared with moderate values of CO_2 (3.6% and 0.5% respectively). Nitrous oxide has a wide range of uncertainty in its source identification and ranges from 3 to 26% of anthropogenic ratio, but has a smaller (0.25%) rate of increase compared to other gases.

Anthropogenic ratios of SOx and NOx are also shown in the table as a reference (58% and 9% respectively). These rates are global totals, therefore, if they were calculated in urban areas one would expect them to be much higher. Increasing rates in the atmosphere are not indicated for these gases because they are decomposed much faster by natural processes compared to minor greenhouse gases.

The IPCC describes another new finding on the cooling effect as follows: "The cooling effect of aerosols resulting from sulfur emissions may have offset a significant part of the greenhouse warming in the Northern Hemisphere during the past several decades. Although this phenomenon was recognized in the 1990 report, some progress has been made in quantifying its effect." (IPCC, 1992, p.5)

There is an argument, though, that the aerosols from volcanoes have a rather short term effect compared to the warming effect caused by greenhouse gases, and the warming effect will override the cooling effect in the long run. Such an argument, however, does not make sense because it is reasonable to assume that we will have a similar scale of volcanic activities with a similar frequency in the long run, unless the warming effect grows overwhelmingly big, which is not necessarily true as we have seen in the previous section.

If aerosols are mainly caused by anthropogenic sources, then we have got some control of the cooling effect. Of course, the intentional control of this cooling effect needs to be carefully studied and to demonstrate safety from other side effects to the environment.

The Global Warming Potential (GWP) measure was proposed to give exchange rates among greenhouse gases in the 1990 IPCC WG I report. But after new findings about significant indirect effects from CFCs and CH_4, the IPCC gave up attempts to give overall exchange rates among gases, and gave numbers only for direct effects and only mentioned indirect effect seriousness.

"The Global Warming Potential (GWP) remains a useful concept but its practical utility for many gases depends on adequate quantification of the indirect effects as well as of the direct. We now recognize that there is increased uncertainty in the calculation of GWPs, particularly in the indirect components and whilst indirect GWPs are likely to be significant for some gases, the numerical estimates in this

Supplementary Report are limited to direct GWPs only." (IPCC, 1992, p.5)

Methane and nitrous oxide emission will become important, if global warming becomes a real problem. Policy with CH_4 and N_2O will affect choosing fuels and technologies. For example, fuel switching from coal to gas could reduce CO_2 emission, but if leakage of methane in its transportation by pipelines and/or tankers and in end use is large, then the greenhouse effect of methane will offset or override the reductions in CO_2. Another example is nitrous oxide emissions from fluidized bed combustion. Even if efficiency improvements of pressurized fluidized bed combustion reduce CO_2 emission per unit of electricity generated, nitrous oxide emission might offset the reduction in CO_2 emissions. These trade offs between gases will be discussed quantitatively in chapter 4.

2.5 Impacts of global warming on society

The most frequently cited index of global warming is the global mean surface temperature. It is convenient to have one figure representing everything, but when we think about the impacts on society, an increase in global mean temperature does not mean very much. More important indices to society would be regional variation of temperature, precipitation and soil moisture changes, and daily and seasonal pattern of these indices. Frequency of unusual events like storms or droughts are also important.

The IPCC attempted to estimate these indices of for five selected regions and gave results of model calculations, but notes that the "Confidence in these estimates is low, particularly for precipitation and soil moisture." (IPCC, 1990, WG I, p. 156)

Seasonal and daily pattern change are more difficult to predict because the data needs of a model will be increased significantly compared to just the annual average or daily average. Observation of a hundred years' historical trend shows winter temperatures increase while summer temperatures did not change much. (Fig. 2-5-1, IPCC, 1990, WG I, p. 217) Beardsley discussed night time temperature increases due to the sulfate aerosol effect. (Fig. 2-5-2, Beardsley, 1992) These could mean a milder climate, which would be good for most people, however, it might be bad for some people. But these seasonal and daily pattern are more closely related to our daily life than just the mean temperature.

Sea level rise is often discussed as a social impact because it is the only direct consequence of a global mean surface temperature increase. It has drawn attention through scary stories of flooding all over the world caused by a possible increase in sea level of several meters. "The IPCC assessment has substantially lowered the accepted estimates of sea level rise over the next century. Rather than the dramatic scenarios of flooding of many of the world's coastal cities and fishing off the steps of the Capitol building, the IPCC estimates that sea level would rise less than 1 meter over the next century, even if greenhouse emissions increases at the maximum assumed rate." (EPRI, May 1991, p. I-14)

The basic problem of the discussion of sea level rise lies in effects of vertical land movement on measurements of sea level and the impacts on society. Sea level rise has been measured by tide gauge relative to the land. However, land moves due to several reasons; plate tectonic influence, sedimentation, ground water and oil extraction. Further the movements are not uniform geographically, and "there is a historical geographical bias in the data set in favor of Northern Europe, North America and Japan." (IPCC, 1990, WG I, p. 266)

Therefore substantial potential errors are included in the measurement of sea level. Based on these measurements, a 10 - 20 cm sea level rise was predicted during the last 100 years, and this tendency for sea level to increase is automatically included in the future sea level rise prediction. This means without any warming sea level will rise 20 cm by the end of the 21st century by present model calculations.

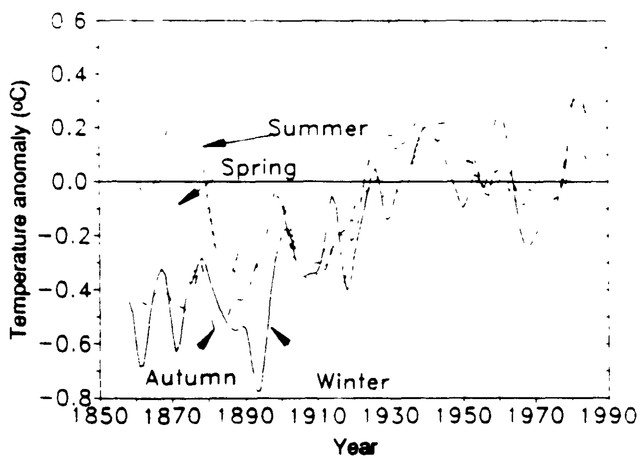
Although the IPCC executive summary concludes: "The predicted rise is about 20 cm in global mean sea level by 2030, and 65 cm by the end of the century." (IPCC, 1990, WG I, p. xi), the author of the chapter 9 : Sea Level Rise seems to be unwilling to explore long term beyond 2070 with these uncertainties.

"Under the Business-as Usual scenario, the best estimate is that, for the year 2030, global sea level would be 18 cm higher than today. Given the stated range of uncertainty in the contributing factors, the rise could be as little as 8 cm or as high as 29 cm. By the year 2070, the projected range is 21-71 cm with a best-estimate of 44 cm, <u>although it should be cautioned that projections this far into the future are fraught with many uncertainties, many of which are external to thermal expansion and land ice melting</u>." (IPCC, 1990, WG I, p. 276, emphasis by the author)

Land movement usually affects society much quicker than possible sea level rise caused by global warming, as well as measurement problem. Most coastal zone management necessary in the decades will be required by regional land movement and not by sea level rise. It will be difficult to identify how much change is caused by sea level rise even if there is some such rise. IPCC working group III, though, made hypothetical cost estimates to protect countries worldwide against the effects of a 1-meter sea level rise in 100 years. Total amount protection costs are calculated at $500 billion worldwide. This is not very large when distributed worldwide. Annual protection costs as a percentage of GNP were calculated 0.04% worldwide. (IPCC, 1990, WG III, p.153)

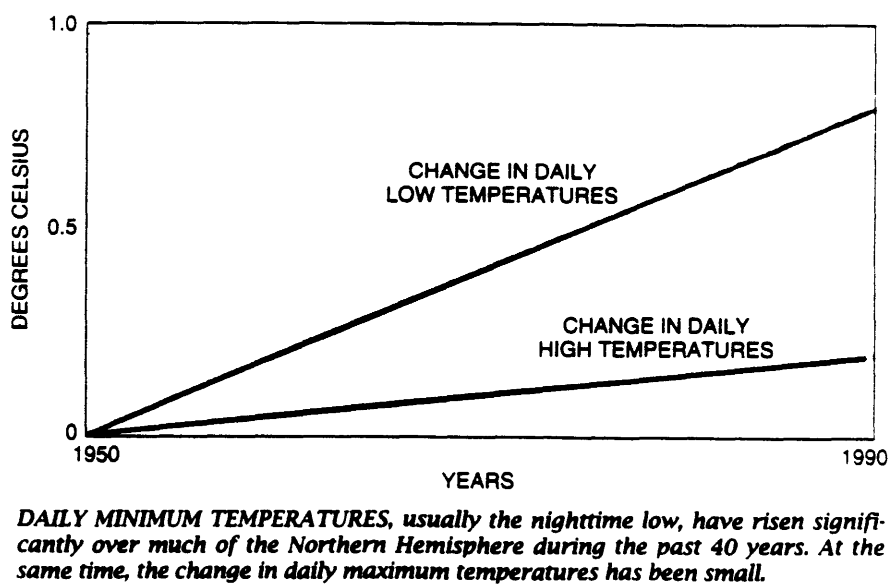
Nordhaus estimated a rather small economic impacts of global warming to the US. (Nordhaus, 1991, p. 41) In addition the National Resource Council concluded in its adaptation panel that: "People in the United States likely will have no more difficulty adapting to such future changes than to the most severe conditions in the past, such as the Dust Bowl." (National Research Council, 1991, Synthesis Panel, p. 45) However, one could argue that only limited impacts have been taken into account in this estimate, or that for developing countries the cost would be higher. However, there is really no way to know such changes would result in net cost or benefits to society. As countries develop they become less vulnerable to climate change.

Fig. 2-5-1: Seasonal Temperature Change



Source: IPCC, 1990, WG I, p.217

Fig. 2-5-2: Daytime and Nighttime Temperature Change



DAILY MINIMUM TEMPERATURES, usually the nighttime low, have risen significantly over much of the Northern Hemisphere during the past 40 years. At the same time, the change in daily maximum temperatures has been small.

Source: Scientific American, February 1992, p. 24

2.6 IPCC scenario and Business as Usual

IPCC's estimate of global surface mean temperature increase of 1.5 -4.5°C is not a future forecast, but rather a calculation based on assumptions named "Business as Usual". Since it is a scenario and not a forecast, it depends on many arbitrary assumptions. Therefore problems and confusion can arise when one tries to interpret the results as forecasts. This section discusses this issue. Robert Margolis provides an excellent discussion of this issue in his master theses. (Margolis, 1992)

The first issue is that scenarios are exaggerated to get a visible difference between the scenarios. "Clearly, the scenarios were defined in a restrictive manner. That is, the modellers were given target years for doubling of equivalent CO_2 concentrations, and then they constructed scenarios to meet the given targets through trial and error (i.e., by adjusting input assumptions)." (Margolis, 1992, p. 81)

The CO_2 emission rate is not forecasted by the model, but rather variables and parameters are chosen to create the desired CO_2 emissions scenarios. In the IPCC, policy scenarios were created by working group III (WG III). These scenarios were then used by working group I (WG I). We can imagine the situation during the scenario making process, WG I requested that WG III create scenarios with which natural variables such as global surface mean temperature and precipitation have visible differences between the scenarios.

We must pay attention that it is quite a different matter to draw scenarios and to forecast the future. We could create any kind of scenarios by imagination which are not necessarily likely to happen in real world. But when forecasting the future we must stick to the real world and make an effort to generate results which are as much probable as possible.

IPCC scenarios are scenarios and not future forecasts. But they are often understood as future forecasts by the misleading phrases like "Business as Usual" or "best estimate". And the tricks are used to urge policy makers to take some actions by creating pictures showing what might happen in scenarios when no action is taken now.

Second issue is an inappropriate name of "Business as Usual (BaU)". Naming of this scenario created internal conflict within IPCC, and it is called "Scenario A" or "High Emission Scenario" or "Business as Usual". What was originally meant was that it is a scenario in which CO_2 emission will be doubled by around the year 2030. But by the name of Business as Usual, it implicitly means that it will most probably happen if current trends continue or without any particular policy to change it. (Margolis, 1992) This is quite different from what the scenario originally intended.

One important (and probably intentional) assumption in BaU scenario is that future energy sources are heavily dependent on coal. It is understandable if the scenario was made to emit highest amount of CO_2, because coal produces the highest CO_2 emissions per heat content. But if the scenario is named "business as usual", then we must ask if it is a probable future. Is this the most probable future that depends on coal for half of the energy supply in 2050, and two thirds of it in 2100? (Fig. 2-6-1)

Scenario B according to Table 2.5 of IPCC WG III report should be "gas-intensive" scenario, however it is still heavily dependent on coal. All scenarios A though D have similar patterns of energy supply from oil, gas and hydro, and the differences are total energy consumption and whether it is supplied primarily by coal or by biomass and solar.

Oil and gas resources are assumed to be limited, with only small amounts are available at low prices. The remaining resources are assumed to be very expensive. Hydro is also available in limited resources. Nuclear is defined as a "back stop energy" with unlimited resources by Edmonds et al. (Edmonds, 1985) However it is assumed that only a small amount is available at low cost and the remaining resources are available only at high cost in IPCC energy model.

The assumption of limited hydroelectric resources seems reasonable because of geographical constraints, but oil and gas resource assumptions are controversial if we look back at the historical trend of increased reserves. This will be discussed in Chapter 4. Biomass is categorized as a resource-constrained renewable energy by Edmonds et al. (Edmonds, 1985) This is a reasonable assumption given the limitation on land use and the competition between using land for energy v.s. food supply as discussed in chapter 4. However, it looks like it is treated virtually without constraints in the IPCC's scenario C and D "controlled and accelerated policies scenarios".

These unlikely assumptions were made to create scenarios with targeted CO_2 emissions by adjusting parameters and exogenous input data.

The IPCC's BaU scenario has high CO_2 emissions as intended. This is mainly due to the high energy consumption growth rate and partly to high coal dependence. It is unlikely to expect such huge increases in coal use as we will see in chapters 3 and 4. Assuming intentional and extreme increases in coal use combined with strong energy consumption growth, results in high CO_2 emissions, and encourages a switch from coal to biomass and solar, which is unfair to coal.

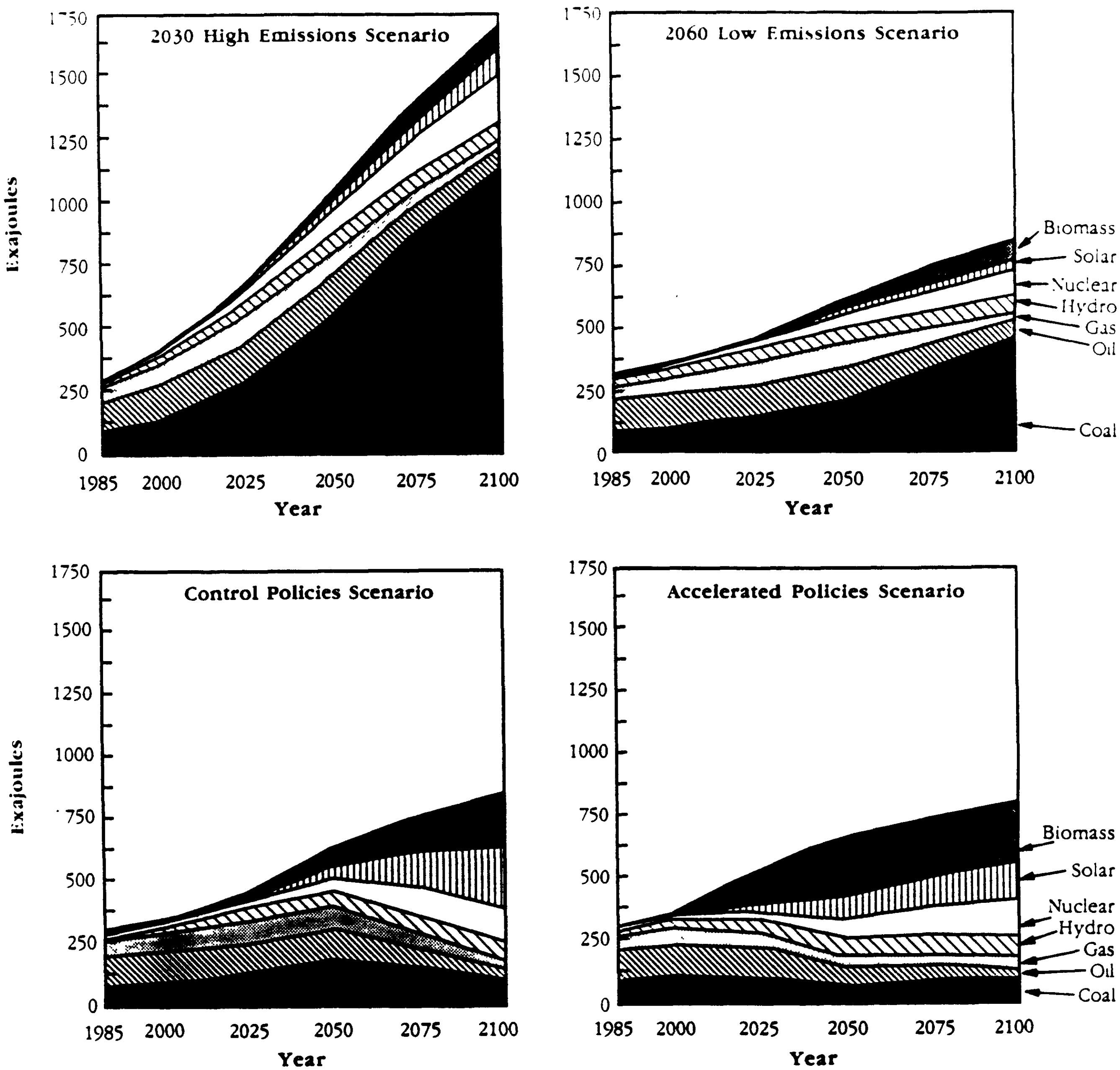
These assumptions could be used as the leading justification for a carbon tax. But what is most likely to happen when a carbon tax is introduced is not scenario C or D. Biomass and solar energy cost will not be reduced so easily as the IPCC assumed. A shift to nuclear might be encouraged by a carbon tax, but it has own safety, radioactive wastes and proliferation issues. Oil and gas will benefit from a carbon tax, where they are in competition with coal their market shares will grow. Thus CO_2 emissions will not be reduced so much as the IPCC expected.

The last issue is that population growth rate and economic growth rate have a much more significant impact on the level of energy consumption and CO_2 emissions than the differences between the IPCC's 1990 scenarios. The IPCC's 1990 scenarios are all based on one population estimate (World Bank, Zachariah and Vu, 1988), and two economic growth rate assumptions: higher and lower growth.

We can see a bigger difference in global energy supply (or consumption) between the higher and lower growth cases than among scenarios. (Figs 2-6-1 and 2-6-2; IPCC, 1990, WG III, p. 32, 33) The IPCC arithmetically averaged the higher and lower growth cases in the process of summarizing their results. Thus only the average values were shown. The large differences between the higher and lower growth scenarios were filtered out of the process.

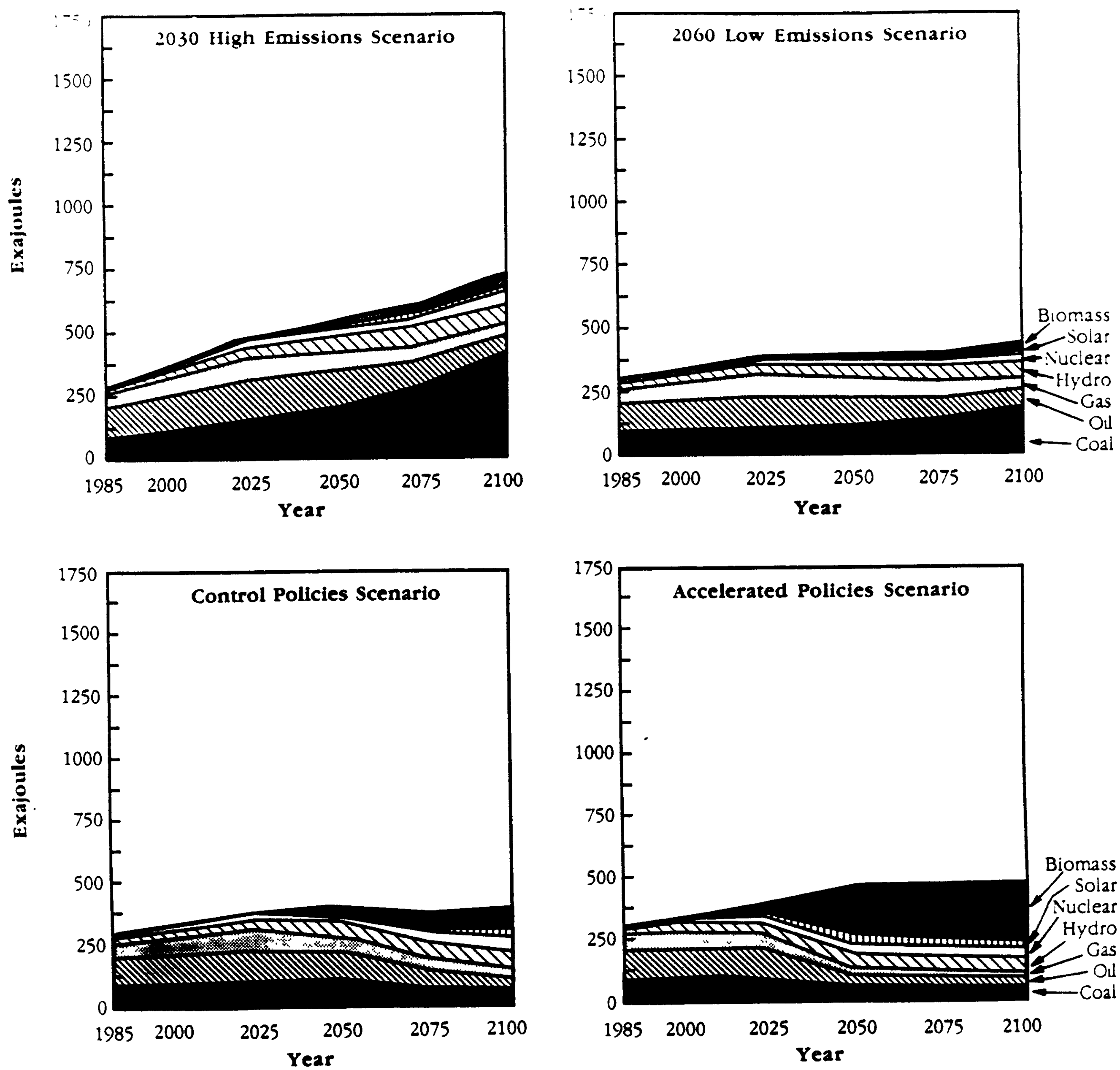
Since there was a great deal of criticism for assuming only one world population estimate in the 1990 report, the IPCC put additional population estimates of United Nations' medium low case and medium high case, as well as some other assumptions of economic growth rates (Table 2-6-1) in their 1992 supplement. (IPCC, 1992, p. 11) The results show a big difference in CO_2 emissions between scenarios as expected, although they did not show the results of energy consumption in the supplement. Despite these case studies, in the summarizing process, the large variations are ignored and conclusions are unchanged using "best estimate" or median values. (Figs 2-6-1 and 2-6-3)

Fig. 2-6-1: Global Primary Energy Supply by Type: High Growth Case



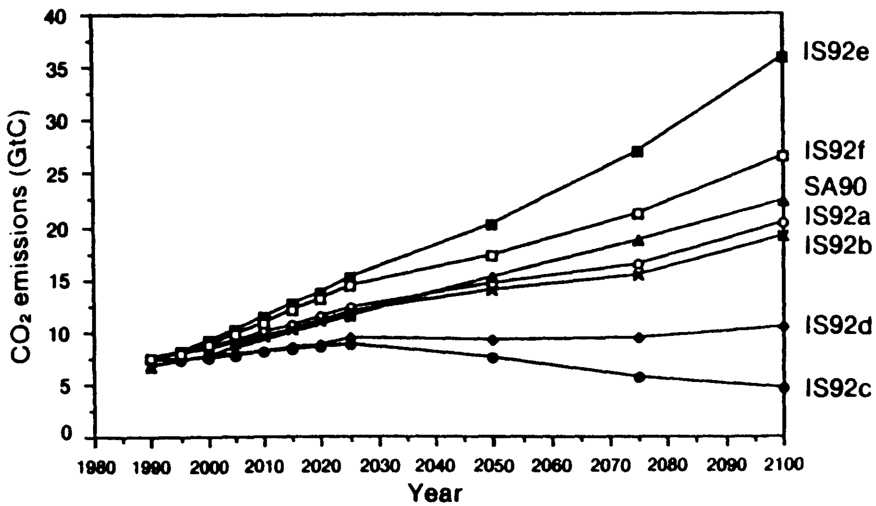
Source: IPCC, 1991, WG III, p. 33

Fig. 2-6-2: Global Primary Energy Supply by Type: Low Growth Case



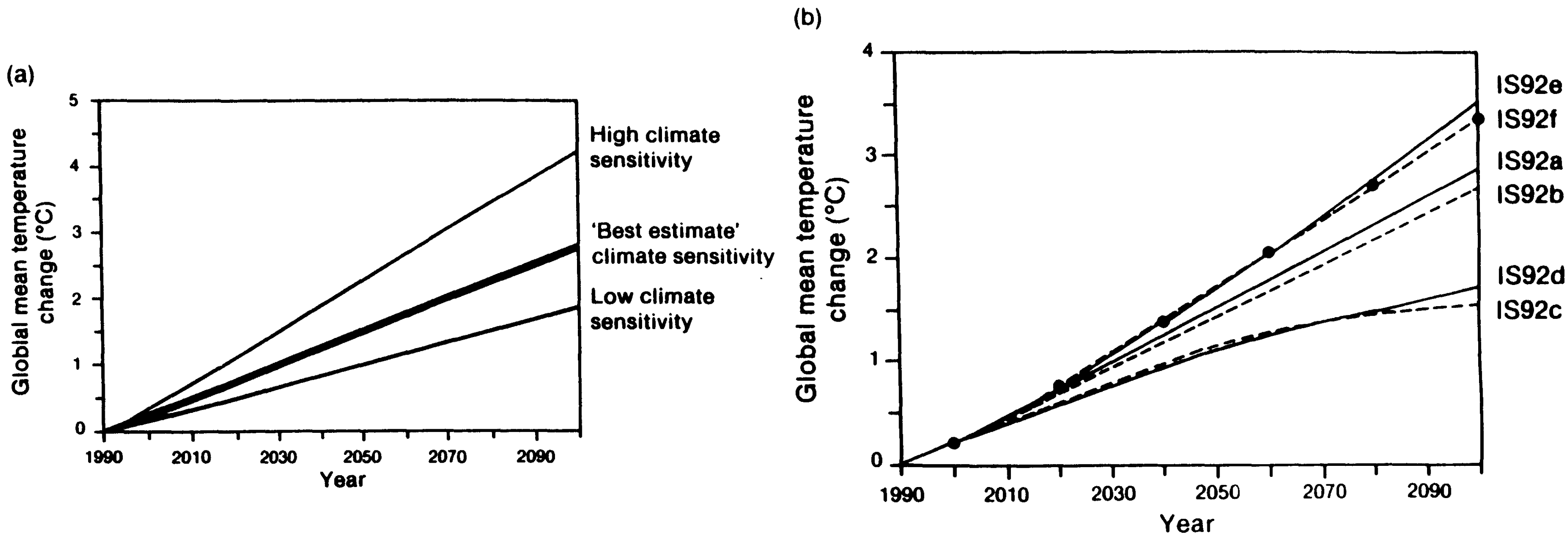
Source: IPCC, 1991, WG III, p. 32

Fig. 2-6-3: CO2 Emissions with IPCC 1992 Alternative Scenarios



Source: IPCC, 1992, p. 13

Fig. 2-6-4: Temperature Change Estimates with Alternative Scenarios



(a) Temperature change under scenario IS92a, (b) Best estimate temperature changes under IS92 and SA90. Solid circles show SA90

Source. IPCC, 1992, p. 18

Table 2-6-1: Populations and Economic Growth Assumptions in the Six IPCC 1992 Alternative Scenarios

Scenario	Population	Economic Growth	
IS92a	World Bank 1991 11.3 B by 2100	1990-2025: 1990-2100:	2.9% 2.3%
IS92b	World Bank 1991 11.3 B by 2100	1990-2025 1990-2100	2.9% 2.3%
IS92c	UN Medium Low Case 6.4 B by 2100	1990-2025 1990-2100	2.0% 1.2%
IS92d	UN Medium Low Case 6.4 B by 2100	1990-2025 1990-2100	2.7% 2.0%
IS92e	World Bank 1991 11.3 B by 2100	1990-2025 1990-2100	3.5% 3.0%
IS92f	UN Medium High Case 17.6 B by 2100	Same as "a"	

Source: IPCC, 199, p. 11
Note: Energy supplies, CFC and other assumptions also different among alternative Scenarios.

2.7 Conclusions

We can conclude this chapter as follows:

- There is no consistent evidence that global warming is occurring.

- Carbon dioxide (CO_2) is not a major greenhouse gas. The IPCC depends on positive feedback of water to get a visible results from doubling of CO_2.

- Water is the major greenhouse gas. Not only the radiative balance but also convection must be taken into account in model calculations of the greenhouse mechanism.

- Carbon dioxide has the smallest ratio of anthropogenic to natural sources among minor greenhouse gases.

- The impacts of global warming on society are estimated to be small, although further study in the scientific and economic area are needed especially at the regional and country levels.

- It is important to distinguish between scenarios and forecasts, and the words "business as usual" or "best estimates" were inadequately used in the IPCC. This created severe the confusion.

- Changing population growth rate and economic growth rates give more significant differences in energy consumption and CO_2 emissions than the difference among IPCC scenarios. Appropriate rates of developments to sustain world population, economy and environment should be sought separately from the global warming issue.

- Consequently, global warming should not be given a higher priority in energy and environmental policy than other more serious issues like energy security or urban air pollution and waste management.

3. Energy and Environmental Policy

If there was only one central government on earth, and it controlled energy policy, then the most efficient system to optimize world energy use and environment could be achieved. However, the reality is that no such government exists, and every country is trying to optimize its own energy system, and struggling with environmental problems. Adding up each optimized subset will not necessarily make an overall optimized system.

This chapter reviews and discusses the following items:

- Energy consumption and supply
- Environmental issues and countermeasures
- Regulations, Taxes and Emission Rights
- Global Environmental Policy
- Technology Transfer

3.1 Energy consumption and supply

We will review the historical trends in energy consumption and supply and then develop a probable scenario based on the historical review.

3.1.1 Historical trend

World Energy Consumption

Fig 3-1-1 shows world energy consumption during the past quarter century. (BP statistics, June 1991) In 1990, the world total energy consumption was 360 exajoule (EJ, 10^8 J) or 8 thousand million tons of oil equivalent (MTOE) or 340 quad (quadrillion BTU, 10^{15} BTU). I will use SI unit as much as possible and other units will be used as supplement. (Conversion rate used in this paper: 1 MTOE = 44.6 EJ = 42 quad)

Energy consumption started at 170 EJ in 1965, and constantly increased except during two oil shocks of 1973 and 1979. It has more than doubled in the past quarter century. Thus the average annual growth rate of energy consumption has been 3%. It increased at an annual rate of 5% until the first oil shock happened in 1973, followed by a couple of years stagnation, and then it started to increase again in 1976 at 3 - 4 % per annum until the second oil shock in 1979. The second one affected the growth rate longer than the first and no or a decrease of consumption was recorded until 1983. After 1983 a moderate increase of 2 - 3 % per annum began. From 1989 until the present, there was a small increase reflecting world wide economic stagnation and the economic/political collapse in eastern Europe and former USSR.

Oil increased its share from 40% in 1965 (68 EJ) with a very high growth rate of 7 - 8 % per annum until 1973 when it recorded a high of 48.3%. It stayed much the same until another peak of 47.1% in 1978. It then gradually reduced its share to 38.6% in 1990 (138 EJ), but the consumption rate of oil increased from 1986 to 1989. The average oil consumption growth rate during the past quarter century was 2.87%. We see the peak numbers of 47 - 48 % of share in total energy consumption as a critical number which introduced unusual events.

Natural gas use also saw a big increase during this quarter century. It started at 16% of total energy consumption in 1965 (28 EJ), increased at an average rate of 4.18%, and ended up with a share of 22% in 1990 (78 EJ). It has a similar historical trends to oil but was affected less by the oil shocks, and has extended its share after the shocks as an alternative source of energy. Although it has not appeared in statistics yet, the recent collapse of Central European countries (CE: Albania, Bulgaria, Czechoslovakia, Hungary, Poland, Romania, and Yugoslavia by BP definition) and former USSR, which are the largest supplier and consumer of natural gas, will reduce gas consumption in 1991 and 1992. But since proved reserves increased much faster than that of oil and coal, natural gas consumption is very likely to increase in the medium term.

Coal decreased its share from 38% in 1965 (65 EJ) to 27% in 1990 (98 EJ) with the lowest average consumption growth rate of 1.65% among major primary energy sources. It had a constant decrease of share except after the second oil shock with a slight increase (1%) of share where coal is expected as an alternative energy source for oil. But when oil returned to a lower price in 1986, its share started reducing again. Who would expect as bright a future as seen the IPCC's BaU scenario based on this trend?

The longer term trend shows a more pessimistic picture for coal. Fig. 3-1-2 shows the long term energy trend fossil fuel energy consumption from the beginning of this century to 1980 extracted from Fujii's paper. (Fujii, 1990) Coal supplied almost 100% of the fossil fired energy at the beginning of the century but its share was gradually reduced to around 30% of total fossil fuels by 1970. It slightly increased during 1980', but returned to gradual reduction after 1986 as we have seen above. Gas may have a bright future but based on its current trend coal doesn't.

There was a giant leap in the use of nuclear energy during the past quarter century. It started from almost nothing (0.3 EJ, 0.2% of total energy supply), but increased with an annual average growth rate of 18.4% and ended up with 5.7% of the total energy supply in 1990, a level of 21 EJ. Note that nuclear energy supply was calculated based on the amount of oil required to fuel an oil-fired plant in order to generate the same amount of electricity.

Hydroelectricity generation has kept a constant position in the primary energy supply. It started at 11 EJ (6.1% of total energy supply) and its supply increased at an annual average rate of 3.36% and ending up at 24 EJ (6.7% of total energy supply) in 1990. Hydro energy supply was calculated on the same base as nuclear.

Regional Energy Consumption

Fig 3-1-3 illustrates a more detailed trend of the national or regional character for each primary energy source.

Oil consumption was heavily influenced by the two oil shocks in the US and Western Europe. It was moderately affected in Japan, and had no affect in the centrally planned countries. In response to the oil shocks OECD countries instituted policies to reduce their oil dependence. Thus the price of oil stayed high in the early 1980's and oil consumption in the OECD was reduced. But with the collapse of oil prices in 1986 oil consumption began to gradually increasing again. Despite the Iraqi invasion of Kuwait and the Gulf War, the price of oil did not stay high. This was due to the Saudi Arabia's production increases. Thus oil consumption is still gradually increasing. Again we must be careful not to become too dependent on oil.

Gas consumption was dominated by the US in 1965, but it had a peak in 1972 and never came back again to that peak. This was due to limited pipeline transportation capacity and the failure of government price controls. (see EPRI journal, Jan./Feb. 1992) Another remarkable trend in gas consumption has been the rapid increase in the former USSR and CE countries. But since 1988 gas consumption has stayed at the same level or has been reduced.

In Japan, gas consumption has increased due to the increase in LNG power generation and the expansion of residential and commercial use of natural gas. However, LNG is still expensive (60% higher than for US domestic use of gas) due to the high cost of liquifaction and transportation, and a small portion of the worldwide market. (LNG trade is one quarter of international trade but only 4% of total consumption.)

The most remarkable thing about the trend in coal consumption is the Chinese expansion. Chinese consumption of coal started at 7.4 EJ in 1965 and increased at an annual growth rate of 4.7% ending up at 23 EJ in 1990 (tripled from 1965.) Abundant coal resources, growing energy needs for industrial use, importance as an exportable commodity, and keeping the price around one third of the world market price by the Chinese government has lead to the continuing dominance of coal in China. (see Leduc, 1991)

The former USSR and CE were the largest coal user for a long time. It consumed 20 EJ of coal in 1965. Coal consumption in the former USSR and CE reached a peak of 24 EJ in 1979 and has never come back to that level again. Since 1989 coal use dropped at a rapid rate reflecting the weak economy and political conflicts, and ended up at 19.6 EJ in 1990.

In the US, coal has had a slow but steady growth. The US consumed 13 EJ in 1965 which was 22% of the total US energy consumption then. Coal use increased at an average rate of 1.9% in the past quarter century. It lost share down to 17% in 1971, but came back to a 24% share at 21 EJ in 1990.

Japan depended on coal for 29% of its total energy consumption in 1965 (2 EJ), but coal was replaced mainly by oil and partly by gas and nuclear later. In 1979, coal consumption was still 2 EJ but its share in total energy was reduced down to 13.6%. After the second oil shock, coal was designated as an alternative energy to oil, and also due to the rather high price of oil in early 1980's, both coal's consumption and market share were increased to 3.3 EJ and 19.7%, respectively by 1985. But when the oil price dropped in 1986, coal consumption stagnated at a level of 3.3 EJ and the share was decreased again down to 17.2% by 1990.

Japanese coal consumption has changed from domestic coal to imported overseas coal during this period. The reason for this change is first because the supply of domestic coal decreased with the replacement of oil, and second its price was not competitive with overseas coal. After the oil shocks, the low price of overseas coal attracted the attention of Japanese industries. Then coal mines were developed overseas and the infrastructure was erected both the overseas and domestically. In addition to these factors, the appreciation of the Yen made overseas coal more attractive in price relative to domestic coal. The price of domestic steam coal was 2.5 times higher than the CIF price of imported steam coal in 1990, Denkijigyoubinran, 1991.

Nuclear energy had two major leaders: the US and Western European countries, followed by USSR & CE countries and Japan. The UK dominated (60%) a still very small nuclear supply in 1965. There was a rapid increase in nuclear capacity in the US by 1970. There was a peak of 3.4 EJ (50% of the world total) in 1978. Due to low capacity factors caused by the Three Mile Island plant accident in 1979, nuclear generation decreased to 3 EJ in 1979 and 1980. Another increase in nuclear consumption was triggered by oil price hike, increased capacity factors, and the addition of new plants since 1983. Nuclear consumption ended up at 7 EJ in 1990. Nuclear power plants need a long lead time before they start generating power. There has been no new nuclear power plant orders since 1978 in the US. Therefore there won't be much of an increase in nuclear energy consumption will be expected in the decades in the US.

In Western European countries (WE: European members of OECD) nuclear energy grew slowly until 1980, when France started extensive growth in its nuclear supply. The total WE nuclear supply exceeded that of the US by 1982 and rapidly increased until 1986. When the Chernobyl accident happened in April, it affected nuclear policies in several European countries, resulting in shut downs in Italy and slow downs in Sweden and the UK. It ended up at the same level as US nuclear consumption of 7 EJ in 1990. There are no extensive policies aimed of increasing nuclear capacity in the next decades except in France. (Kaigaishokoku no denkijigyou, 1991)

The USSR and CE countries supplied nuclear energy at 2.6 EJ in 1990. Chernobyl was the single worst accident in the history of nuclear power and affected nuclear energy policies worldwide. Recently social and political change in the region has attracted attention to safety issues in USSR type nuclear power plants, as well as the availability of surplus plutonium and highly enriched uranium from nuclear weapons. Unless safety issues are resolved it will be unlikely for the nuclear supply in this region to increase.

Japanese nuclear plants supplied 2.2 EJ in 1990. It is the only country, except France, in the world which has an aggressive plan to increase its nuclear supply capacity (around double the capacity by 2010 from 1990).

Hydroelectric power supply has not changed much during the past quarter century in the developed countries. However constant increase was recorded in the rest of the world, especially in Latin America.

Oil Dependence in Primary Energy Consumption

Fig. 3-1-4 shows the primary energy consumption of OECD countries in 1989 and 1980. (OECD, 1990) The total OECD countries' oil dependence was reduced from 48.3% in 1980 to 42.5% in 1989. Efforts were made throughout the US, Japan and EEC, however Japan's oil dependence is still high (57.3% in 1989).

Energy for Electric Power Generation

Fig. 3-1-5 shows the electricity generation input for OECD countries in 1989, 1980, and 1973 (OECD, 1990) This figure also shows that the Japanese have been heavily dependent on oil even in the electric power generation sector. A drastic increase in nuclear occurred in all of the OECD countries, especially the EEC. A remarkable revival of coal occurred in the US.

3.1.2 Defining a more probable Business as Usual Scenarios

Based on the energy consumption and supply trends discussed in the pervious section, this section tries to develop a more probable business as usual scenario. It focuses on fossil fuel choices. Population growth, economic growth, and energy growth rates, which have more significant impacts on energy consumption and CO2 emission are fixed at the same rates as in the IPCC's BaU high growth scenario.

The first case (Base case) fixes the amount of primary energy supply. This means that primary energy consumption grows at the same rate as the IPCC BaU high emission scenario, but leaves the percentage supplied by oil, gas, coal, nuclear, and hydro unchanged during the scenario. Fig 3-1-6 shows the base case energy supply and CO2 emissions. CO2 emissions in 2100 are 29 GtC/year. This is 6% lower than the IPCC's BaU High Growth scenario (31 GtC). The consumption growth rate is assumed to be the same for oil, gas coal, nuclear, and hydro, and it is 1.52% from 1985 to 2000, 2.06% from 2000 to 2025, 1.76% from 2025 to 2050, 1.25% from 2050 to 2075, and 0.78% from 2075 to 2100. It is assumed that biomass and solar do not increase their contribution to the energy supply for the whole period.

The second case (Modest Gas Growth case) reflects the current trend of faster growth in the gas consumption rates, while total energy consumption is assumed to be the same. During the past quarter century, the annual growth rate for gas was 4.18% while the total energy consumption growth rate was 2.99%. Since the total energy consumption growth from 1985 to 2000 was set at 1.52 % (around half of the past quarter century growth rate), the gas growth rate was chosen to be 2.10 % (also half of the past quarter century of the same period.) The coal consumption growth rate was reduced to 1.1% to compensate. Similar adjustments are made to the gas and coal consumption growth rates, and are as follows respectively: 2.6% and 1.6% (2000 - 2025), 2.16% and 1.36% (2025-2050), 1.45% and 0.85% (2050 - 2075), 0.98% and 0.58% (2075 - 2100) All other primary energy growth rates remain the same as in the base case. Fig. 3-1-7 shows energy supply and CO2 emissions for the Modest Gas Growth case. The CO2 emissions at 2100 are 27.3 GtC, which is 9% less than IPCC's BaU high growth case or 6% less than Base case in this study.

The third case (Rapid Gas Growth Case) assumed a higher growth rate for gas: 1% higher than the total energy consumption rate from 1985 - 2050 and 0.5% higher than the total energy consumption rate from 2050 - 2100 (Fig. 3-1-8). The coal growth rate was adjusted to compensate for this. It turned negative after 2025. (0.72% in 1985 - 2000; 0.98% in 2000 - 2025; -0.24% in 2025 - 2050; -1.75% in 2050 - 2075; -4.22% in 2075 - 2100). The CO2 emissions in 2100 are 24 GtC/year which is 21% less than IPCC BaU High Growth scenario, or 16% less than base case in this study.

The Rapid or Modest Gas growth case illustrate a more probable energy supply future than the IPCC's BaU High Growth case. Of course, these are based on the assumption that the reserves of oil and gas will be extended as the production of these fuel grow, but this assumption is reasonable given what happened in the past.

In another word the IPCC's BaU scenario sets CO_2 emissions around 20% higher than that of the more probable case, when the population, economic and energy growth rates are fixed. However the population, economic and energy growth rates have a bigger influence on CO_2 emissions rates. These parameters are very important when thinking about possible energy futures. CO_2 is not a very good indicator as we have seen in chapter 2.

Fig. 3-1-1 World Energy Consumption Trend (a)

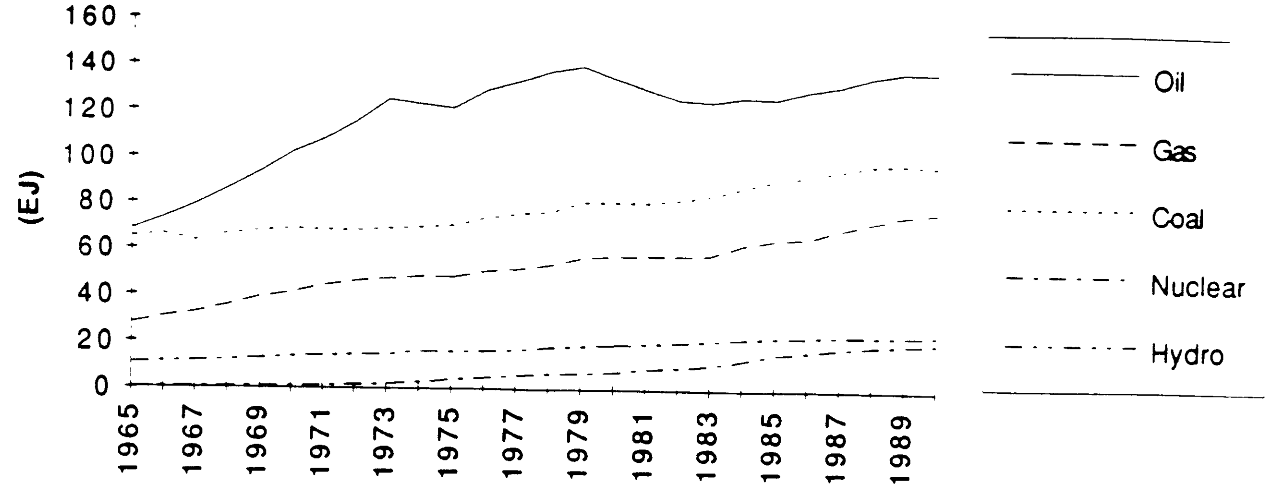


Fig. 3-1-1 World Energy Consumption Trend (b)

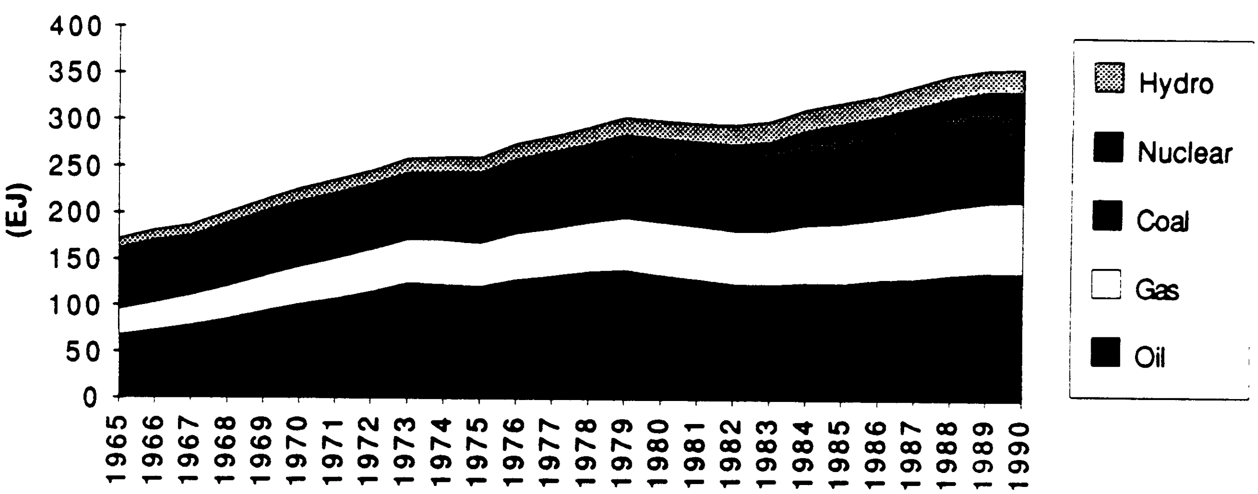
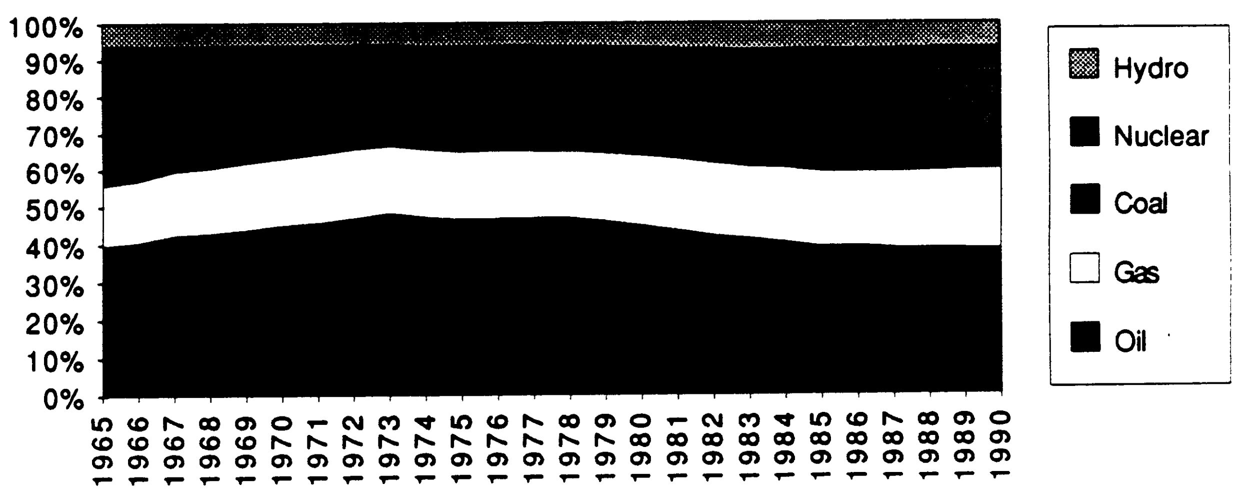


Fig. 3-1-1 World Energy Consumption Trend (c)



Source: BP Statistics, 1991

Fig. 3-1-2: World Long Term Fossil Energy Trend (a)

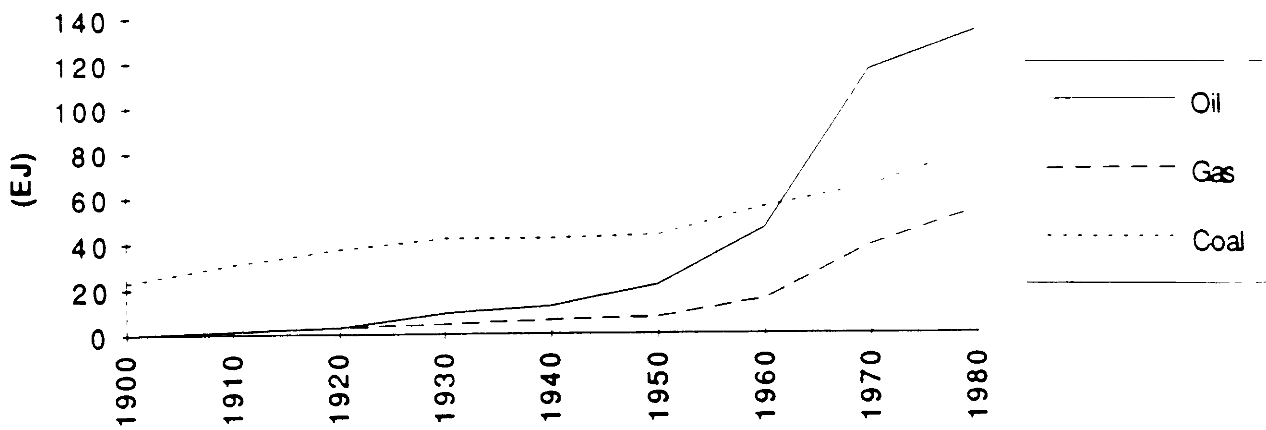


Fig. 3-1-2: World Long Term Fossil Energy Trend (b)

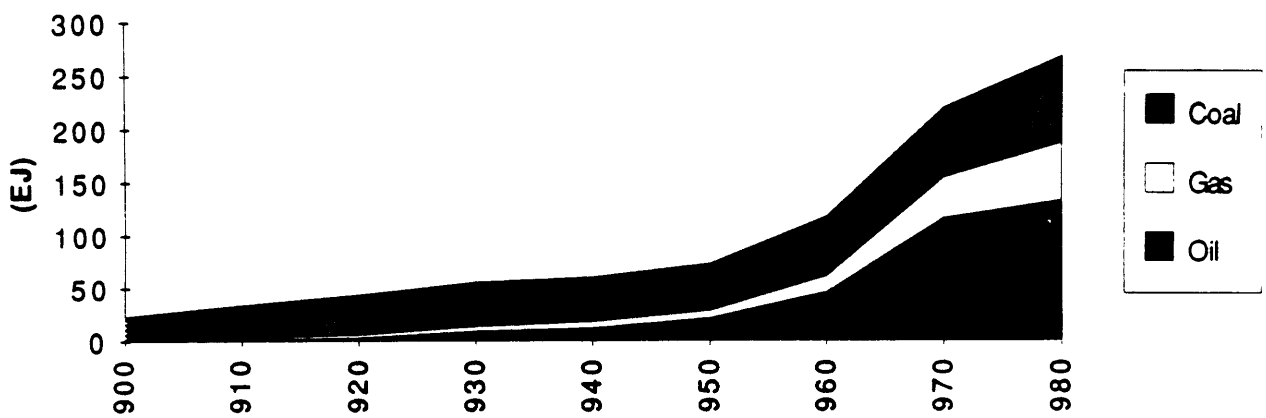
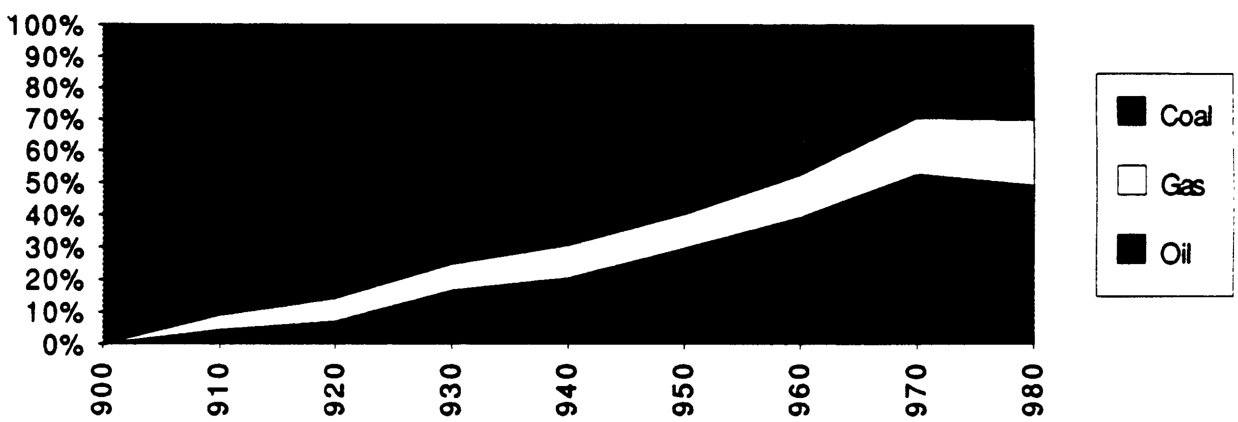


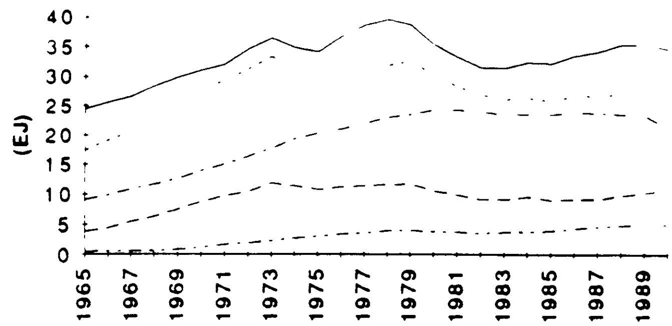
Fig. 3-1-2: World Long Term Fossil Energy Trend (c)



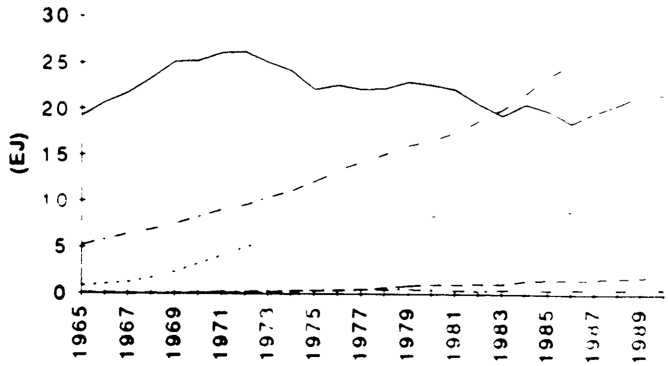
Source: Fujii, 1990

Fig. 3-1-3 Regional Energy Consumption Trend

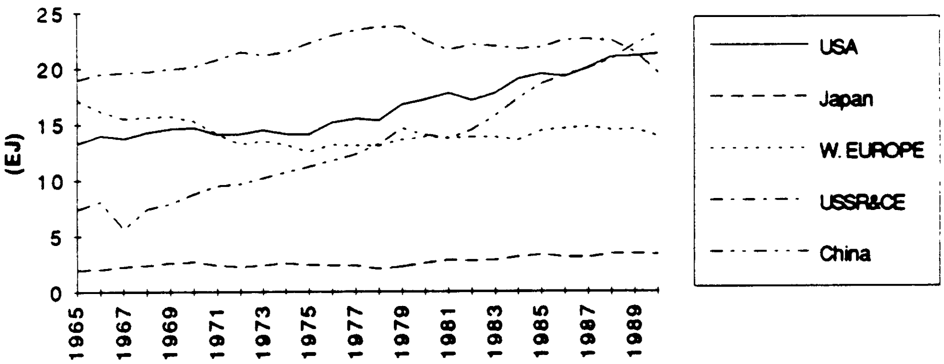
(Oil)



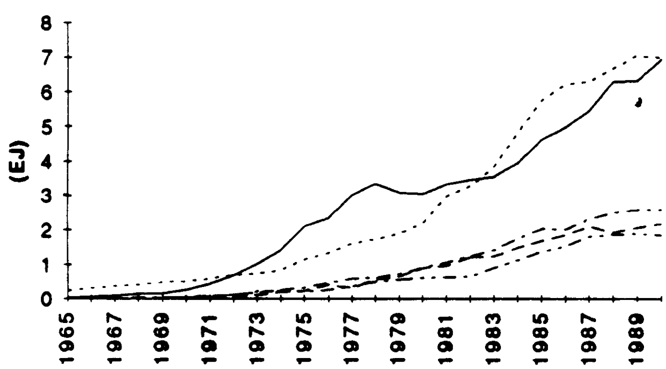
(Gas)

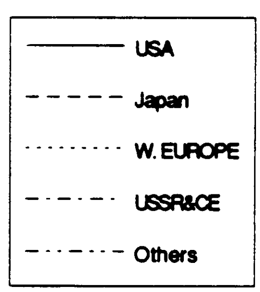


(Coal)

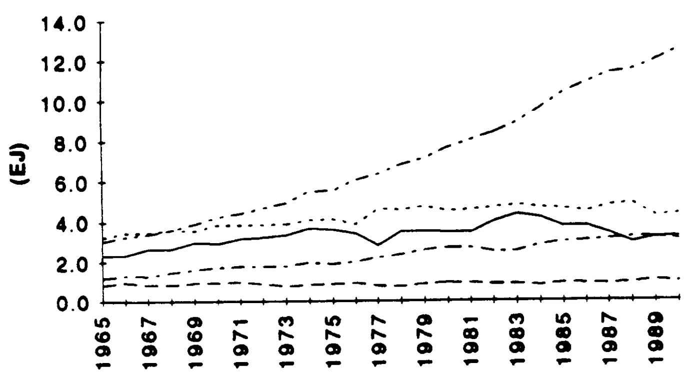


(Nuclear)



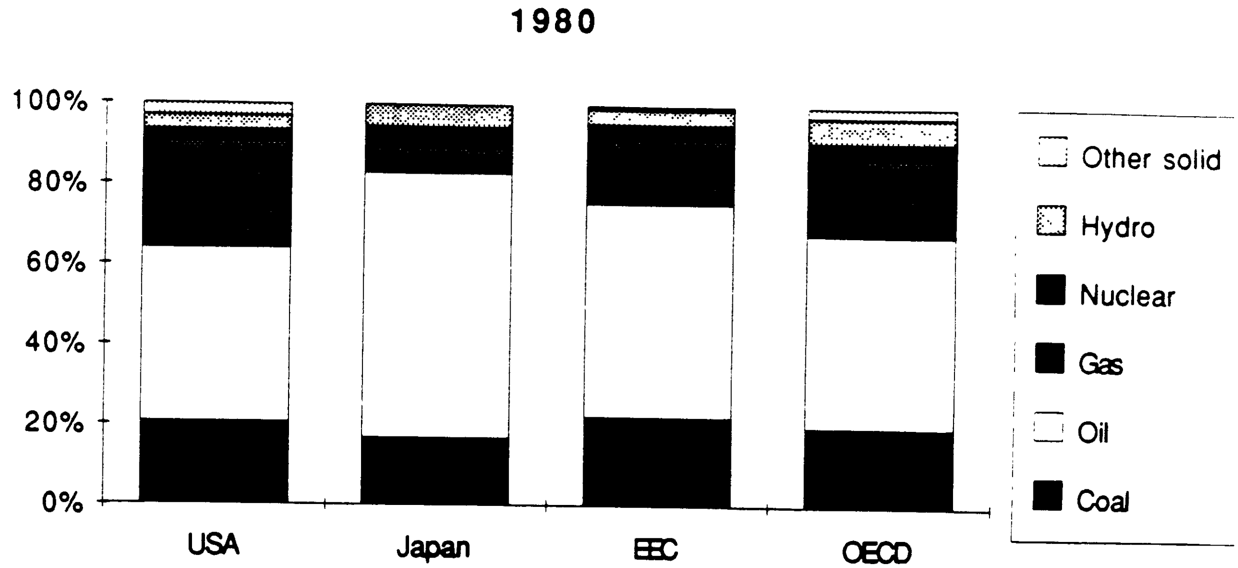


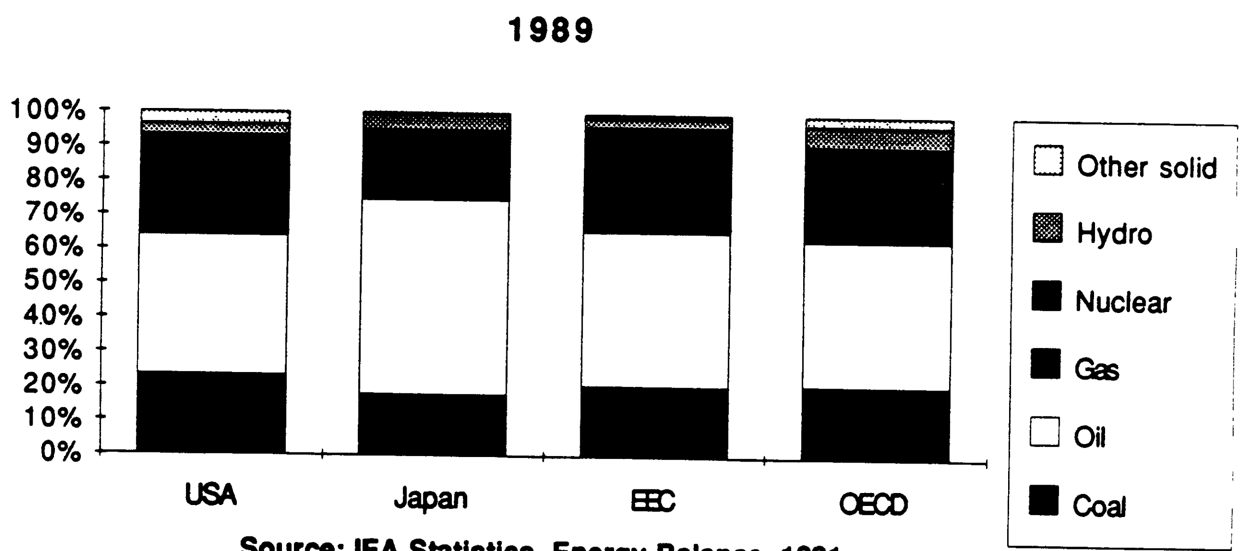
(Hydro)



Source: BP Statistics, 1991

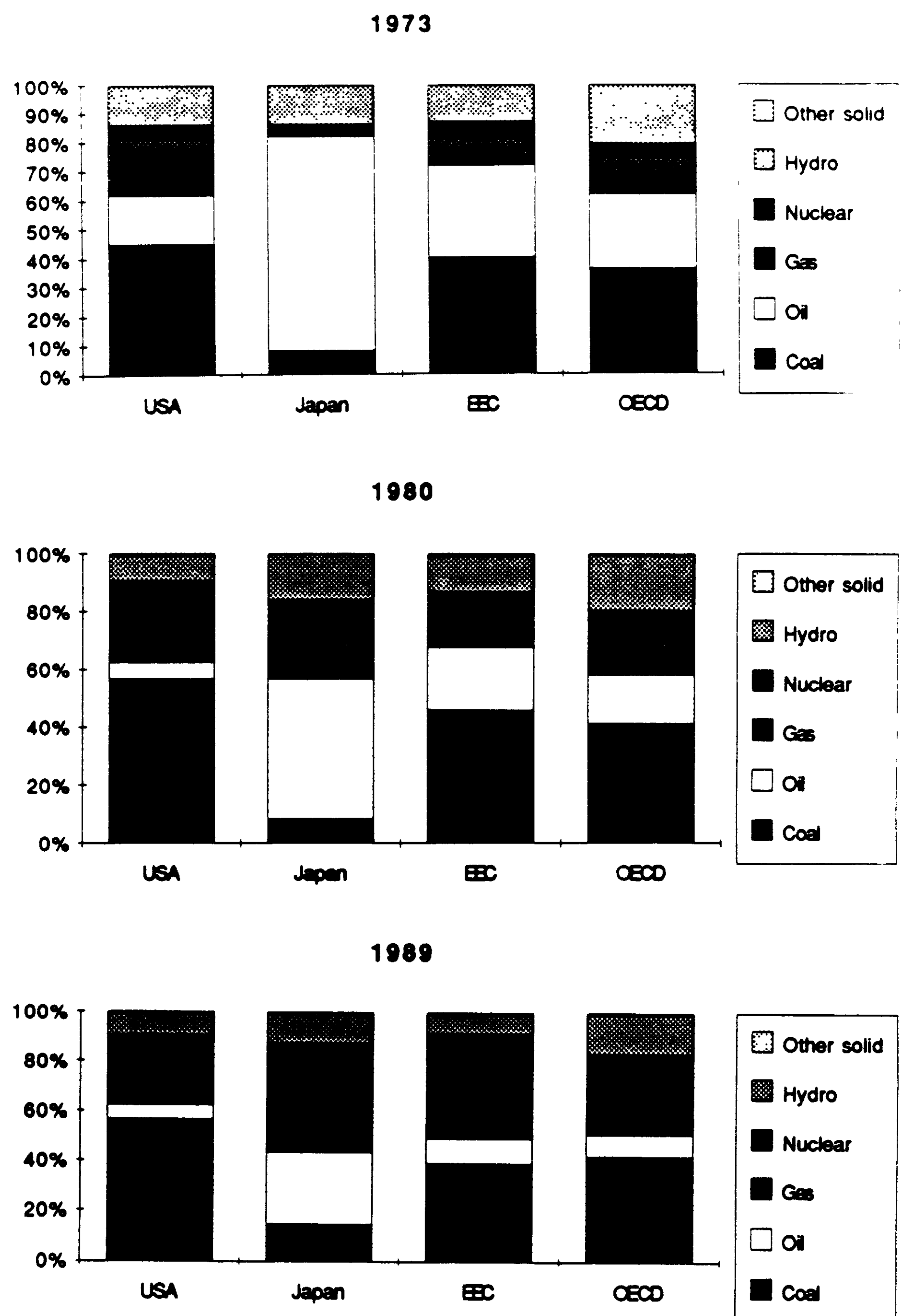
Fig. 3-1-4: Primary Energy Consumption





Source: IEA Statistics, Energy Balance, 1991

Fig. 3-1-5 Electricity Generation Input



Source: IEA Statistics, Energy Balance, 1991

Fig. 3-1-6: Probable Scenario (Base Case)

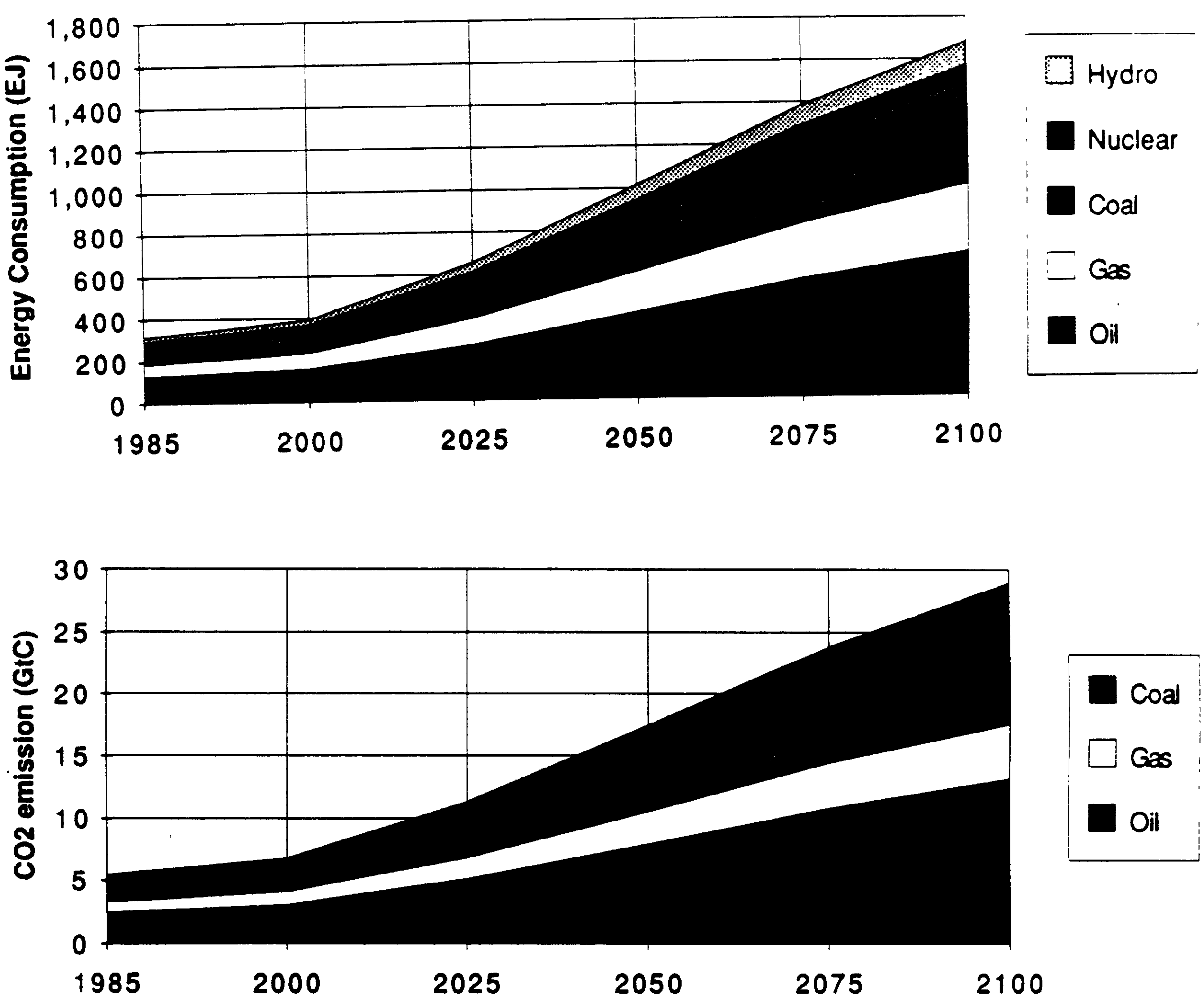
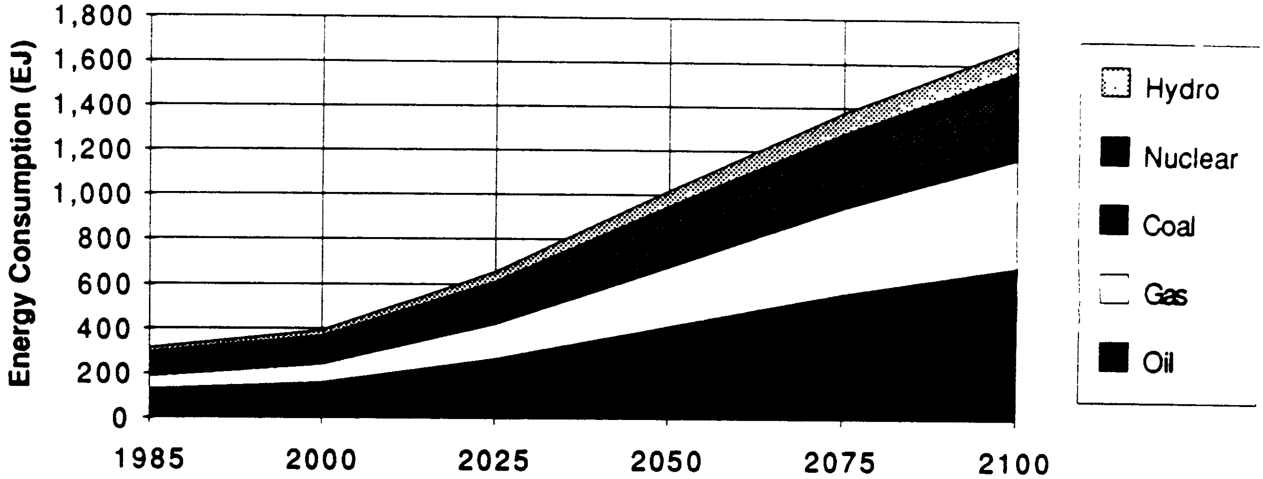


Fig. 3-1-7: More Probable Scenario (Modest Gas Grwoth)



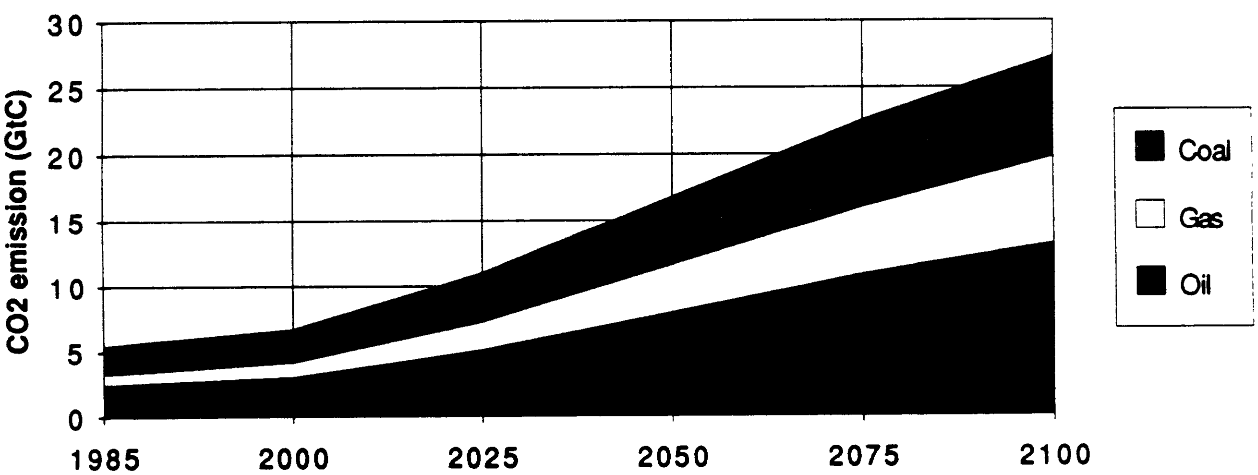
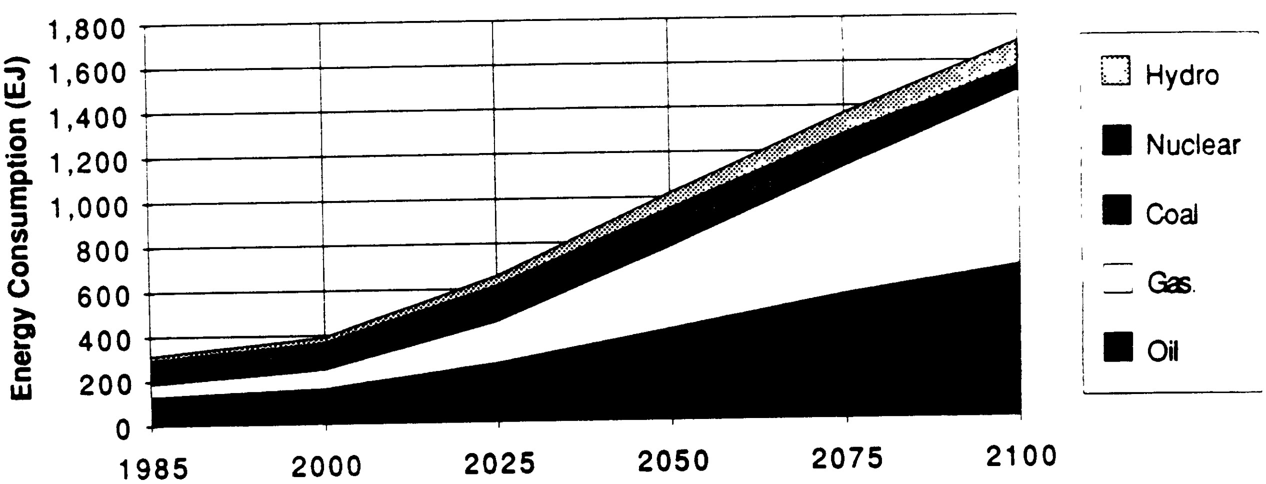
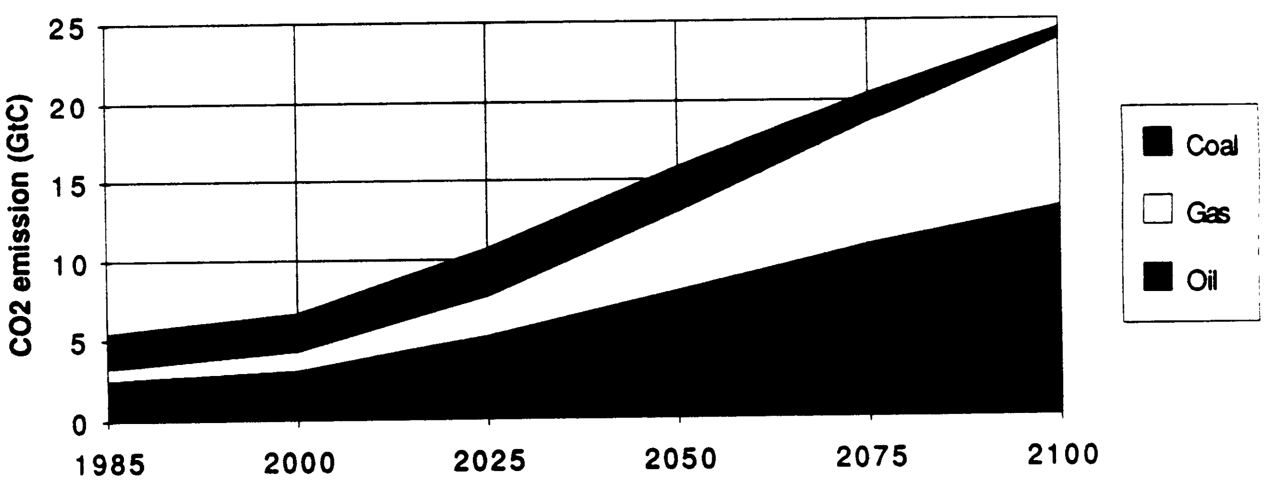


Fig. 3-1-8: More Probable Scenario (Rapid Gas Grwoth)





3.2 Environmental Issues and Countermeasures

Environmental issues cover a wide range from local to global issues including air quality, water quality, hazardous material, noise, vibration, odor, deforestation, biodiversity, and desertification. Global warming, biodiversity, deforestation, and desertification issues are global issues as in discussed in Rio de Janeiro recently (June 3 - 12, 1992). Ozone depletion is a global environmental issue. CFC's reduction targets were set in the Montreal Protocol in 1987 and strengthened in the 1990 London amendments to the Montreal Protocol. These reductions have been further accelerated in the US and other countries after discovery of ozone depletion precursor (ClO) increases last winter. (see Benedick, 1991) Radioactive wastes could be thought of a global issue because they require very long term management (several tens of thousand years.) Water quality could also be a global issue where it relates to the ocean. Water quality is definitely an international issue when dealing with rivers which go through several countries as in Europe. This section, however, will concentrate on air quality issues because they directly relate to global energy and environmental policy.

Sulfur dioxide (SOx) and Nitric Oxide (NOx) are good examples for reviewing environmental policy and technical countermeasures. SOx and NOx are considered to be "associated with the threat of acid rain" (NES, 1991). Acid rain was first recognized as a problem in Sweden. However, SOx and NOx were initially recognized as a cause of urban air pollution known as "photo-chemical smog" in Japan in the 1960's. Strict environmental control laws and regulations are enforced in Japan, and many scrubbers and selective catalytic reduction (SCR) units have been installed in electric utility and industrial boilers to reduce SOx and NOx respectively. As a result, "Few nations have deployed pollution control technologies and requirement as aggressively as Japan." (WRI 1990)

Table 3-2-1 summarizes the ambient air quality standards in major countries. (Ando, 1991a) Japanese standards are the strictest among these countries. "The level of allowable sulfur dioxide pollution varies according to a region's 'K-value.' The more polluted the air, the lower the K-value; the lower the K-value, the more stringent the emissions limit. Japan has established health-based ambient standards for most conventional pollutants from stationary sources." (WRI 1990)

These measures apparently reduced the emission rate both in ton/year and grams/kilowatt hour, however what effects have been on ambient air concentrations and the health of people is controversial. Only the SO2 ambient concentrations has clearly been reduced. NOx concentrations remain almost at the same level due to the vehicle emissions. "Japan is the only industrialized nation to have adopted a system for identifying and compensating the victims of air pollution. Victim Payments are made from a trust fund that derives its revenue from a tax on sulfur dioxide emission." (WRI 1990) The number of identified patients suffering from disease due to air pollution has been increasing. (Fig. 3-2-1) Ando discusses this point as follows: (Ando, Nov. 1991)

"SOx concentration in the ambient air has been dramatically reduced from the annual average of 0.06 in 1967 to 0.01. This is one sixth of the former value and is the world cleanest. However the number of patients identified has been increased despite the cleaner air. During 1972 and 1973 it was discussed that the cause of the increase in patients, despite the SO2 reductions, was increases of NOx emissions. Then the NOx standard was made world's strictest, and NO2 concentrations have declined slowly since 1980. But the number of patients were still increasing and reached 100,000... It has been shown that there is no relation between SOx and the number of patients. And finally identifying patient procedure has been stopped. Looking back to the ambient air condition of those days in Yokkaichi, SO2 concentrations were not necessarily high, but the sulfuric acid mist was extremely high. It is apparent that plenty of sulfuric acid mist had been emitted from the chemical factory. The conclusion is that we miss-identified the cause." (Japanese original translated by the author)

Ando also denies that SO2 and NO2 caused acid rain in Japan, which is commonly discussed in mass media these days. (Fig. 3-2-2, Ando, Nov. 1991)

Curtis Moore classified each country's approach to air pollution control in two ways: Ambient Air Quality Standards and Technology-Based Regulation in WRI 1990 (p. 202). Most countries have both ambient air quality standards and emission standards, but which is driving the countermeasures taken differs from country to country. Moore took an example of Canada as the country which has a stricter ambient air quality standard. "Canada has no uniform technology requirements for old power plants. But its ambient standards program - designed to prevent a level of acid precipitation that would harm sensitive resources - will also achieve significant results: a 40 percent reduction from 1980 to 1994 in sulfur dioxide emissions in Canada's eastern provinces." (WRI 1990, p.204)

Germany is an example of a country which is driven by Technology-Based Regulations according to Moore. "The Federal Republic of Germany, for example, has relatively weak ambient standards. But technology requirements that are collectively the world's most stringent have been used to achieve reductions of sulfur dioxide emissions by over 50 percent within five years." (WRI 1990, p. 204)

As we have observed in Table 3-2-1 Japan has the most stringent standards for both ambient air and emissions. However, the driving force in Japan is definitely a technology based requirement (emission standard) agreed upon by local governments in the case of stationary sources. As a result of stringent regulations, Japan is second to none in installed unit numbers of Flue Gas Desulfurization (FGD) units for $SO2$ control and Selective Catalytic Reduction (SCR) units for NOx control (Table 3-2-2).

Table 3-3-3 shows another look at FGD and SCR installations in terms of capacity and percentage versus installed fossil-fired power plant capacity. The US leads in installed capacity of FGD (70 GW) but is only one eighth of its total fossil-fired plant capacity. Japan follows with 60 GW and around half of its fossil plant capacity. Former West Germany installed 43 GW of FGD which is 62% of its total capacity. Japan leads in installed capacity of SCR (45 GW) at 38% of its total capacity, and former West Germany exceeds Japan in terms of percentage of its total capacity (43%) with its installed capacity of 30GW. SCR installed in the USA is negligible at less than one percent with less than 4GW capacity. Figs. 3-2-3 and 3-2-4 show the historical trends for FGD and SCR installation respectively.

Apparently technology-based (or emission based) standards drove Japan and Germany to effectively enforce technical countermeasures. (Fig. 3-2-5) But the effectiveness of money invested to improve ambient air quality is another matter. There might be "over control" in Japan and in former West Germany. "Over control" according to Moore, "is the removal of more pollution than is necessary to protect either health or the environment... The 'certainty' of a technology-based strategy is to some mindless rigidity which wastes limited social resources"(WRI 1990, p. 204)

Ando argues: "The major cause of increasing patients is sulfuric acid mist and dust from diesel vehicles. They have installed 3,000 of FGD's in Japan, and if NOx countermeasures are added into account, 10 trillion Yen ($ 77 billion at 130/$) has been spent. I would not say that all of them, but probably half of them were not necessary... Besides the money, to avoid the wasted energy and resources, we must select countermeasures which are really needed." (extracted and translated from Japanese original by the author, Ando, Nov. 1991, p.38)

It is very difficult to loosen emission standards once they are established, even if they prove to be unnecessarily strict and are not cost effective. For example, once a coal-fired power station has been built and fully equipped with FGD and SCR, it is difficult to build the next coal-fired power plant without FGD and SCR within a near by community, even if the ambient air quality does not require it.

Japan started its environmental policies with its tragic history of Yokkaichi and Minamata. These created an atmosphere where it was morally bad to think about economics when we discussed pollution countermeasures. (Ando, Nov. 1991, p.29) Actions were effective in some cases but cost a lot and wasted energy. Ando estimated energy consumption and CO_2 generation and argued against wasting resources (Table 3-2-4)

The US has a different approach. The Clean Air Act amendments of 1990 rely heavily on a "market based" control strategies through an "emission trading" system. Total allowable emissions for the country or a region are calculated first and allocated to emission sources. Permits to emit certain amounts of pollutants can be traded on the market like monetary instruments. This is potentially a more flexible way of controlling pollutants than a technology based approach. However the initial calculation of total allowable emission needs to be reasonable and the allocation to each source needs to be acceptable.

The lesson we have learned here is that the technology based (Emission based) approach is certain, easy to enforce and effective in the short term, but it might result in over control and thus waste resources. On the other hand market based approach seems to be more flexible, although the response time until it is effective might be longer than the command and control approach.

The CFCs reduction process to cope with stratospheric ozone depletion has often been discussed as analogy for CO_2 reductions. But when we look at the ratio of man made gases to natural emissions in chapter 2 (Table 2-4-1), CFCs and CO_2 are two extremes at the opposite ends. This means CO_2 reduction processes should not be argued as the same level of CFCs reduction processes because of the differences in anthropogenic rates of gases as well as the differences in economic impact to reduce these gases.

The global warming and the CO_2 issues are quite different from either the SO_x/NO_x issue or stratospheric ozone depletion issue. A simple analogy as controlling processes should be avoided, and one should be cautious about over control due to not knowing the real problems and causes for the following reasons:

- CO_2 is not a major greenhouse gas and whether the global climate is warming by anthropogenic causes or will be is not certain yet.

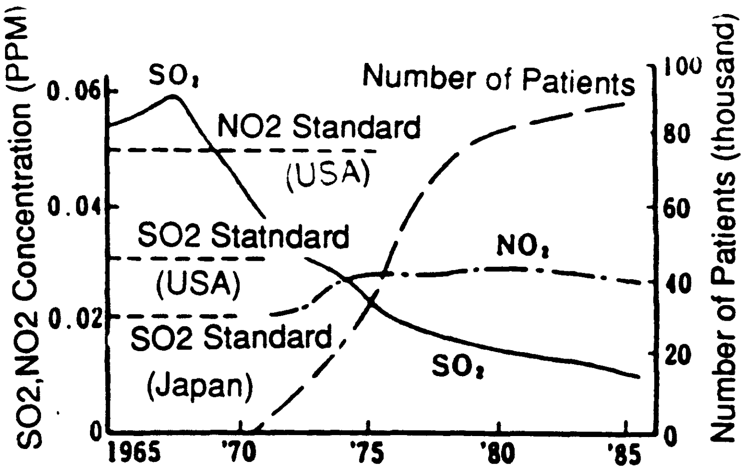
- Economic damage caused by potential global warming is uncertain but likely to be small.

- CO_2 emissions by human activity is still much smaller than natural CO_2 emissions, unlike the case for CFCs and NOx/SOx emissions.

- CO_2 reductions in large amounts will require large amounts of resources.

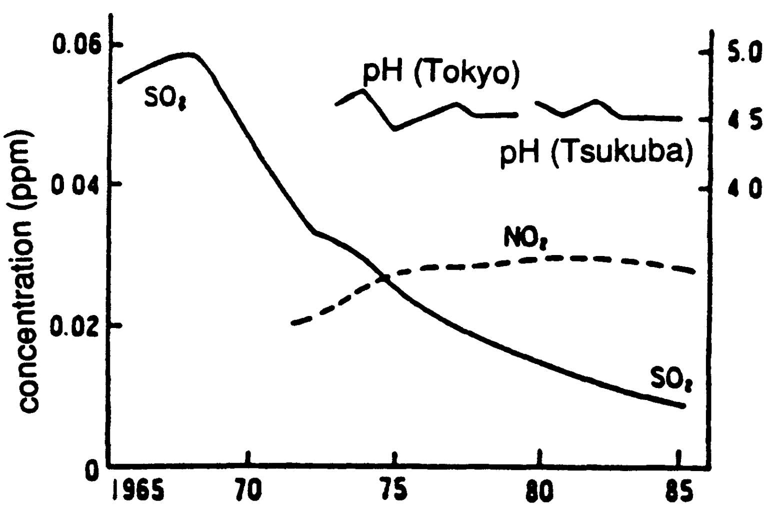
- CO_2 reductions are directly related to energy policies and fuel switching which could cause more serious problems than potential global warming.

Fig. 3-2-1· U·ban Air Pollution and Number of Patients in Japan



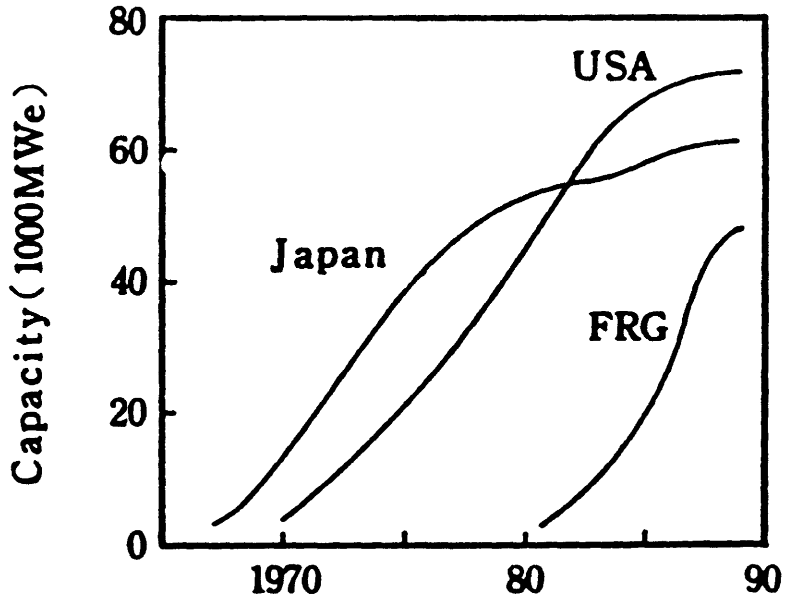
Source: Ando, Nov. 1991, p.34

Fig. 3-2-2: SO2 and NO2 concentration in the atmosphere and pH in Tokyo area



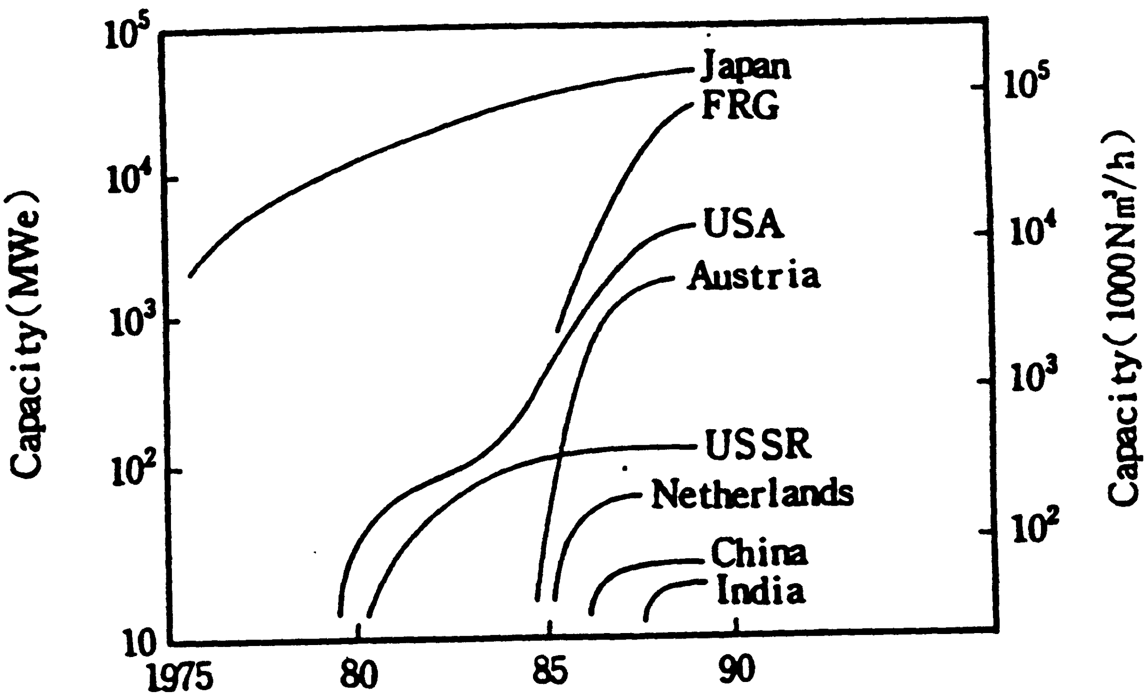
Source: Ando, Nov. 1991, p. 35

Fig. 3-2-3: Flue Gas Desulfurization (FGD) Installed Capacity in US, Japan and Germany for SOx Control



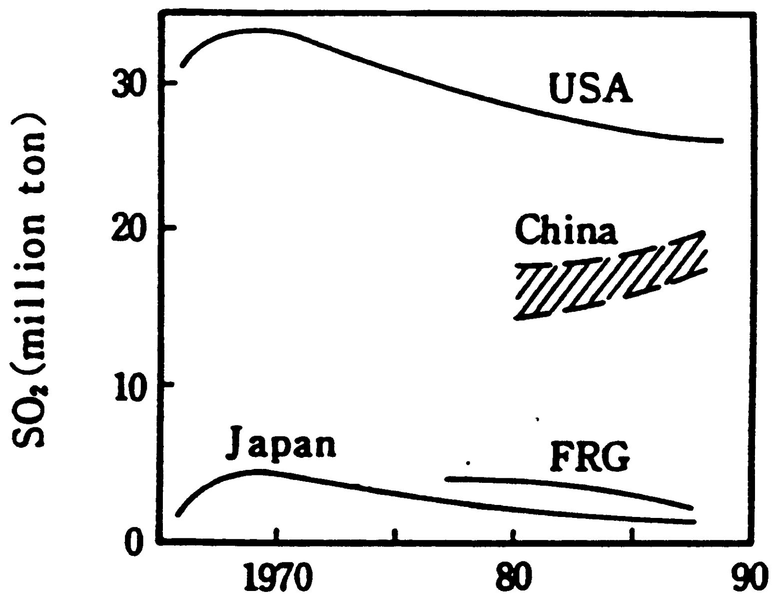
Source: Ando, Oct. 1991, p. 15

Fig. 3-2-4: Selective Catalytic Reduction (SCR) Installed capacity for NOx control



Source: Ando, Oct. 1991, p. 44

Fig. 3-2-5: SO2 emission trend



Source: Ando, Oct. 1991,p. 15

Table 3-2-1: Ambient Air Quality Standard

	SO_2, ppm		NO_x, ppm		SPM(a)	Oxidants
	Daily	Yearly	Daily	Yearly	Daily	Hourly(b)
Japan	0.04	0.016	0.04-6	0.02-3	100	0.06
USA	0.14	0.03		0.05	260	0.06
FRG		0.05		0.04		
Italy	0.15				300	
Canada	0.06		0.10		120	
China(c)	0.15	0.06	0.10		300	0.16
Korea	0.15	0.05	0.15		300	0.10
Taiwan(c)	0.10	0.05			210	0.12
Thailand	0.11	0.035			330	0.09

(a) Suspended particulate matter. In $\mu g/m^3$.
(b) Mainly ozone. In ppm. (c) In residential region

Source: Ando, Oct. 1991,

Table 3-2-2: FGD and SCR Unit Numbers Installed (1989)

	Japan	US	W. Germany	Others	Total
FGD	1,800	300	160	100	2,360
SCR	350	30	80	30	490

Source: Ando, Nov. 1991, p. 33

Table 3-2-3: FGD and SCR Installed Capacity in Fossil Fired Power Plants

	Japan	USA	W. Germany
Fossil Fired Plant (MW)	118	561	69
FGD capacity (MW)	60	70	43
FGD percentage (%)	51%	12%	62%
SCR capacity (MW)	45	4	30
SCR percentage (%)	38%	1%	43%

Sources: U. N. Energy Statistics Yearbook for Fossil Fired Plant Capacity
Ando, Oct. 1991 for FGD, SCR capacity

Table 3-2-4: Energy Consumption and CO2 Emission in Removal Process

(million ton/year)

Gas	Removal process	Removal		Energy needed	CO_2 formed
		Current	Future	As coal, Future	Future
SO_2	FGD	10	30	15-20	50-80
NO_x	SCR	1	3	1-3	4-10
CO_2	SA(a)	100	4000	500-700	1100-1500

(a) Solvent absorption

Source: Ando, Oct. 1991

3.3 Regulations, Taxes and Emission Rights

This section discusses the regulatory and economic approach to controlling emissions under uncertainty about global warming.

Ambient air standard is the approach the IPCC tried. It is almost only a fact that everyone admits that the atmospheric CO_2 concentration has been increasing. And there is a basic and intuitive idea that changing nature is bad and it is best to keep it as it is. The IPCC concluded that over 60% reduction of CO_2 emissions will be required to stabilize the atmospheric CO_2 concentration.

Increased concentrations of atmospheric CO_2 themselves (even if they are doubled) will not harm the human health as lead or oxidant do, nor damage property or nature as acid rain does. And there is still not enough evidence that CO_2 and other minor greenhouse gases are warming up the globe. The IPCC's conclusions are based on arbitrary scenarios and are not forecast of the future as we have seen in chapter 2. Although CO_2 concentrations will be a sign to monitor as one indication of the relationship between human activities and nature, there will not be an ambient air quality standard for CO_2 in the sense of other pollutants (pollutant is not an appropriate word for CO_2) like SO_2 or NO_2 has been set.

The technology based (or emission based standard) approach has been very effective for enforcement in a short term but sometimes caused over control problem as we have seen in previous section. It is not appropriate to apply this approach to CO_2 emission because its lack of flexibility wastes resources. It became very popular and a kind of fashion to declare CO_2 stabilization targets, but these targets have no reasonable meaning and potentially distort energy and environmental policy.

Setting energy efficiency standards might be a good way to encourage utility company to replace old units which have poor heat rates by newer or advanced technology with better heat rates, thus consuming less energy while producing the same or more electricity output. But if it honors electricity bills then it might encourage end users to consume more electricity and consequently no primary energy consumption might be saved at all. The same thing will happen when motor vehicles energy efficiency is made stricter to improve km/litter (or miles/gallon). Total consumption of gasoline might not be reduced with improved fuel efficiency but with more mileage. Therefore when energy efficiency standards are enforced, price incentives must also be carefully considered.

Emission rights are not appropriate with all the uncertainties with global warming because to establish a tradable market governments or international organizations must quantify the total allowable emission quantity, and allocate it. It is impossible to quantify reasonable CO2 allowable emission quantity at this stage.

It is common to discuss environmental taxes or a carbon tax, but a carbon tax is not appropriate because it distorts energy policy and encourage fuel switching. The disadvantages of the policy distortion will be discusses in chapter 4. Taxes should be used not to reduce CO2 but to encourage energy savings.

Fig 3-3-1 compares energy price for US electric utility and carbon tax when $100/tC incurred. US Coal is a major energy source for electric power generation (57 % in 1989) and it is quite cheap (average $1.38/GJ in the range of $1.35/GJ and $1.40) because most of the coal is indigenous and required small transportation fee. The oil price of $3.21/GJ indicates an average crude oil price which ranges from $2.2/GJ to $4.8/GJ during the Iraqi invasion of Kuwait and gulf war. During the same period the gas price for US utilities averaged $2.20/GJ with ranges from $2.0/GJ to 2.7/GJ.

If the carbon tax of $100/ton of carbon is applied, the tax to coal, oil, gas will be $2.38/GJ, $1.92/GJ and $1.37/GJ, respectively. Coefficient of 23.8, 19.2 and 23.8 teragram of carbon per exajoule has been used. (Edmonds, 1985, p.266) Fuel price increases are 173%, 60%, and 62%, and after tax prices are $3.76 GJ, $5.13/GJ and $3.57 for coal, oil and gas respectively.

Coal is cheap but electric power companies require coal and ash handling facilities, which are not required for oil and gas fired power plants. Environmental facilities such as scrubbers and precipitators will be required for coal or oil but not for gas. Nobody will use coal if the fuel prices of oil or gas are equal to or cheaper than coal. Apparently $100/tC will encourage every utility company to switch fuel from coal to gas or oil.

What will actually happen, though, will be that gas and oil suppliers will find huge demand and big margins in competition with coal, they will increase price of gas and oil until they find a new balance with the increased price by carbon tax. Another scary scenario is that oil and gas suppliers will wait to raise the price until the coal industry dies completely and then control the price in any way they want.

DOE studied several cases of carbon tax ranging from $25/tC to $750/tC comparing with the current policy case and National Energy Strategy (NES) Action case in its report to congress. (DOE, Sep. 1991) Although they estimate a moderate shift from coal to gas in utility use in a decade or two, they underestimate the effect of carbon tax on fuel switching among fossil fuels partially due to ignoring fuel switching capability of existing boilers and partially due to the arbitrary oil and gas price estimates and constraints the models they used: Fossil2.

"In response to the taxes, cheap energy conservation measures are substituted for fossil fuel consumption in early periods, and low-carbon fossil fuels are substituted for high-carbon fossil fuels in the later periods." (DOE, Sep. 1991, V. II p.6.9) Actually utility gas consumption will decline compared to the NES action case in all tax cases until 2000, utility oil consumption will not differ from NES action case, and utility coal consumption is of course less than the NES case in all tax cases, but still increasing its consumption if the tax is less that $100/tC until 2010. (Ditto, p. 6.43 - 45)

It is very easy to use oil in existing coal-fired power plants. No or only minor modification, if any, will be needed to switch from coal to oil, and oil is available anywhere in the world at an international market price plus any carbon tax. Using gas in coal-fired boilers is also easy and only minor modification will be required. For combustion modification from coal to oil or gas requires only a couple of months, even if it is needed. Gas might not be immediately available at some sites, because of pipeline constraints, however, if huge demand is there, pipeline capacity will be created in a couple of years.

Oil and gas price estimates at current policy scenario are controversial. World oil price has been exogenously assumed (Vol. II, p.5.14) to be doubled by 2005 from $3.1/GJ of 1990 price to $6.1/GJ, and increased to $8.6/GJ in 2030. Lynch discusses the general trend of higher oil price projection and calls "Not just wrong, biased". (Lynch, May 1992)

"The wellhead price of natural is determined endogenously by the model (Fossil2). This price depends not only on the world price of oil through the competition between oil and gas, but also on the resource and available reserves of gas, and to a lesser extent, competition with coal." (DOE, Sep. 1991, V.II, p.5.15, underlined by the author) It has been calculated to increase from $1.9/GJ in 1990, quadrupling to $7.9/GJ in 2030. All the tax case studies started from this arbitrary and controversial setting and submerged the fuel switching incentives of carbon tax.

Although Fossil2 assumed open oil markets and introduced price input exogenously, it assumed the US gas market almost closed, with only limited imports from Canada and Mexico and LNG considered in the entire period of simulation, despite the recent extensive increase of proven reserves in Russia and Middle East.

Rather than depending on one future scenario, we should look at the present status of coal, oil, gas, and look back to the historical trend of each fuel and physical nature of each.

Loser will be coal industries, and winners will be gas suppliers (if not domestic then international) and oil suppliers if a carbon tax is applied.

Is there any way we can just give energy efficiency incentive which is always good and no controversial fuel switching incentive? Energy tax based on the each fuel's heat content gives an equal amount of tax per heat content to each fuel. It is still heavier to coal and lighter to oil and gas, because the base price of coal is low. Only a fuel price tax based on price per heat content will give equal burden to coal, oil and gas in proportion to their price, and give incentive to suppliers to keep prices as low as possible in competition with other fuels.

Figs. 3-3-2 and 3-3-3 shows how an energy tax and a fuel price tax affects the price of coal, oil and gas. Nuclear and all renewable should also incurred these taxes due to their nature. The background idea is every energy use including nuclear and renewable have impacts on the environment as discussed in chapter 4. Sometimes it is hard or impossible to measure environmental impacts. Therefore rather than measuring every impact to environment and converting it as externality, tax payers should pay according to how much energy they used or how much they paid for the energy they used. In this study, however, to concentrate in fuel switching, nuclear and renewable are neglected from the calculation.

Both energy and fuel price tax cases are calculated so that the tax revenue is the same as carbon tax of \$100/tC. Tax revenue from \$100/tC in US will be \$144 billion based on the coal, oil and gas consumption in 1990. (DOE/EIA Sep. 1991) It will be 2.9% of GNP in 1990. To get the same amount of tax revenue, \$1.89/GJ of energy consumption tax or a 77.25% fuel price tax will be required. In the energy consumption tax case, the coal price increase will be 137%, while the oil and gas price increases will be 59% and 86%, respectively. Table 3-3-1 shows the details of calculation for carbon tax, energy consumption tax and fuel price tax cases.

Let's look at these cases when applied to Japan, which has a quite different scheme of energy supply and consumption. Figs. 3-3-4 to 3-3-6 show fuel prices and taxes of these cases.

Since Japan depends on imported fuels heavily (90% of coal, almost 100% of oil, and 97% of gas), fuel prices indicated are all CIF basis averaged in fiscal year 1990 (FY1990, April 1990 through March 1991). The indigenous coal price for utility use is around two- to three-fold of imported coal price, and no longer economically competitive.

The average coal CIF price is \$2.03/GJ which is 50% higher than the US utility coal prices, ranging from \$2.00/GJ to \$2.07/GJ during the FY 1990. The crude oil price is \$3.34/GJ which is almost the same as the US price, ranging from \$2.30/GJ to \$5.10/GJ during the FY 1990. Gas price is 60% higher than that of US, because it must be liquified and transported by LNG tanker and vaporized again before the final consumption. An average price of LNG in the FY 1990 is \$3.46/GJ with its range from \$2.84/GJ to \$ 4.15/GJ. LNG prices are usually slightly higher than oil prices and linked closely to the price of oil, however, its fluctuation is smaller than that of oil (around half).

If the carbon tax of \$100/tC were incurred, the price increase of coal, oil and gas will be 117%, 56% and 40% respectively. With a carbon tax, the price range is too close for coal to compensate its additional capital and operational requirement such as coal handling, ash handling, and environmental facilities. Oil and gas are apparent winners, and coal is a loser here also.

Total tax revenue will be \$19 billion if 1989 consumption rate is used (OECD Energy Balance 1990), which is 0.7% of 1989 GNP. The percentage of GNP is less than one fourth when compared with the US (2.9%). This is mainly due to the difference of energy intensity (E/GNP) between US and Japan. The figure happens to be a number which was proposed in "Earth Summit" at Rio de Janeiro as a target of environmental ODA from developed country to developing country.

Therefore in Japanese case, \$100/tC of carbon tax will provide all the necessary revenue for environmental aid to reach the international target, after completely killing coal related technology and creating heavy dependence on oil again, aside from the general influence to the economy.

With an energy consumption tax, the burden on coal will be less than in the carbon tax case, but still percentage increase of price will be double compared to oil and gas (97%, 57%, 57% respectively) to get the same tax revenue.

Only the fuel price tax will avoid an unnecessary preference for oil and gas, with equal percentage of 66% of each fuel price to get the same revenue, if it must be extracted from fossil fuel consumption. Table 3-3-2 shows the details of calculation for the carbon tax, energy consumption tax and fuel price tax cases in Japanese case.

Fig. 3-3-1: Carbon Tax (USA, $100/tC)

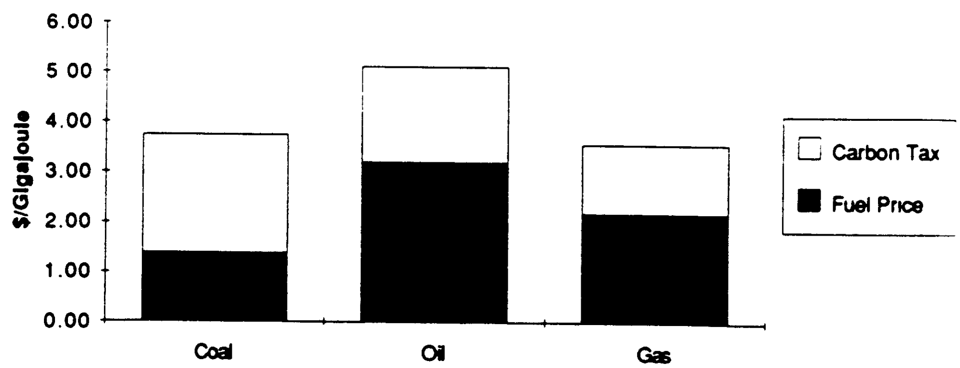


Fig. 3-3-2: Energy Tax (USA, $1.9/GJ)

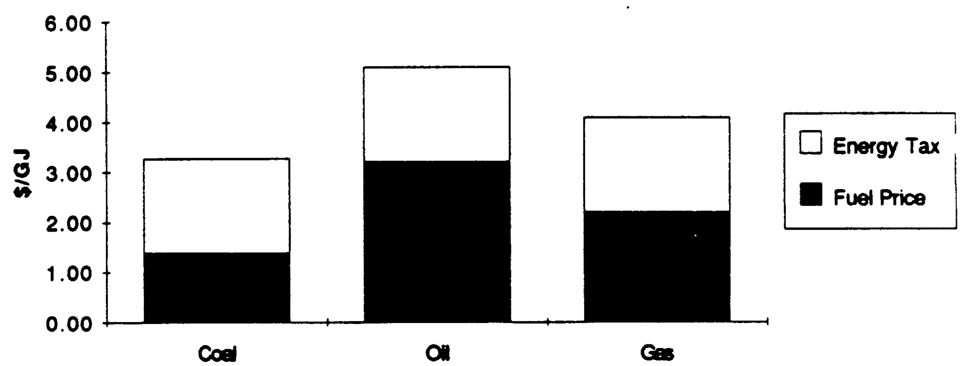


Fig. 3-3-3: Fuel Price Tax (USA, 77%)

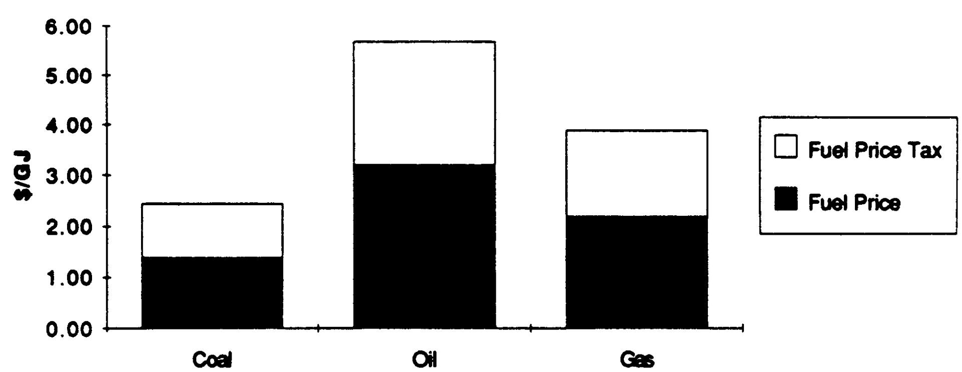


Fig. 3-3-4: Carbon Tax (Japan, $100/tC)

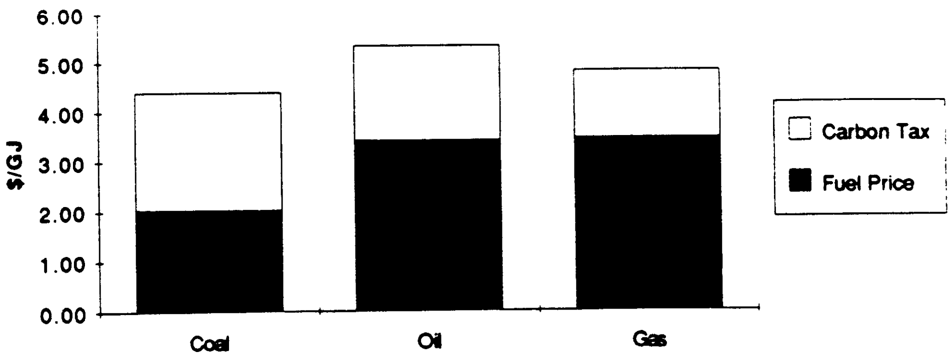


Fig. 3-3-5: Energy Tax (Japan, $2/GJ)

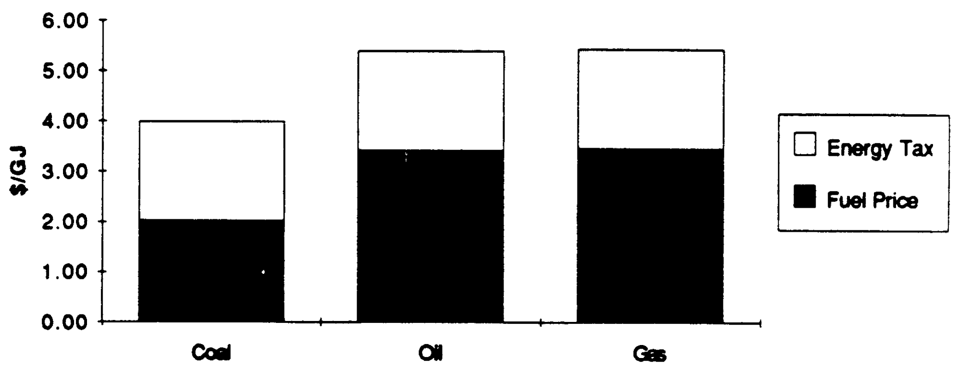


Fig. 3-3-6: Fuel Price Tax (Japan, 67%)

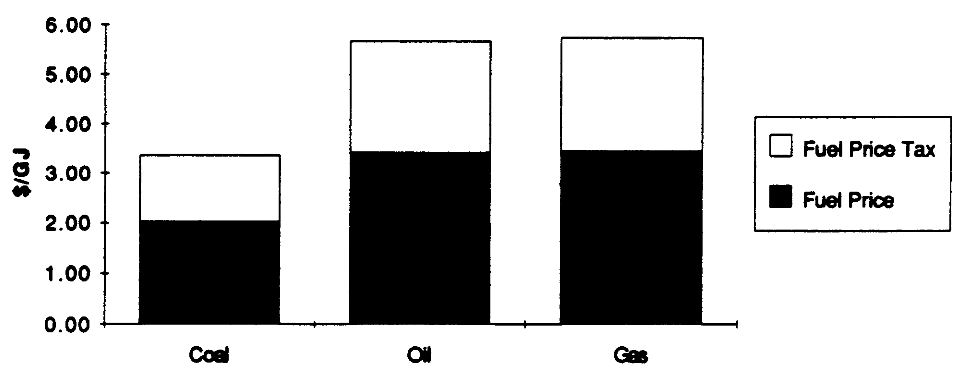


Table 3-3-1: Carbon Tax, Energy Tax and Fuel Price Tax in USA

Carbon Tax

	Coal	Oil	Gas
Fuel Price for Utility Use (US 1990,$/GJ)	1.38	3.21	2.20
CO2 emission (kgC/GJ)	23.8	19.2	13.7
Tax ($/GJ if $100/tC applied)	2.38	1.92	1.37
percentage increased by tax	172.58%	59.86%	62.28%
Fuel Price after tax	3.76	5.13	3.57
Consumption (billion fuel units,p42,73,84)	0.89	6.20	18,837.00
Heat Value (MBTU/fuel units, p139,140)	21.34	5.41	0.001031
Consumption (EJ)	20.14	35.40	20.49
Tax revenue (billion $)	47.94	67.97	28.07
Total revenue (billion $)			143.98
Percentage of GNP	GNP (1990)=	4,961.43	2.90%

Energy Tax

	Coal	Oil	Gas
Fuel Price for Utility Use (US 1990,$/GJ)	1.38	3.21	2.20
Coefficient to make revenue neutral	1.89365529	1.89365529	1.89365529
Tax ($/GJ)	1.89	1.89	1.89
percentage increased by tax	137.31%	59.04%	86.08%
Fuel Price after tax	3.27	5.10	4.09
Consumption (billion fuel units,p 117)	0.89	6.20	18,837.00
Heat Value (MBTU/fuel units, p140)	21.34	5.41	0.001031
Consumption (EJ)	20.14	35.40	20.49
Tax revenue (billion $)	38.15	67.03	38.80
Total revenue (billion $)			143.98

Fuel Price Tax

	Coal	Oil	Gas
Fuel Price for Utility Use (US 1990,$/GJ)	1.38	3.21	2.20
Coefficient to make revenue neutral	0.77245134	0.77245134	0.77245134
Tax ($/GJ)	1.07	2.48	1.70
percentage increased by tax	77.25%	77.25%	77.25%
Fuel Price after tax	2.44	5.68	3.90
Consumption (billion fuel units,p 117)	0.89	6.20	18,837.00
Heat Value (MBTU/fuel units, p140)	21.34	5.41	0.001031
Consumption (EJ)	20.14	35.40	20.49
Tax revenue (billion $)	21.46	87.70	34.82
Total revenue (billion $)			143.98

Fig. 3-3-2: **Carbon Tax, Energy Tax and Fuel Price Tax in Japan**

Carbon Tax

	Coal	Oil	Gas
Fuel Price for Utility Use (Japan 1990,$/GJ)	2.03	3.42	3.46
CO2 emission (kgC/GJ)	23.8	19.2	13.7
Tax ($/GJ if $100/tC applied)	2.38	1.92	1.37
percentage increased by tax	117.23%	56.08%	39.55%
Fuel Price after tax	4.41	5.34	4.83
Consumption (MTOE1989, OECD EB p285)	73.24	117.35	40.51
Heat Value (EJ/MTOE, OECD EB p17)	0.04	0.04	0.04
Consumption (EJ)	3.07	4.91	1.70
Tax revenue (billion $)	7.30	9.44	2.32
Total revenue (billion $)			19.06
Percentage of GNP	GNP (1989)=	2,700.00	0.71%

Energy Tax

	Coal	Oil	Gas
Fuel Price for Utility Use (US 1990,$/GJ)	2.03	3.42	3.46
Coefficient to make revenue neutral	1.96937213	1.96937213	1.96937213
Tax ($/GJ)	1.97	1.97	1.97
percentage increased by tax	97.00%	57.52%	56.86%
Fuel Price after tax	4.00	5.39	5.43
Consumption (MTOE1989, OECD EB p285)	73.24	117.35	40.51
Heat Value (EJ/MTOE, OECD EB p17)	0.04	0.04	0.04
Consumption (EJ)	3.07	4.91	1.70
Tax revenue (billion $)	6.04	9.68	3.34
Total revenue (billion $)			19.06

Fuel Price Tax

	Coal	Oil	Gas
Fuel Price for Utility Use (US 1990,$/GJ)	2.03	3.42	3.46
Coefficient to make revenue neutral	0.65887105	0.65887105	0.65887105
Tax ($/GJ)	1.34	2.26	2.28
percentage increased by tax	65.89%	65.89%	65.89%
Fuel Price after tax	3.37	5.68	5.75
Consumption (MTOE1989, OECD EB p285)	73.24	117.35	40.51
Heat Value (EJ/MTOE, OECD EB p17)	0.04	0.04	0.04
Consumption (EJ)	3.07	4.91	1.70
Tax revenue (billion $)	4.10	11.08	3.87
Total revenue (billion $)			19.06

3.4 Global Environmental Policy

CO_2 emission rates are not an appropriate index to depend on in the process of making global energy and environmental policies, and setting an arbitrary target of CO_2 is a mistaken energy and environmental policy. Energy consumption is the index that should be set as the standard or target. CO_2 emission rate has been closely related to the energy consumption, because fossil fuel has been dominant energy source so far, and it is too easy to calculate CO_2 emission from fossil fuel consumption.

The problem is that it will drive the most secure, stable and cheap source of energy away and give chance to less secure, less stable and more expensive energy sources such as gas and nuclear and even oil to replace coal as we have seen the previous section.

The popular way of declaring a nation's policy of global warming - setting a target to stabilize CO_2 emissions at certain level at certain year - is an inappropriate approach. Again, CO_2 emissions are just one indicator of human activity and not the one to be controlled.

Also, CO_2 emissions stabilization targets ignore countries' development stage. Developing countries need economic growth, and thus energy consumption growth and consequently CO_2 emissions will increase. As a consequence developing countries will never accept such target.

The US government wisely avoided such targets, but ironically it is one of the easiest country to achieve these targets because of its big margin for reductions. Its energy intensity is one of the highest (400 kg oil equivalent(KOE)/$ or 18 Gigajoule(GJ)/$ compared to 150 KOE/$ or 7 GJ/$ in Japan.) And consequently CO_2 emissions per capita in the US is among the highest (5.9tC/capita comparing Japanese value of 2.6tC/capita or world average of 1.1tC/capita). (Kankyouhakusho, 1991)

The Japanese government, on the contrary, is setting a target of stabilizing CO_2 emissions at 1990 level by 2000 first by per capita basis and second on a total emissions basis. Japan is still a developing country with people's quality of life. They want to live in bigger house and work at spacious office and drive a bigger and safer car.

Since the government declared the CO_2 emissions target it has requested that its people lead a simple life (enduring to live in a small house) and promoted nuclear extensively to reduce CO_2 emissions. Is this the way to go? No. What was wrong was setting CO_2 emissions stabilization targets. Guideline of energy consumption per capita basis in absolute value (GJ/capita) should have been used instead of freezing its own status. We must recognize that each country is in a different development stage, and freezing emissions at the present status has no equity.

Therefore there has been two mistakes. Choosing CO2 is one and the idea of stabilizing at the present status is the other. Japanese government made a diplomatic mistake besides these two, by ignoring its own developing stage of quality of life and very small margin for reductions compared to the United States and other developed countries.

What we must think and should put priority from this issue in global policy is population growth, economic growth and energy intensity. Carbon intensity is a far lower priority, because CO2 is somewhat close but not a very adequate index.

Population is the single most important factor to determine economic growth, energy consumption and consequently CO2 emission. The higher population growth rate in less developed countries must be slowed down to improve their living standard and prevent a potential population explosion. Thurow described iron law as follows:

"The histories of the world's richest countries illustrate an iron law of economic development. No country can become rich without a century of good economic performance and a century of very slow population growth. Many of today's poor countries have population growth rates between 3 and 4 percent. If Japan, Germany, and the United States had had such rates of population increase, their standards of living today would be no higher than they were one hundred years ago." (Thurow, 1992, p. 207)

Poor countries tend to have higher population growth rate and are getting poorer. The Meadows' describe it in their book "Beyond the Limits", as "the rich get richer and the poor get children" in a "poverty-population trap." (Meadows, 1992, p37) Figs. 3-4-1 and 3-4-2 show historical trend of per capita GNP of rich countries and poor countries, and birth rates and GNP per capita in 1989 taken from the book.

Meadows argues, however, "With enough investment sustained for a long enough time, with fair pricing for products and fair market conditions, with increased output allocated to the poor and especially to the education and employment of women, a population can lift itself out of poverty." (Meadows, 1992, p40)

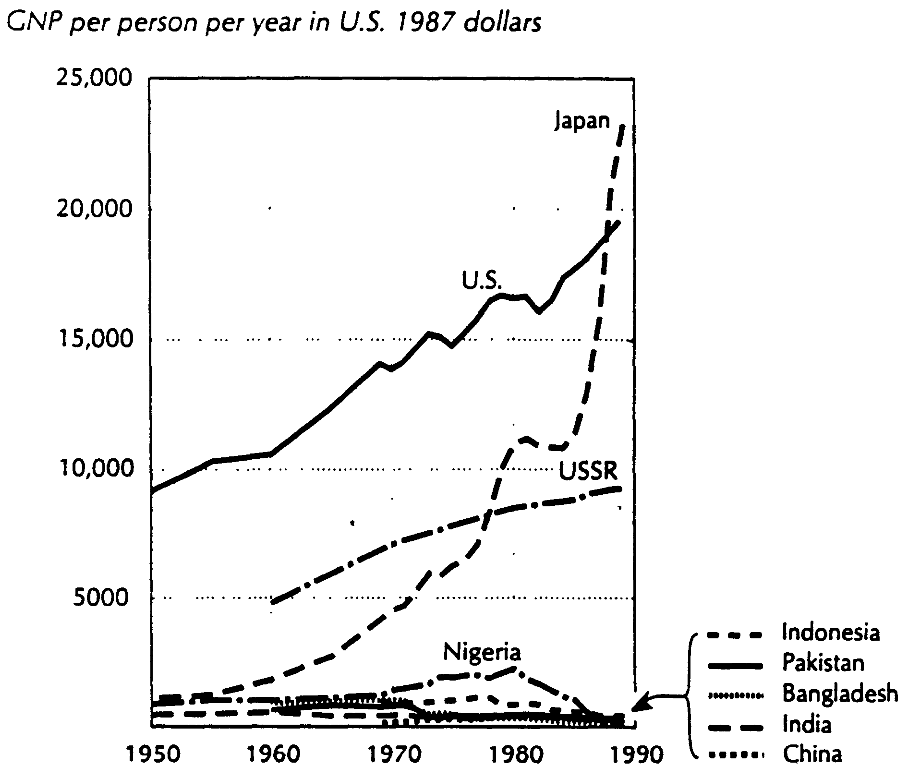
But even the richest countries do not have unlimited resources, and a critical view and selective investment will be needed. "Foreign economic aid should be focused on those underdeveloped countries where population is growing the slowest or where the best efforts are being made to reduce population growth rates. To do otherwise is to waste limited resources in a hopeless task." (Thurow, 1992, p.228)

Economic growth is always needed in capitalism society, but what is an appropriate rate of growth? With unlimited natural resources and environmental capacity, the bigger the growth is the better. But we have been recognized we have limited natural resources and environmental capacity, although we are still uncertain how much they are. Therefore in the long term (in hundreds of years) economic growth should be equal to the energy intensity improvement rate which means that energy consumption rate is constant with renewable energy sources and within a capacity that the environment can accept. However, in a decade or two it will not happen. We must seek lowest acceptable economic growth rate where we can still improve our quality of life within non-renewable natural resources and acceptable capacity of the environment.

It is always good to reduce energy intensity (or increase energy efficiency) whether the globe is warming or not. Therefore investment should be continued to technology development for increase efficiency in all fields: from generating technology such as PFBC, IGCC, and Fuel Cell to energy end uses such as better insulation, improved heat pump, compact fluorescent bulb.

Reducing carbon intensity means switching fuel from coal to oil/gas or coal/oil to gas or using non-carbon technology such as nuclear, hydro or other renewables. However as we will see in the next chapter, every non-carbon technology has flaws other than CO2, and oil and gas are not necessarily preferable for security and price stability reasons. Therefore the carbon intensity should not be more strongly emphasized than energy intensity improvements, or economic and population growth.

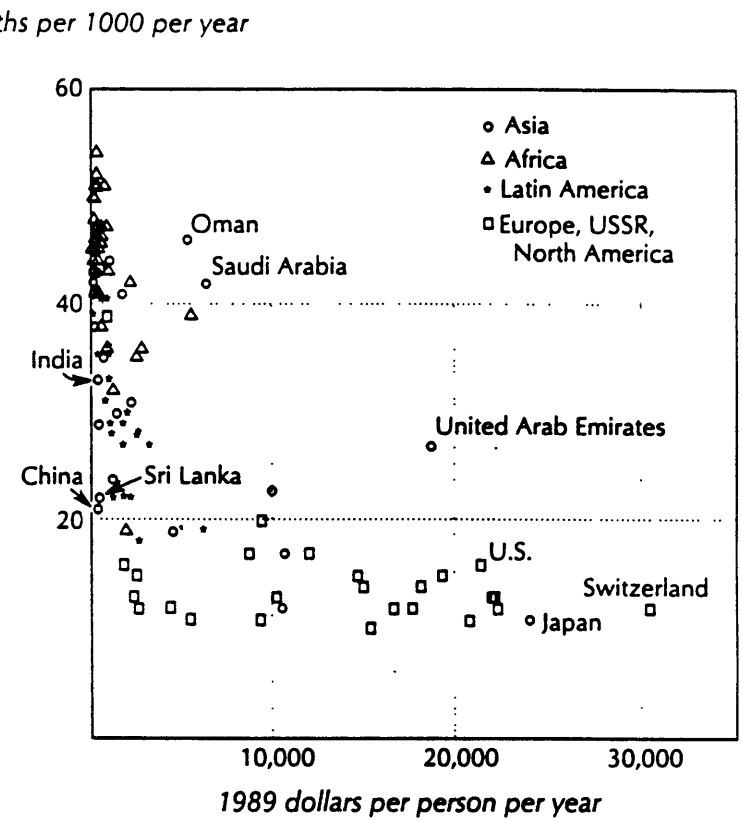
Fig. 3-4-1: Per Capita GNP of Selected Countries



Economic growth takes place primarily in the nations that are already rich. The five countries of Indonesia, China, Pakistan, India, and Bangladesh together contain almost half the world's population. Their per capita GNP barely rises off the axis when it is plotted together with the GNP per capita of the wealthier nations. (*Sources: World Bank; CIA.*)

Source: Meadows, 1992, p.38

Fig. 3-4-2: Birth Rates and GNP per Capita in 1989



As a society becomes more wealthy, the birth rate of its people tends to decline. All of the poorest nations experience birth rates between 20 and 50 per thousand people per year. None of the richest nations have birth rates above 20 per thousand per year except the oil-rich states of the Middle East. (*Sources: Population Reference Bureau; CIA.*)

Source: Meadows, 1992, p.32

3.5 Technology Transfer

Looking back at the developed countries' energy intensity (E/GNP) trend in the last one century, we can and should eliminate or ease growing pain of energy intensity peak by technology transfer to developing countries. (Fig 3-5-1)

However we should note that energy intensity change has two factors: one is efficiency improvement, another is social systems change such as shift from agriculture to manufacture, and manufacture to service industries. The former we can reduce by technology transfer, but the latter we cannot. Further investigation is needed to distinguish the two factors. But in this study simply assume they were half and half, and uses figures from the analysis of the UK historical trend.

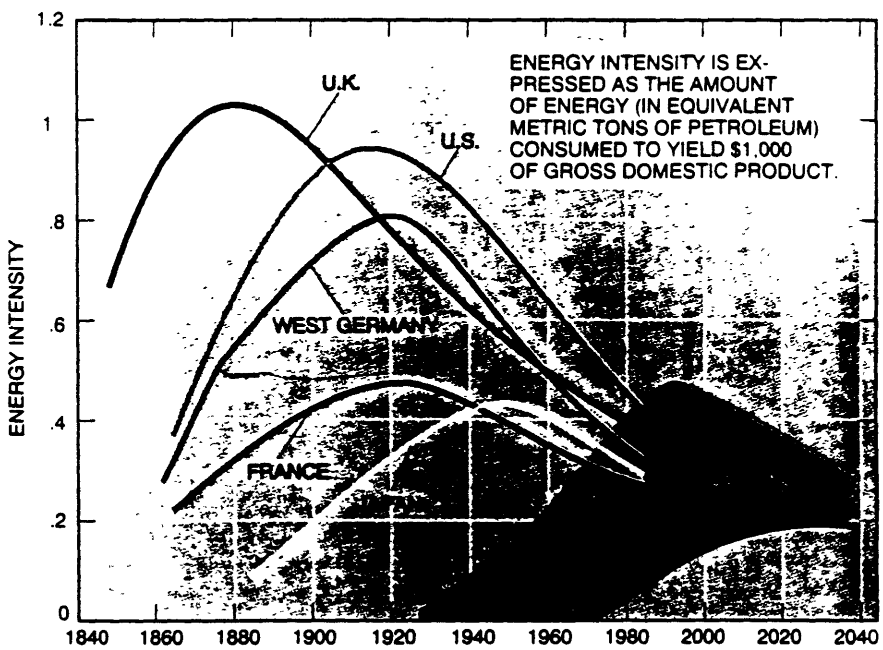
We have a long history of energy intensity date available for the UK. (Demonds, 1985, p, 49) Taking 1975 as the base line year when the energy intensity was 38.53 MJ/$, and calculating total energy saved during the year 1883 - 1975, we will get around 20 EJ over 100 years. When we look other developed countries, some countries like France and Japan had already achieved fairly low curves, while others like US and Germany were lower, but with similar experience as the UK. So let's assume 10 EJ in the population level of UK (56.3 million in 1980) as standard. If it is applied to present China (with 20 times population of UK), 200 EJ will be saved if we can eliminate this whole bell shaped curve. But as assumed before, if half of the problem is inevitable the social system changes, then we could save only 100 EJ in China in next 100 years which is still more than 3 years of Chinese current primary energy consumption.

If this calculation is applied to all developing countries whose population is estimated to be 9,500 million in 2100 by World Bank 1988 estimate, then we will get total energy saving around 1,000 EJ in the next 100 years at the same assumption, which is around 3 years of total world energy consumption.

More importantly at the peak year, only half or less energy will be required if this technology transfer goes well than otherwise. Current E/GNP is even lower than in 1975, 15 MJ/$ in US and 13 MJ/$ in Western OECD and 5 MJ/$ in Eastern OECD in 1985.

Thus, energy intensity is the single most important factor to reduce energy consumption and technology transfer helps a lot to ease peak period of the intensity during the development process.

Fig. 3-5-1: Energy Intensity Trend



IN INDUSTRIALIZED COUNTRIES the energy intensity (ratio of energy consumption to gross domestic product) rose, then fell. Because of improvements in materials science and energy efficiency, the maxima reached by countries during industrialization have progressively decreased over time. Developing nations can avoid repeating the history of the industrialized world by using energy efficiently.

Source: Scientific America, Sep. 1990, p.112

3.6 Conclusions

This chapter concludes as follows:

- World energy consumption has doubled in a quarter century. How to reduce its growth rate is the critical issue rather than the how to reduce CO_2.

- Oil dominates world energy consumption despite the two oil shocks and still has tendency to increase despite the effort of seeking alternative energy sources. Attention must be paid to too much dependence on oil again.

- Natural gas is increasing its production, share in energy, and proved reserve rapidly world wide especially in USSR and Central Europe. Liquified Natural Gas is still a small portion of total gas consumption because of the high capital cost of infrastructure.

- Coal is constantly decreasing its share in energy consumption in this century. But developing countries, especially China, have been and will be increasing coal consumption as a cheap and stable source of energy for development.

- Nuclear had a giant step in recent quarter century, but cannot be expected to do as much in the future because of safety, waste and proliferation issues.

- Hydro has kept a constant position in primary energy supply share, but is saturated in the developed countries, and growing in the developing countries especially Latin America.

- More caution must be taken about trying to over control CO_2 without knowing the real problems and causes, or the impacts on energy and environmental policy and the global economy.

- Economic incentives to encourage efficiency improvement should be applied not for global warming but for effective use of natural resources.

- Carbon taxes are not a good policy because they encourage unnecessary fuel switching.

- Fuel price tax could be used to encourage energy efficiency without creating unnecessary fuel switching incentives.

- Calculating externalities by measuring and assessing every possible environmental impact is impractical, therefore, as an alternative, conserving input energy is proposed.

- Setting reasonable atmospheric concentration target or emission stabilization or reduction target of CO_2 is impossible in the sea of uncertainty, therefore creating CO_2 emission right market is also impossible at this moment.

- The CO_2 emission rate is not an appropriate index, and setting a target of CO_2 at an arbitrary level is misleading energy and environmental policies.

- Energy consumption is the index that should be set as the standard or target.

- Carbon intensity should not be given stronger emphasis than energy intensity improvement, or economic and population growth.

- Energy intensity is the single most important factor in reducing energy consumption and technology transfer helps a lot to ease peak period of the intensity during the development process.

4. Electric Utilities' choice

This chapter discusses resources, reserves, price, trade distribution, end use, and environmental and safety issues of fossil fuels with regard to electric utilities. It also gives some examples of minor greenhouse gas tradeoff's relating to fuel and technology choice. Nuclear energy is discussed on its safety, waste and proliferation issues. Renewable energy is discussed in terms of its resources and environmental aspects. It also discusses technologies and policies for energy efficiency on both supply and demand sides.

4.1 Fossil Fuels

Should we stop burning coal to cope with global warming? It is absolutely true that coal emits the most CO_2 per heat content among the major fuels (coal: oil: gas = 5:4:3, "golden ratio" according to David White, Ford Professor at MIT). However there is still no evidence that global warming is happening, and it is not clear that how much CO_2 and other minor greenhouse gases are really warming up the globe with all the positive and negative feedback. And even if there is a global warming, the impact on society is estimated as not very large as we have seen in Chapter 2. Global warming does not have high priority among all other environmental concerns such as urban air and water pollution, toxic or hazardous waste. We should not stop or slowing down burning coal for this reason alone.

Global warming is not an issue itself. We should however think of clear sign such as CO_2 concentrations increase in atmosphere, as warnings against wasting too much resource and depositing too much waste. CO_2 is just an indicator, and not the thing to combat. Setting a target of how much energy to use should be preferable. Setting how much CO_2 we can emit is similar to the energy target but in fact not quite appropriate target, because we can reduce CO_2 emissions but still waste energy. It would be a natural conclusion to slow down the use of coal when we set CO_2 emissions target, but still want to use much energy for economic growth. The mistake is in setting a target for CO_2 emissions.

The US government wisely opposed setting such targets to avoid impacts on the economy and protect industries from suffering unnecessary burden. The Japanese government "vacillates" (Henry Jacoby, Professor at MIT) its policy between US and European countries initiatives, but agreed to set the CO_2 emissions target stabilizing at 1990 level by 2000, primarily on a per capita basis and secondarily a total emissions basis. The government requires its people to endure remains at a simple life with the already very low energy consumption, and promotes nuclear energy, also a major interest of most of the electric power companies.

Even if Japan stops using all coal, there would not be a significant difference in global CO_2 emissions (supposing CO_2 emissions should be reduced), when major coal consuming countries like China and US continue to keep using it. It would have only a symbolic effect: "we did it, so you should do it." Major coal consuming countries, because of their heavy dependence, will not change their policy without apparent evidences that CO_2 is really bad. Thus, it is unlikely to really happen. Japan would thus be throwing away clean coal technologies that have been developed for decades. Japan, which has advanced clean coal technology, should preserve it and further develop it to fit the need of major coal consuming countries and which do not have advanced technology yet, such as China.

4.1.1 Resources, reserves and price

The supplies and consumption of fossil fuels discussed in chapter 3 are the most accurate numbers that we can rely on. However, when talking about resources of fossil fuels, they are all vague numbers with a wide range of estimates. (See for example, Edmonds, 1985, p.8, p. 78 - 81 for oil, p. 121 & 122 for gas, p. 156 for coal) An apparent and important difference in resources of gas, oil and coal is, however, that while gas and oil are treated as limited resources, coal is treated as a virtually inexhaustible resources in many studies relating to energy policy studies.

It is more logical and reliable to look closely at proved reserves first and then think about resources. Figs 4-4-1 through 4-4-3 show regional distribution of gas, oil and coal proved reserves respectively, and Figs 4-4-4 though 4-4-6 show their historical trends. And Table 4-4-1 summarize resources, reserves and production of fossil fuels.

The former USSR and Central Europe have the biggest gas reserves with 1,700 EJ (38.5% of world total), and the Middle East follows at 1,400 EJ (31.5%). Gas proved reserves started with less than 1,000 EJ in 1965, but expanded quickly, and were around 2.5 times bigger by 1974. Despite a small decrease just after the two oil shocks, proved reserves have been constantly increased until present time and doubled from 2,300 EJ in 1974 to 4,500 EJ in 1990. The former USSR and Central Europe and Middle East extended their reserves drastically, while North America reduced its reserves gradually in a quarter of century.

Gas reserves can be seen in two different ways. In one view, "Gas' global geographic distribution (both reserves and estimated resources) is far broader than oil's." (EPRI Journal, Jan/Feb 1992, p.6) But in another view, "The resources are very large but the long term role of gas will be constrained by the dangers of relying on a limited number of concentrated resource areas." (Grubb, 1991, Vol. I, p.143)

The Middle East has the single biggest oil reserves (65.6%) in the world. This causes all the problems related to energy from the first oil shock to Gulf war in 1991. The Middle East has dominated oil reserves from early stage (around 60% in 1965 already). World proved oil reserves doubled from 2,200 EJ in 1965 to 4,400 EJ in 1974. They remained at this level until 1986 for over a decade. The increase in 1987 is due to the Middle East and Venezuela, while the increase in 1989 was mainly attributed to Saudi Arabia. (BP Statistics, 1991, p.3)

Coal reserves are seven times bigger than oil reserves and nine times bigger than gas reserves, and more evenly distributed in the world than oil and gas. Table 4-4-1 shows that the coal resources is 7.6 times bigger than its reserves, while the ratios are 2.2 and 2.4 for oil and gas respectively. Edmonds explains this as follows: "The quality of the estimates of the coal resource base is poor. Moreover, the concepts of reserves tend to be used with somewhat different meanings as applied to other energy resources. These problems arise largely <u>because coal is practicably inexhaustible over the horizon of most energy studies. As a result, it has been enough to know that coal resources are big</u>." (Edmonds, 1985, p.154, emphasis by the author)

"For many countries coal is the main indigenous fossil resource: switching away from it could increase imports, lessen energy security, worsen balance-of-payments problems, and generally fly in the face of the brief that countries should make use of the resources they have." (Grubb, 1985, Vol. I, p. 152)

"Today, most analysts believe that nuclear power has an important role to play but that energy supplies will remain dominated by fossil fuels, with <u>a long-term renaissance for coal because of its large resource base</u>...... The long-term trend in hydrogen-to-carbon ratio of global energy consumption must in this view halt as demand outpaces the constraints on oil, gas and nuclear power." (Grubb, 1985, Vol. I, p. 145, emphasis by the author)

As we can see the trend of gas, oil and coal proved reserves are all increasing. The reserve to production ratio has often been misunderstood to imply that the resources will be exhausted in the years the ratio indicates. At the time of oil crisis, many mass media's reported oil will be exhausted within thirty years or so, and sometimes panic resulted. But after twenty years these ratios are still the same or in some cases higher, because the reserves have been extended even with increased production.

At the end of 1990, the ratios of proved reserves to production for oil and gas are around 50 years while that of coal is over 400 years. Although the ratios of resources to production are not dependable figures, oil and gas are around 100 years while coal is more than three thousand years.

This difference causes the generally pessimistic view of oil and gas price forecast that they will inevitably increase, while coal price remains low. In combination with carbon tax, however, this pessimistic view justifies the higher tax on coal. But if the present trend of increasing gas and oil reserves continues, oil and gas will stay at the present level except for the vacillation of world wide events, and oil and gas will replace coal with high carbon tax. Ironically, this pessimistic view of oil and gas accelerates their consumption, when combined with carbon tax.

Another factor showing the effect of the concentration of fuel resources characterize the price stability of each fossil fuel. Figs. 4-1-7 and 4-1-8 show medium and short term history of US fossil fuels for electricity generation, respectively. It is obvious that the most concentrated fuel, oil, vacillates its price in a wide range and frequently, while the most evenly distributed fuel, coal, remains quite stable in its price, and natural gas, with moderate resource distribution, stays in the middle.

Tables 4-1-2 and 4-1-3 shows short term fuel price variation in the US and Japan respectively from April 1990 to March 1991 during the period when Iraq invaded Kuwait and the Gulf War started and ended. Table 4-1-4 compares average fuel prices of both countries during the same period.

Crude oil prices in the US and Japan are almost identical because, they are determined in the world oil market. Japanese oil price is only 3% higher on average than those of the US reflecting a slightly higher transportation fee. The lowest oil price in this period was recorded just before the Iraqi invasion into Kuwait (33% lower than the average in this period) in both US and Japan. The highest price was recorded a couple of months before the Gulf War started (40% higher than the average).

Japanese imported Liquified Natural Gas (LNG) prices are around 60% higher than those for US natural gas, most of which is domestically produced and consumed. Price fluctuation has a similar pattern and follows oil price in a modest way. The lowest price was 10% lower than the average in the US and 18% lower than average in Japan, and the highest was 21% higher than average in the US and 20% higher in Japan.

Japan imported 90% of the coal it consumed at around 50% higher price than the US' indigenously produced and consumed coal. This difference comes mainly from transportation fees, but is partially due to better quality (lower sulfur content, lower ash content etc.). But in both countries coal prices were quite stable (within 2% from average) despite the energy related events which happened during the period.

4.1.2 Trade, distribute and end use

Oil is the most extensively traded fossil fuel. Table 4-1-5 shows the amount of imported fuels for OECD countries in 1989. A total of 63 EJ of oil, consisting of 47 EJ of crude oil and 16 EJ of petroleum products, was imported into OECD countries, while around 7.8 EJ of coal and 8.3 EJ of gas were imported. Eight times more oil is traded than coal or gas.

The reason for the heavy trade of oil is primarily the end use need and secondarily the ease of transportation of oil. Around half of traded oil was used for vehicles and 8% for air transportation. There is no competition with other fossil fuels in the transportation sector. And it is rather easy and low cost to transport oil by huge tanker or pipeline. Not so much infrastructure is needed for the loading and unloading compared with coal and LNG, because it is liquid.

Oil is, however, not an attractive fuel for utilities, because of its variability in price and poor security of supply. OECD countries have been putting efforts to reduce oil dependence since the first oil crisis. But when the oil market weakens, then such efforts slow. Utility industry has alternative fuels and not like the transportation sector, and should keep away from oil. Oil use should be limited to special cases, such as start up auxiliary fuel, or peak load use.

Gas is transported and distributed easily if there is sufficient pipeline capacity and a distribution grid. But it is not so cheap to transport it in LNG form. Table 4-1-4 indicates the approximately 60% higher price for LNG than domestically produced and used natural gas in the US, because LNG requires specially designed tanker and liquifying and vaporizing facility and loading/unloading facilities. But even with a domestic pipeline grid, US utilities have experienced unreliable and unstable supply of gas in the past.

"The perceived shortage of gas led, in 1978, to a congressional mandate for a phase out of the existing use of gas by utilities and prohibition against new utility and industrial gas-fired plants. This prohibition remained in effect for nearly a decade. Many users of gas took to heart the message that it was to be avoided as a future utility fuel option. Gas was thought to be such a premium fuel that it should not be used for power generation, especially since domestic coal was plentiful and inexpensive. " (EPRI Journal, Jan/Feb 1992, p. 6).

Gas is indeed a premium fuel. It can be used directly at the end user cleanly for heating and cooking, and usually for these purposes better than electricity, if enough caution is paid for safety. Even though gas has highest electric power generation efficiency, it is still dumping more than half of the heat into the ocean or atmosphere. If it can be directly used, it should be used as such.

If the direct use of gas is extended, then it may not be an attractive fuel to the utility any more, because of supply security. Gas supplier will give higher priority to providing secure supply for residential, commercial and industrial use, and the lowest in utility use. This is natural, because gas is distributed to the utilities at the lowest price, and only at the lowest price, it is competitive to other fuels in power generation. Even in the case of gasified gas, it is more reasonable to be used as a feed stock or direct end use, if it can be sold without a safety problem. Gas should be considered as a complementary end use form of final energy (complementary to electricity) rather than as competitive primary energy source.

Therefore gas use for utilities as a primary energy source should be limited to special applications. Such applications will include cases where a plant is built in an urban area and local environmental concerns are too strict for other fuels or available space for fuel storage is limited but sufficient gas supply from a pipeline is available.

Coal on the contrary, has a lot of handling difficulty due to its nature as a solid. To cope with this difficulty many attempts have been made to create easier handling; liquifaction, fluidization by the mixture with oil (COM) or water (CWM). None of them are yet competitive with bulk solid transportation.

However, even with 50% higher cost than US domestically produced and consumed coal, and also with high environmental cost (e.g. installation of scrubbers and SCR's) imported coal has proved to be competitive with other power source, especially nuclear, and many imported coal power stations have been operating or under construction or planning stage in Japan.

Coal is not suitable for direct residential and commercial use in modern society. It will never be used directly in the transportation sector. It can only make sense when used in a large scale; cement industries, steel making or electricity generation.

Since generating electricity is the only way of converting plentiful and stable energy resources of coal into a practical form of energy, it should be promoted with careful local, regional and global environmental attention as a reasonable use of natural resources, rather than killed it by uncertain global warming.

4.1.3 Environmental and safety issues

It is apparent that gas is the cleanest fuel in a traditional sense (SOx, NOx, and dust emission) as well as having lower CO2 emissions. Oil follows and coal is the dirtiest in a traditional sense. But now technologies are commercially available so that coal is clean enough to be accepted to the public and still be competitive with oil and gas as we have seen in chapter 3. It will, however, never be competitive if used with a facility for the removal and disposal of CO2. (EPRI, June 1991) But all these, SOx, NOx, and even CO2, are easier to treat than nuclear radioactive waste and hazardous materials, because they are produced by chemical reactions. Oil causes environmental problem mainly through the transportation sector. Urban air pollution is a much more serious and acute issue than uncertain global warming.

In addition to the environmental issues at the power generation site, each fuel has environmental and safety issues at production and transportation. Oil spills from tankers are the biggest concern. Oil spills or fire at well caused by sabotage as in the Gulf War attracted much attention. Coal mines have argued for their environmental impacts, such as deforestation in case of surface mine, land dislocation and subsidence by the underground, and safety of coal miners is an important issue.

"The LNG ship collision is believed to be the most likely event that could trigger the most serious type of LNG accident." (Edmonds, 1985, p.133, see also Det norske Veritas, 1975) The reason of this as follows: 1. The most likely cause of a major spill from an LNG tanker is a ship collision. 2. The most likely place for a collision to occur is in a busy port shipping cannel. 3. Since most ports are adjacent to large urban areas, the magnitude and extent of the damage from a ship collision could be very severe. 4. Due to the large quantities of LNG carried by tankers and the fact that a water spill would spread much faster and evaporate much more quickly than a land spill. (Edmonds, 1985, p. 133)
"The environmental effects of pipeline construction are minimal compared with LNG safety hazards." (Edmonds, 1985, p. 134)

4.1.4 Examples of trade off between minor greenhouse gases

Followings are some examples of trade off between minor greenhouse gases related to fossil fuel use, although the author does not think greenhouse effects of minor gases, including CO2, are a critical issue.

CH4 v.s. CO2 (conversion from coal to natural gas)

Methane is another minor greenhouse gas which is emitted to the atmosphere with the production of gas and coal, and transportation of gas. The global warming potential (GWP) is reported to be 21 at 100 years integration in IPCC 1990 including indirect effect (direct 6 plus indirect 15). IPCC supplement of 1992 revised direct effect to be 11 at 100 years integration, but doesn't specify indirect effects. If original indirect effect remains the same, then total GWP of methane should be 27.

There are several reports that compare allowable leakage of methane and reduction of carbon dioxide by conversion of fuel from coal to natural gas. (EECC, Feb. 1992, p.13, Cruztzen, Jan 1992, p. 339-342, Cruzen, April 1992, p. 380 - 381). The general conclusion of these are that if the leakage of methane is less than 10 %, then it is reasonable to convert fuel from coal to gas, from the viewpoint of global warming potential. A simple calculation using IPCC's GWP could confirm these conclusions. (Appendix 1, CH4 v.s. CO2)

There are technical and political reasons to be aware of this kind of tradeoff, and the US comprehensive approach is theoretically correct. If we are going to switch fuels from coal to gas for the reason of global warming alone, this comparison must carefully made. However, given the unreliable conversion rate (GWP) as well as uncertain global warming, it is still immature to apply this approach to real policy making.

One of the basic and significant flaws in calculation of GWP is that we don't know the CO2 lifetime or circulation time. Although IPCC use 120 years in the GWP calculation, it is still controversial, and significantly affect the calculation results.

Another flaw is that we don't still know indirect effect of each minor greenhouse gas, and the indirect effects might be as big or larger than the direct effect. Methane, Chlorofluorocarbons, and Nitrous oxide all have significant indirect effect through ozone depletion. The IPCC 1992 supplement mentions these facts but failed to give numbers in terms of GWP.

As we have discussed in 2.4, however, methane has high anthropogenic ratio in total emissions and a high growth rate of concentration in the atmosphere, the impact of the gas should be carefully studied before making extensive use of the gas aside from the uncertain global warming effect.

Natural gas, however, is a very convenient fuel for end use energy, unlike coal. It can be directly used in the residential and commercial sector for heating or cooking or even air conditioning through distribution pipelines. It could also be used in the transportation sector as compressed natural gas vehicle. It is too valuable a resource to just burn at power station to generate electricity, at least if its supply has a real limitation. Coal in contrast can be used only at highly centralized system like power stations or steal making.

N_2O v.s. CO_2 (Pressurized Fluidized Bed Combustion)

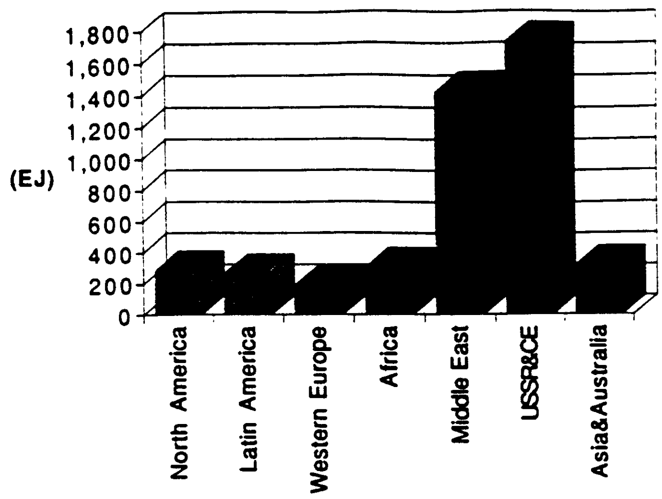
Let's look at another example of the tradeoffs between minor greenhouse gases. Pressurized Fluidized Bed Combustion (PFBC) combined cycle power generation has high efficiency and good environmental performance and it is expected to be the next generation coal-firing technology. PFBC is assumed to be the dominant coal firing technology in the next century in both the models used by IPCC and economic calculations in September 1991 DOE report.

Since fluidized bed combustion burn coal at rather low temperatures around 850°C, it has a good effect on of NO_x emission, but emits some N_2O, another minor greenhouse gas whose emission from conventional coal, oil, and gas firing boiler is negligible. Then from the viewpoint of global warming, PFBC reduces CO_2 emission by efficiency improvement, but contributes an increase in N_2O concentration in the atmosphere. The sources of natural and man made N_2O are still not clearly known. But we can calculate this tradeoff at the emission side simply using the global warming potential. (Appendix 2, N_2O v.s. CO_2)

The result shows the critical N_2O emissions from PFBCs is 50 ppm, assuming a 10% relative plant efficiency increase and GWP of 270 taken from IPCC (100 years integration period) is reasonable. This means if there is less than 50 ppm N_2O emissions from PFBCs, use of them will slow down global warming, otherwise it will accelerate global warming.

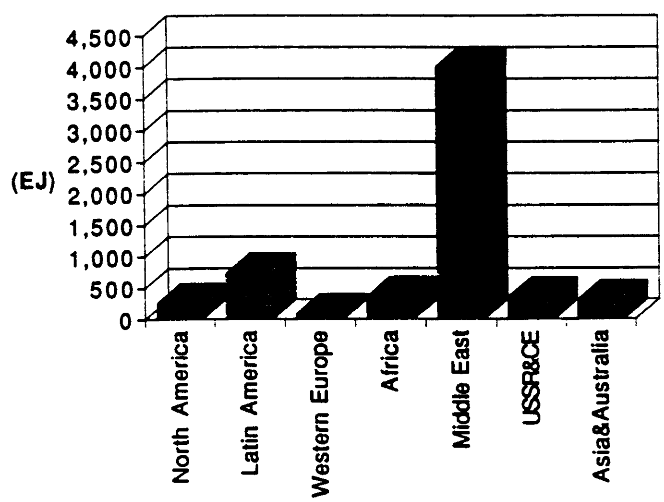
If global warming is actual, this fact is a serious concern. Some measures should be taken to reduce or eliminate N_2O from PFBC emissions. But again as we have seen in chapter 2, the global warming is just too uncertain to take expensive actions. With all other good features of PFBC, killing the technology only for this uncertain reason is unwise. Of course technology should be developed, and some measures are already proposed, to reduce N_2O both as a minor greenhouse gas and, more seriously, because of its ozone depleting effect.

Fig. 4-1-1: Natural Gas Proved Reserves at End 1990



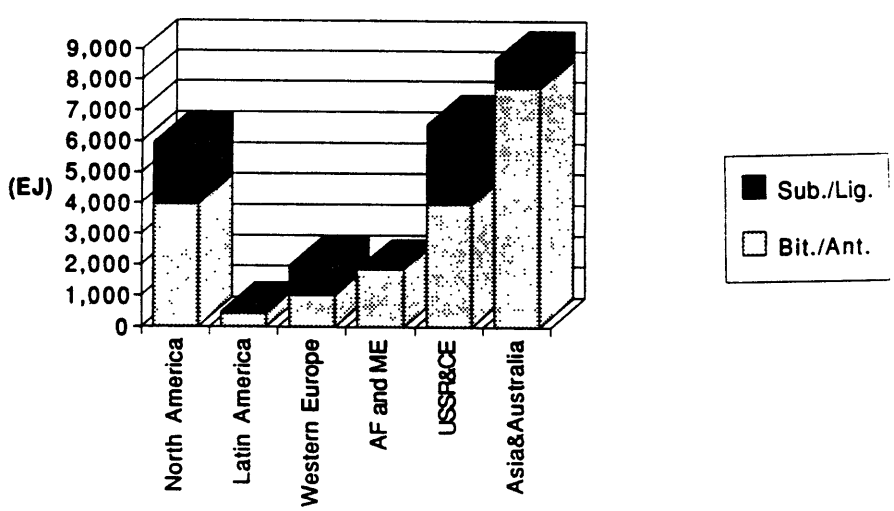
Source: BP Statistics, 1991

Fig. 4-1-2: Oil Proved Reserves at End 1990



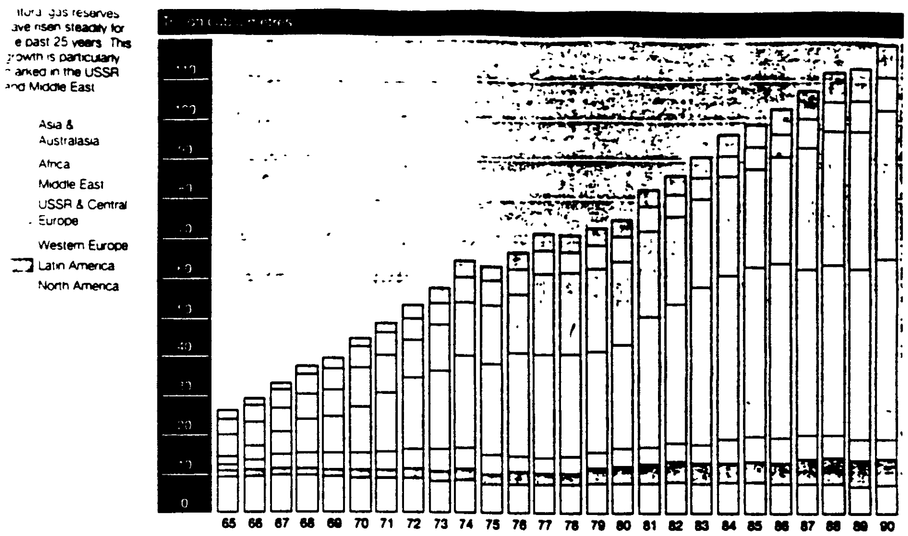
Source: BP Statistics, 1991

Fig. 4-1-3: Coal Proved Reserves at End 1990



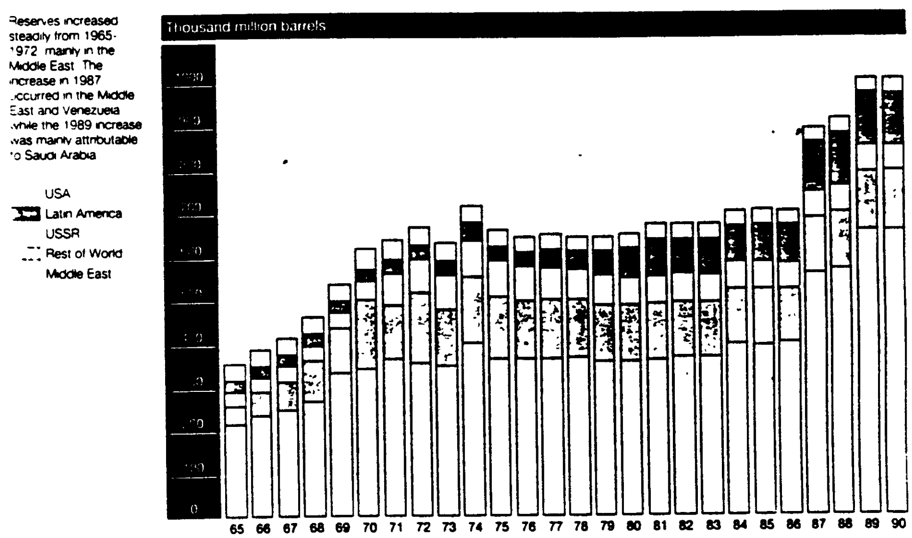
Source: BP Statistics, 1991

Fig. 4-1-4: Natural Gas Proved Reserve Trend



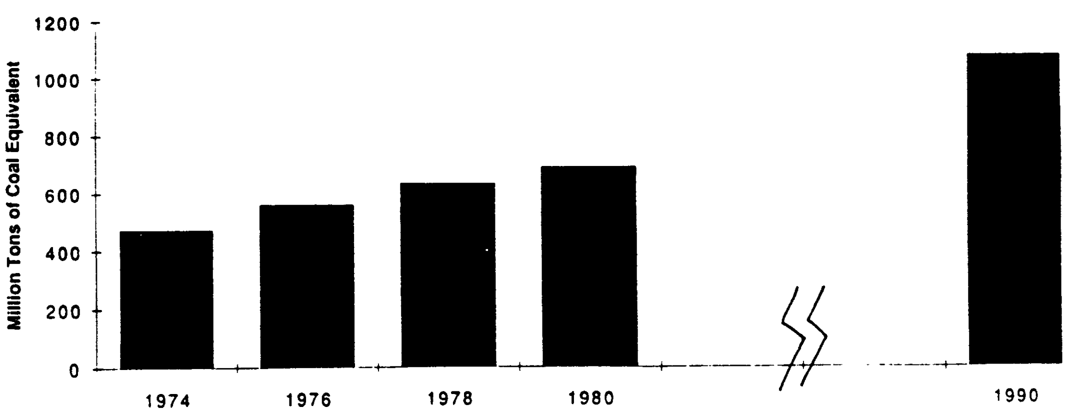
Source: BP Statistics, 1991

Fig. 4-1-5: Oil Proved Reserve Trend



Source: BP Statistics, 1991

Fig. 4-4-6: Coal Reserve Trend



Source: Edmonds, 1985 and BP Statistics,1991

Fig. 4-1-7: US Fossil Fuels Costs for Electric Utilities, 1973-1990

(Dollars per Million Btu)

Fossil Fuels Costs, 1973-1990

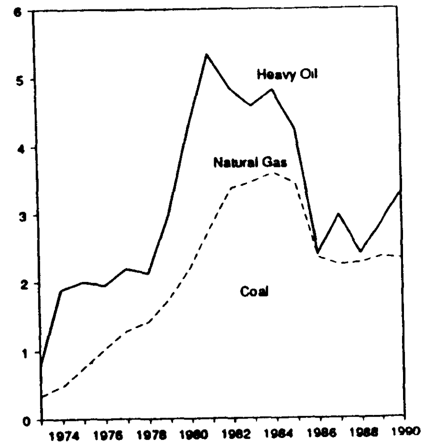
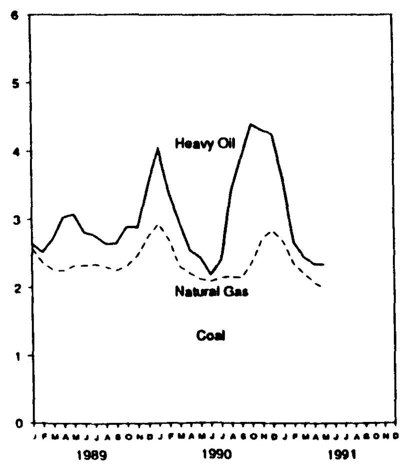


Fig. 4-1-8: US Fossil Fuels Costs for Electric Utilities, Monthly, 1989-1991

Fossil Fuel Costs, Monthly



Source: Monthly Energy Report, Sep 1991, p 115

Table 4-1-2: US Fossil Fuels Cost

US 1990	Coal $/GJ	Crude Oil $/GJ	Natuaral Gas $ /GJ
April	1.40	2.55	2.10
May	1.40	2 43	2.01
June	1.39	2 24	1.98
July	1.37	2 41	2 03
August	1.37	3 52	2.05
September	1.37	4.48	2 03
October	1.39	4 95	2.24
November	1.37	4 57	2.58
December	1.35	3 91	2 68
January 91	1.38	3.42	2 53
February	1.39	2 84	2 22
March	1.38	2 67	2 09
Average (A-M)	1.38	3.33	2 21

Source: Monthly Energy Review, September 1991, DOE/EIA p 282

Table 4-1-3: Japan Fossil Fuels Cost

Japan 1990	Coal $/GJ	Crude Oil $/GJ	Natuaral Gas $/GJ
April	2.06	2.73	2 98
May	2.02	2.51	2 91
June	2.03	2.42	2 91
July	2.03	2.30	2 84
August	2.00	2 45	2 92
September	2.00	3 35	3.24
October	2.02	4 53	3 82
November	2.05	5 10	3 95
December	2.04	4.89	3.88
January 91	2.00	4.27	3 91
February	2.05	3.69	4 15
March	2.07	2 85	4 04
Average	2.03	3 42	3.46

Source: Denkijigyoubinnrann, heiseisannnennbann, MITI

Table 4-1-1: Fossil Fuel Resources, Reserves and Productions

(EJ)

	Gas	Oil	Coal
Resources (1987 WEC)	10,838	13,692	315,813
Reserves (BP 1990)	4,513	6,121	41,540
Resource/Reserve	2.40	2.24	7.60
Production (BP 1990)	79	140	97
Resource/Production (year)	138	98	3,252
Reserve/Production	57	44	428

Source: Grubb, 1991 and BP Statistics, 1991

Table 4-1-4: US and Japan Fossil Fuels Cost Comparison

1990 JFY	Coal $/GJ	Crude Oil $/GJ	Gas $ /GJ
US	1.38	3.33	2.21
Japan	2.03	3.42	3.46
Japan/US	147%	103%	157%

1990 JFY	Coal/Coal	Oil/Coal	Gas/Coal
US	1.00	2.41	1.60
Japan	1.00	1.69	1.71

1990 JFY	Coal/Oil	Oil/Oil	Gas/Oil
US	0.41	1.00	0.66
Japan	0.59	1.00	1.01

Table 4-1-5: Fossil Fuels Imports to OECD Countries in 1989

	Gas	Crude Oil	Oil Products	Total Oil	Coal
MTOE	186	1,059	366	1,425	175
EJ	8	47	16	64	8

Source: IEA Statistics, OECD Energy Balance, 1991, p.69

4.2 Nuclear

It is absolutely true that nuclear power generation can reduce CO2 emissions while producing the same amount of electricity as fossil-fired power plants do. Uchiyama and Mortimer independently agree that nuclear power generation create CO2 emissions through construction, maintenance, fuel and waste treatment, but on the order of 5% of CO2 emission from coal-fired power station to produce the same amount of electricity. (see Uchiyama, 1991, p.8 and Mortimer, 1991, p.76)

The problem, however, of promoting nuclear to reduce CO2 emissions is that there are potentially higher risks and possibilities for environmental impacts. These issues are; the safety of nuclear power generation, from high to low level nuclear waste management, and nuclear proliferation issues.

4.2.1 Safety issues

Two major accidents in nuclear history have happened: Three Mile Island in March 1979 and Chernobyl in April 1986. These accidents had a great impact on society in terms of nuclear safety concern as well as actual health damage, death and environmental contamination in the case of Chernobyl.

There are experimental rules in technology development that we learn from failure and develop better designs and materials. The Three Mile Island case made scientists and engineers design safer reactors, create control systems that are more fool safe, and made regulators process license more strictly and thoroughly. Risk assessment methods have also been developed extensively to prove how safe the nuclear is compared to ordinal incidents such as death by cancer from smoking, as well as traffic accidents.

In the Chernobyl case, the general reaction of western countries were to isolate the cause as the USSR design, and emphasize the difference in safety features between them and us. Authorities were explaining that only centrally planned economies would allow such a dangerous design reactor to keep operating, and it will never happen in the western world.

From this logic, we can conclude nuclear is only safe under certain political, social and economic systems which we can trust. It will never be safe at China, North Korea, Iraq or former USSR and central European countries or any developing countries where the economic and political systems are not quite stable yet.

Looking back at the IPCC's business as usual or any other scenarios, major players of minor greenhouse emissions are the developing countries. Developed countries will stabilize their emission in any way. Nuclear will not be applied safely to developing countries. The conclusion from this is that nuclear cannot solve global warming problem.

4.2.2 Nuclear waste treatment and management for the long term

There are clear differences between the outputs from fossil fired power plant and nuclear power plant other than the electricity generated and slightly warmed circulating water discharged to the sea, lake or river (or slightly warmed air at the cooling tower.)

Emissions from fossil-fired power plants, including CO_2, SO_2, NO_x are emitted to the atmosphere, or waste like ash is disposed of in landfills, but no nuclear radioactive wastes are and should be disposed to the environment. It is very well managed in that manner. However, what to do with these waste materials is quite a different matter. We must prevent all such wastes from escaping to environment for the long term.

High level waste needs to be managed for several tens of thousand of years, and we cannot know who will be responsible in what organization for such a long term. "To date no high-level wastes (or spent nuclear fuel) has been disposed in a final repository, and all is now stored in various forms of temporary storage facilities, either on reactor sites, or in specially designed storage facilities. It is difficult to predict what will happen during the lifetime of a repository. Anticipating all possible human and natural actions which could compromise the safety of a repository over a few hundred thousand years is daunting indeed." (Pasztor, March 1991, p. 101)

Even low- and medium- level wastes require hundreds of years of management, and the large quantity causes problems. "Due to the much larger volume of low- and medium-level wastes, and the consequent need for larger repositories, from the point of view of public acceptance the disposal of low- and medium -level wastes may also act as constraints on nuclear growth." (ditto, p. 101)

4.2.3 Nuclear Proliferation

"Nuclear energy is a by-product of weapons research." (Edmonds, 1985, p.170) "Nuclear power is not essential for developing nuclear weapons, but it offers a ready path to obtaining the basic know-how and materials. Major studies concluded with confidence to police forever the line between energy and weapons, and several countries - outside the Non-Proliferation Treaty but nevertheless with some foreign assistance - are now suspected of having obtained nuclear weapons under the cover of nuclear power." (Grubb, 1991, Vol. I, p.163)

Nothing indicates more clearly that the major problem for nuclear power is not technical but political than the nuclear proliferation. The attitude to suspect anyone unknown as a terrorist needed to prevent from proliferating nuclear know how and materials especially plutonium and highly enriched uranium which is so easily converted from power source to weapons. This uncomfortable attitude must be sustained unless all the conflicts and wars disappear anywhere on earth, which is unlikely in the near future.

Suspicions of such conversion could be targeted not only to terrorist groups but also governments. Iraq and North Korea have been suspected by international organizations and other countries of attempting to develop nuclear weapons.

Japan limits the use of nuclear energy to peaceful uses, and has been promoting it and still sticking to the nuclear fuel recycling because it is so called a quasi-indigenous energy where almost all other energy is imported from overseas. An extensive use of plutonium and the inevitable temporal stock piles of these potentially weapon convertible materials will call suspicion from other countries especially Asian countries occupied by Japan during World War II. This is particularly true in the world new order being sought after collapse of former Soviet Union.

Transportation of plutonium from Europe to Japan causes another problem. "Environment and arms control advocates announced an international campaign yesterday to oppose Japan's plan to ship a ton of highly toxic and radioactive plutonium from France to Japan this year, saying it could easily fall into the wrong hands or be released in an accidents." (Tolbert, Boston Globe, May 22, 1992)

And the US House of Representative passed a law prohibiting ships loaded with plutonium passing through US territorial waters unless the NRC admit it as safe.

"Bush administration is reviewing the transportation plans and has the right to approve or disapprove them because the United States supplied the original uranium fuel used in the Japanese reactors." (ibid.) Is this kind of energy really indigenous?

It must be concluded that nuclear promotion and extensive use of nuclear fuels to reduce CO_2 emission and to cope with uncertain global warming could cause much more serious international problems.

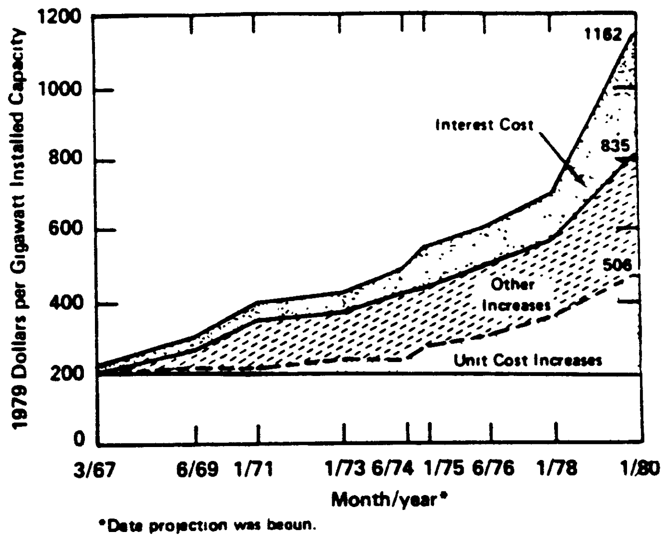
4.2.4 Nuclear Economics

"A crucial factor shaping public attitude has been the costs of nuclear power, compared to the benefits it provides." (Pasztor, March 1991, p.104) Edmonds summarized the effects of safety and regulation of nuclear power plants in Table 4-2-1 (Edmonds, 1985, p. 179), and concluded that around half of cost increase during 1970 is due to stricter safety standards (another half due to unit cost increase). (ibid., Fig. 4-2-1, p. 177, p. 189)

Another interesting observation was described by Grubb: "The essential paradoxes of nuclear economics are illustrated by the French program, widely hailed as the world's most successful. The industry established a nuclear production line which produced reactors faster and cheaper than anywhere else. But with the country's energy industries geared so heavily towards nuclear, the pressures against ceasing construction were formidable even when the extra plants were not needed, and France now has massive over capacity. The operating costs are lower than conventional plants, so that France can and does sell electricity to undercut all other sources in Europe at an operating profit. Yet in reaching this position, Electricite de France has acquired the largest private debt in the world, one which, according to the Financial Times, there is little chance of it paying off." (Grubb, 1991, Vol. I, p. 161, emphasis by the author)

We should learn a lesson from this that once heavy capital investment has been accelerated and got inertia, nobody can stop it. We must be very careful to start this huge inertia, and the global warming is definitely not a good reason to put a pedal on it.

Fig. 4-2-1: Nuclear Power Cost Escalation in US



Source: Edmonds, 1985, p.177

Table 4-2-1: Effects of Safety and Regulations on Nuclear Power Plants

Codes and standards	1971[a]	1980[b]
Number of codes and standards nuclear plants must comply with	150	1800
Time requirement		
Time required from commitment to commercial operation	6–7 yr	10–12 yr
Material requirement		
Concrete (1,000 cu yd)	90	153
Rebar steel.(1,000 tons)	11	19
Structural steel (1,000 tons)	4.4	10
Cables (1,000 linear feet)	2000	4500
Conduits (1,000 linear feet)	175	425
Labor requirement		
Engineering and services (10^6 hr)	3.4[c]	8.1
Craft labor (10^6 hr)	6.2[c]	16.9

Source: John H. Crowley, "Nuclear Energy—What's Next?" Draft paper presented at Workshop on the Electric Imperative, Atomic Industrial Forum, June 1981, Monterey, Calif.

[a]Typical for 1,000-MW reference design as per WASH-1230.

[b]Material and labor requirements are based on estimates for an 1139 MW reactor. Reported figures are standardized to 1,000 MW assuming straight proportionality.

[c]1972 figures.

Source: Edmonds, 1985, p.179

4.3 Renewables

Renewables could be characterized very differently depending on the observer. Electric power companies view them as vulnerable to natural conditions (electric power company hates unreliability most), site specific, low capacity factor, small scale (except hydro and some geothermal), high capital investment, not yet proven (except hydro and geothermal), and not flexible in control or storage (except hydro and biomass).

Environmental advocates view them as pollution free, not centralized but dispersed, unlimited and the ultimate natural resources with the apparent exceptions of huge hydro plants and some geothermal.

In this chapter we will review each technology, whether they really do not have an impact on the environment, and whether they are ready to replace fossil fuels as a way to cope with the uncertain global warming.

4.3.1 Hydroelectric Power

Hydroelectric power has been developed for a long time with huge dams for irrigation and flood control. Fig. 4-3-1 shows installed and installable capacity in MW of nine regions. (Edmonds, 1985, p.220)

In western Europe around half of the recoverable resource has been already developed, and in OECD countries more than one third has been developed, while less than ten percent (few percent in most cases) has been developed in developing countries. It looks as if hydroelectricity has great potential to supply energy to developing countries.

If we compare this potential, however, to the total primary energy requirement in the high growth, high emissions case (The IPCC's Business as Usual: BaU scenario), it appears that hydro has a significant resource constraint. The estimated total world hydro resource base is estimated at 95.44 EJ, and among them only 37.26 EJ (40%) is estimated recoverable. (Edmonds, 1985, p.217) Although Edmonds reported that for some areas like Brazil new estimates are two or more than the value which appeared in the Fig. 4-3-1, it will be safe to say that these estimates are far more accurate than fossil resource estimates, because they are based on ground observable physical data, namely elevation and precipitation data.

Even if all the recoverable hydro resources are developed, we can only get 37.26 EJ of electricity, equivalent to 113 EJ in thermal content using a factor of 0.33. This is only one third of present-day primary energy consumption. Since new discoveries of this resource are not expected, this estimate will be much the same in 2030 or 2100. According to the IPCC's BaU scenario, primary energy consumption in 2030 and 2100 will be 720 EJ and 1,680 EJ. This means all recoverable resources developed in the world can only support energy of 15.7% and 6.7% of the total requirement in 2030 and 2100, respectively. Hydroelectricity is supplying 6.7% of energy at present date.

This resource constraint is a big factor affecting hydroelectricity's ability to replacing fossil fuel in energy supply. There are, however, other environmental concerns mainly related to the dam construction. Impacts on the local environment is big immediately upstream of dam due to the filling with water and downstream of the dam by the change in the water run off pattern. Usually, the run off pattern is actively controlled for irrigation and flood control and passively controlled the electric load control and to avoid over- and under- filling.

Hydro power is generally good and give more benefits than harm on society. But this is changing natural pattern. If we think of very long term, and looking back the history of Egypt, we will be reminded that the Nile gave Egyptian fertile soil through its flood. Controlled run off patterns might reduce the fertility of downstream. We could easily solve this problem by using fertilizer, but extensive use of fertilizer may contribute to an increase in N_2O, another minor greenhouse gas.

Heavy metal leaching from upstream soil is another immediate concern of dam construction. The James Bay project in Canada is said to be afraid of the effect of mercury leaching on native Indian residents, threatening their lives through contamination of fish with mercury. Thus, hydroelectric power is not free from pollution nor impacts on the local or regional environment.

4.3.2 Biomass

"Despite its exotic sounding name, biomass is not a new source of energy. Wood biomass dominated commercial fuel markets in the developed nations prior to the introduction of coal. Wood, dung, and agriculture wastes remain the second most important energy source in developing nations, accounting for approximately 30 percent of energy consumption." (Edmonds, 1985, p. 231)

"Biomass is the major energy source in the majority of the world's population, but as used traditionally it is inefficient and labor-intensive, and societies move away from it as they develop." (Grubb, 1991, Vol. I, p. 168)

Although globally and in a long term biomass will be considered to be a zero CO_2 emission natural resources in theory, locally and in a short term it will not. We should not forget the fact that in the industrial revolution process in UK, they switched fuels from wood to coal because extensive use of wood damaged the surrounding environment: forests and woods.

Excessive use of biomass as fuel will be more harmful to local and regional environments than the uncertain benefit it would provide to the global warming problem. Another concern and constraint of biomass is competition with food production. As we have seen in chapter 2, the single major factor of increase in energy consumption is population growth. The world will be needing more land to produce food to feed ourselves. Agricultural productivity might increase dramatically, but cultivated land will not expand so easily. And biomass competes at the very same place where agriculture is suitable.

Rather than competing with agriculture, it will make more sense to use urban, industrial and agricultural waste as a source of biomass energy, since it will emit CO_2 anyway or in some case emit CH_4. It is far better to be decomposed into CO_2 and H_2O in energy recovery process. (Ogden, 1990, Larson 1990) Table 4-3-1 shows the potentially available biomass resources from urban (including industrial) waste, agricultural waste and land based biomass firm in 2050. (Edmonds, 1985, p. 238)

Urban, industrial and agricultural waste all together will be more than total recoverable hydroelectric resources in 2050 (135 EJ), and these wastes will be increased with the human activities. These wastes need to be disposed or incinerated anyway, therefore, recovering energy will be good both in terms of resource conservation and environmental impact. However, in the energy recovery process, the emissions of chlorine, heavy metals or other hazardous materials must receive careful attention, of course.

Biomass energy requires similar technology either in burning, gasifying or liquifying process to that of coal from handling the raw materials to emission treatment. Among other renewables this will be the best fit to current electric power or industrial needs if the raw material price is low enough. An economic incentive to encourage to use these wastes will be required.

4.3.3 Solar

Solar energy is the source of all life's activities and the original source of all other forms of energy except nuclear and geothermal. Solar energy has also been actively used in human life for heating, drying and for sanitation purposes for a long time in history.

There are no resource constraints. If we use the world average available solar energy of 1,5000 kWh/m2/yr (Edmonds, 1985, p.192), and assume 10% of conversion efficiency to electricity, 100 km square of land will give 5.4 EJ of electric energy per year. and if we convert it into thermal energy for comparison purposes with a factor of 0.33, then we will get 16.3 EJ/year, which is around 5% of the present world energy consumption. In

2100 of IPCC's BaU scenario if we want all of energy from solar which is 1680 EJ, then we will need only 1000 km square of land.

Suppose we have enough money to support such huge project of construct solar plant in Sahara desert, what will happen? Since the land area will be covered by energy absorber, either cell or mirror, reflection of the land will be significantly affected (even ten percent change it means 17 W/m2 locally). This will affect the local or even the global climate directly and significantly.

If the battery cells or mirrors are placed in the Pacific Ocean, it will prevent sunlight from going into the ocean and water from evaporation, and directly affect ocean creatures and climate pattern significantly, much more than the land case.

This is an extreme case and is very unlikely because of very high cost of construction and maintenance, and difficulty in transporting energy. What I want illustrate here is that even solar energy cannot be free from impacts on the environment if it is extensively and excessively used.

Another environmental concern comes with storage and transportation of energy produced by solar. Solar, wind, wave and tidal energy need some kind of energy storage device for practical use, because the variation of energy from time to time. It could be battery for smaller scale uses, or production of methanol or hydrogen, a combination of other energy storage method like pumped hydro, compressed air energy storage (CAES), or superconductivity magneto electric energy storage (SMES) for larger scale.

In the small-scale and dispersed use case, which means photovoltaics use, disposal of used batteries as well as used photovoltaics cells themselves need careful attention and management, because they usually contain toxic or hazardous materials like lead, cadmium, arsenic, etc.

It is not wise to construct large-scale concentrated solar plants in places where competition occurs with other uses like agriculture, primarily because other uses will be more productive per area basis and secondarily because of less insolaration in such places. It will be more reasonable to build centralized solar plants in desert or arid area. Centralized solar station favors certain kind of places, and storage stations like pumped hydro, CAES, and SMES also favors a different type of places. Therefore, it's very difficult to find out place both favor.

Methanol or hydrogen production requires feed stocks which need to be transferred to centralized solar power station. Natural gas might be found nearby in the desert, but water is the single most scarce resource in desert. Therefore some supplemental resources will be needed. Alternatively if solar energy is the only product, net production efficiency is very low and consequently a lot of land is needed, and plant costs are very high.

In conclusion, centralized solar stations will effect local and global climates if excessively used. Small-scale application at roof top or on the wall, or solar cars with battery storage should be developed with careful attention of waste disposal of toxic or hazardous materials from cells and batteries.

4.3.4 Wind

We have a long history of using wind power as a driving force for ships, and limited application of wind mills as we can find in Netherlands and rural areas. However, wind electric power generation is highly site specific and seasonal, daily and momentary variation is large, and consequently, it will not be a reliable source of energy without some kind of storage.

Atmospheric heat gradients drive the winds, which dissipate 13,000 EJ/yr. (Grubb 1991, Vol. II, p.12) World average wind energy is about 200 kWh/m2/yr at 10 meters above land masses. (Edmonds, 1985, p. 206) It means it is 7.5 times more dilute than direct solar in average. But it differs from place to place, and there might be some ideal places to site wind turbine more economically than solar systems. Altamount Pass is an example of an ideal site for wind firm.

"Wind firms at Altamount Pass, California contain 7,500 wind turbines owned and operated by independent companies who sell the electricity to Pacific Gas & Electric." (Weinberg, 1990, p.147) Constant wind is available all year around, not so much seasonal variation, not much of rain fall and almost no snow. Land is available at almost no cost because it was and is originally ranch land. There will be not so many places this ideal in the world.

On the East Coast of the US or in Japan, it would be difficult find such huge open space. Even if there were land available, we would need much preparation work like cutting down trees and bushes and making access roads, plus maintenance work like cutting branches of trees in summer time so that wind blades rotate freely. If it were in a tropical region, much more tree cutting would be needed and it would cause deforestation.

If it is close to a residential area, local environmental problems like noise, vibration and radio wave obstruction might happen.

Therefore wind power will be feasible only if siting conditions allow and also it will restricted to supplementary purposes (fuel saving mode) in the grid system. It will not replace the major role of fossil energy, although it might help to save some fossil resources.

4.3.5 Geothermal and Hot Dry Rock

Conventional geothermal energy is classified as "Severely constrained" (Edmonds, 1985, p.7) "Geothermal energy does not rely on continuous natural heat flow, but generally extracts, at a rate much faster than natural replacement, heat which has accumulated over centuries in water (aquifer) or hot rocks as a result of tidal friction and natural radioactive decay. Consequently geothermal energy is not a renewable source, although it is usually included as such. It is most easily exploited from aquifers, but this resource is probably fairly small. Pressurized brines, at greater depth, present a largely unknown resource. The theoretical resource from tapping hot rocks or even magmas is immense (the heat energy contained in the top few kilometers of rock worldwide is many times larger even than world uranium resources exploited with breeder reactors) but only a very small portion of this could conceivably be tapped. For these sources, technical and resource characteristics are too uncertain to allow more meaningful estimates." (Grubb, 1991, Vol. II, p. 13)

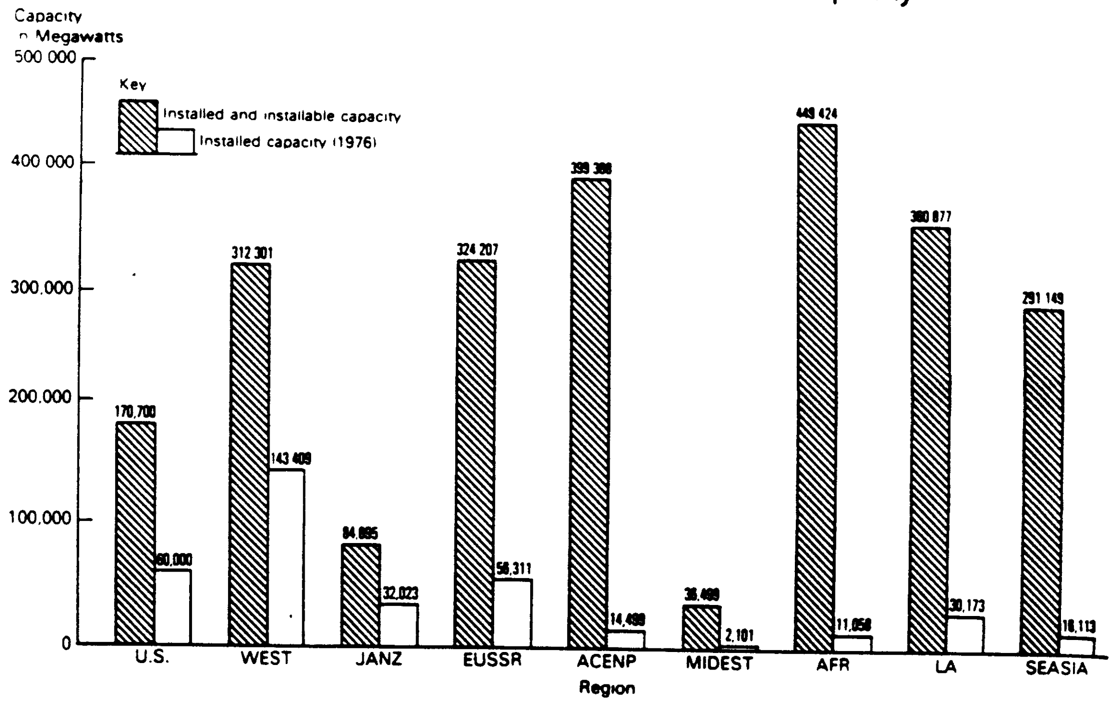
Probably geothermal energy use will have the least impact on the environment as long as it is closed cycle and only heat is extracted from deep in earth, because our concern for the effect of human activity is limited mainly to the surface of the earth. But extraction of heat at excessive rates might cause unexpected land movement caused by thermal stress in a wide range under the ground, or unexpected underground water contamination by injected water might occur. Social issues might be more probable, if the resource is used already for hot springs and power generation is competing with them for heat resources.

4.3.6 Wave, Tide and Ocean Thermal

Resources of wave, tidal and ocean thermal energy are "severely constrained" (Edmonds, 1985, p.7) and have many more resource recovery constraints because of their low energy concentration. Around one per cent of this resource (winds: 13,000 EJ/yr) is converted into waves. (130 EJ/yr, Grubb, 1991, Vol. II, p.12) Tidal energy schemes work by increasing the tidal energy at shorelines, so the natural rate of dissipation (3 TW = 90 EJ/yr) does not represent the theoretical limit. (ibid. p.13) Temperature differentials must be greater than 20C for ocean thermal energy conversion (OTEC) implementation and must be near land masses, where demand exists. (Edmonds, 1985, p.225) Because of this constraint, OTEC application is limited to very specific sites.

All this ocean energy utilization directly affects climate patterns or marine life with temperature changes, oxygen concentration, mixing of materials in the ocean given extensive use. Competition with fishery industries might also cause social problems.

Fig. 4-3-1: Hydroelectricity Installed and Installable Capacity



Source: Edmonds, 1985, p.220

Table 4-3-1: Biomass Potentially Available

Energy Content of Potentially Available Biomass in 2050, by Region (10^{15} Btus)

Region	*Urban Waste*[a]	*Agricultural Waste*[b]	*Land-Based Biomass Farms*[c]
US	3.5	3.5	78.0
OECD West	6.7	3.6	0.0
JANZ	2.0	1.4	12.5
EUSSR	6.4	5.5	93.3
ACENP	12.1	5.8	0.0
MIDEST	2.8	0.7	0.0
LA	9.9	9.9	213.7
AFR	8.3	10.8	164.4
SEASIA	21.7	14.2	0.0
Total	73.4	55.4	561.9

[a]From table 15-2.
[b]Assuming 24.385 × 10^6 Btus of collectible waste per hectare of agricultural land—see table 15-1 notes and land availability estimates of table 15-5.
[c]Assuming 346.875 × 10^6 Btus of biomass production per hectare and land availability estimates of table 15-5.

Source: Edmonds, 1985, p.238

4.4 Efficiency Improvement

Efficiency improvements have all the benefits to reserve any kind of natural resources and reduce impact to the environment. (Takahashi, et.al., Feb. 1986) It is always beneficial whether global warming is true or not. Therefore this is the approach we should always promote. However efficiency improvement often requires initial capital investment including expensive materials and designs, infrastructure like district heating, and research and development efforts. Financial schemes are needed to urge utilities such investment. An energy price tax (not carbon tax) will be best policy for such purposes as well as encouraging end-user toward efficient use of energy.

4.4.1 Supply Side

Wasted resources at production sites such as vented or flared gas should be explored extensively for efficient use and avoid wasting resources. It is unfortunate that the main product (oil) is too easily sold, while gas as a byproduct is relatively expensive to recover at oil producing sites. But the funds collected through energy price tax could be invested to recovering gas facility and pipelines.

Why less efficient older technologies like sub-critical steam conditions plants remain for several decades, when more efficient technologies like supercritical steam conditions plants are commercially available for decades in the US? Because utilities don't like heavy initial investments especially in the US at present, and don't care about slightly higher operation cost which someone (customer) pays anyway. Again financial incentives to ease the heavy initial but efficient capital investment for new technology, and an increased fuel price burden (fuel price tax), and introducing competition between utilities will be needed.

Fig 4-4-1 shows the fossil fired plant efficiency of various conventional and advanced technologies taken from a DOE report. (DOE, Sep. 1991) Although the plant size which affects plant efficiency was not indicated, from the results probably a 200-300 MW size was assumed.

With any conventional or advanced technology, coal has lower efficiency than oil and gas, because it requires energy for fuel preparation (especially pulverizing), ash handling and additional flue gas treatment. In conventional steam power generation, coal-fired plant is around 2% lower (around 5% lower in relative value) in plant efficiency than oil or gas. Conventional steam plant technology has been established 30 years ago and the efficiency has not increased much since then.

One approach to break this efficiency stagnation is to raise the steam condition in Rankine cycle. Electric Power Research Institute (EPRI) in the US has been researching the boiler, turbine and balance of plant design and material improvement in its Improved coal-fired Power Plant (ICPP) project. The new target for steam conditions is 31MPa/593°C/593°C/593°C. Electric Power Development Company (EPDC) in Japan has also demonstrated this and further advanced steam conditions (34MPa/650°C/593°C/593°C) in its Wakamatsu 50 MW plant as Ultra-Super Critical (USC) steam condition project. (Touchton et.al., October 1986, Takahashi et.al., October and November 1988)

With an atmospheric fluidized bed combustion (AFBC) power plant, the pulverizing and desulfurization process is eliminated but a rather big fluidizing energy (fan power) is required. Consequently AFBC's plant efficiency is not improved much from the conventional coal-fired plant. There are already many industrial applications of this technology and several commercial and demonstration plants are operating in the US (100 - 150 MW scale). The largest AFBC plant (350 MW) is under construction at Takehara, Japan by EPDC.

Pressurized fluidized bed combustion (PFBC) is a combined cycle power plant, using a gas turbine compressor directly for fluidizing energy as well as pressurizing the system. Consequently it has high efficiency (over 10% higher than conventional coal-fired plant). This technology is assumed to dominate in coal-firing technology in IPCC's energy model as well as in DOE's report. (DOE, Sep. 1991)

American Electric Power (AEP) built a 70 MW PFBC plant at Tidd plant and now operates it as a demonstration project under DOE's Clean Coal Technology (CCT) #1. AEP has also chosen to build and demonstrate a 350 MW PFBC plant under CCT #2. Another typed of PFBC (circulation PFBC) was chosen to demonstrate the technology under CCT #3. In Sweden and Spain, the same type plants as the Tidd plant 70 MW PFBC are in operation for commercial (district heating and power generation) and demonstration purposes, respectively. EPDC is building another 70 MW PFBC at Wakamatsu, Japan for demonstration purpose.(Takahashi, et.al., May, August, November 1988)

Integrated Coal Gasification Combined Cycle (IGCC) has been demonstrating at Cool Water 100 MW plant in California. The plant was designed conservatively such as using an inlet gas turbine temperature of 1,000°C, wet gas clean-up, and coal-water slurry feed, to demonstrate system reliability and not high efficiency. As a consequence, the plant efficiency is 31 to 32% which is lower than conventional coal-fired plant. To increase plant efficiency, the major parameter is gas turbine inlet temperature. It must be at least 1300 C to compete with PFBC in efficiency. Four projects have been chosen to demonstrate IGCC technology under CCT #4.

Although gas gasified from coal has lower heat value than natural gas, it has still advantages for direct end use, and efficiency is expected to be potentially higher in direct use such as heating, air conditioning and cooking, or could be used as feed stock to the chemical plant rather than converting to electricity. Such applications should also be explored to increase total system efficiency when coal is gasified.

Steam injected/intercooled gas turbine (STIG), integrated gasification steam injected/intercooled gas turbine, humid air turbine (HAT) and integrate coal gasification humid air turbine have eliminated the steam turbine from the combined cycle and made the system simpler, while still keeping higher efficiency, resulting in lower capital cost expected. However all these systems require precious resources other than energy: water in large amounts. Water is injected into gas turbines, where it is evaporated and carried out to the atmosphere with flue gas. The need for good quality water for make up (to eliminate corrosion problem in heat exchangers) will be the potential constraint on these systems.

Fuel cell has high efficiency in small scale uses, therefore, it is more reasonable to use it in dispersed power supply systems rather than big central power stations, both for natural gas and gasified gas. In this case and all combined cycle case, when coal is used as a primary fuel, filtration of coal dust and desulfurization at high temperature will be the critical technology for high efficiency applications.

Unit size affects plant efficiency. A 1000 MW plant usually has 2 - 3% higher efficiency than 200 - 300 MW plant in either coal, oil or gas-fired plant, if the steam conditions are the same. But many US utility companies prefer smaller unit for new plants because of quicker construction time and reduced financial risk. In that sense, gas turbine is the most preferred technology even it has very low efficiency (unless it is built as combined cycle, which has higher capital cost investment). If, however, US utilities continue this behavior, overall generating efficiency will decrease in the future. Financial schemes need to be changed to make them more friendly to high capital investment and less to high operation (fuel) costs for the utility companies.

4.4.2 Demand Side

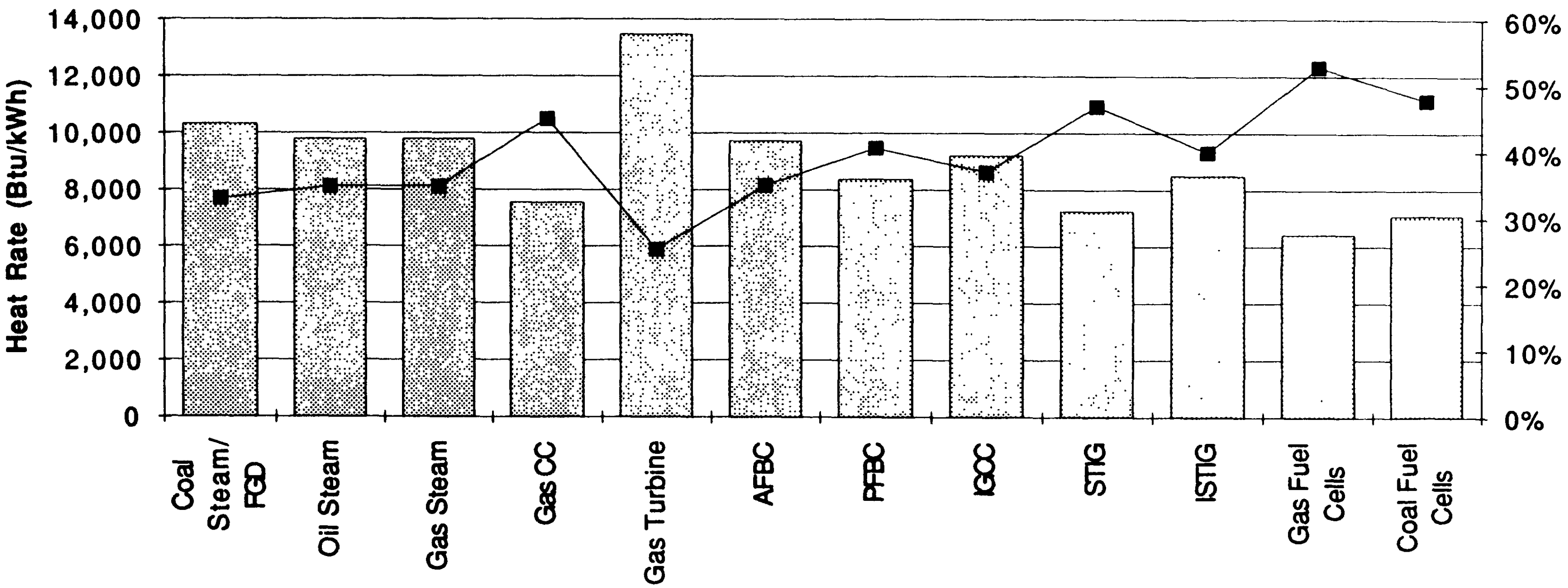
There is more room for efficiency improvements on the demand side than the supply side because of the rather poor efficiency of current applications. Many reports are published finding efficiency increase with less cost or net benefits. (see for example National Research Council, 1991, p. 62; OTA, 1991) But the best way to promote energy efficient technology differs case by case. For example, building insulation could be driven by standards rather than financial incentives, while use of energy efficient light bulb would be encouraged better with financial incentives instead of efficiency standard.

Demand side management (DSM) will be a good way to encourage energy efficiency, but it is only a tool. Technology development is essential to reduction of energy intensity. With the current DSM, utility company stress the elimination of new generating capacity addition which costs a lot, but in the long run, when all the DSM measures are applied, then new capacity will be needed. In addition to that this kind of policy keeps old plant running for a long time, which will reduce system efficiency in the long run due to the lack of new more efficient power plants.

"Large increase in demand will push prices up, perhaps sharply. Conversely, reducing demand will reduce prices. In principle this could seriously limit the impact of policy measures, because measures to reduce consumption would reduce the fuel price, thus stimulating more consumption." (Grubb, 1985, Vol. I, p. 154)

When utility encourage customers to use energy efficient light bulb with rebate, who will pay the cost? With the same unit electricity price, the revenue of the electric utility company will drop with less consumption of electricity. DSM in the electric utility industry will only work with keeping or raising unit prices for electricity.

Fig. 4-5-1: Fossil Fired Plant Efficincy



Source: DOE, Sep. 1991, Vol. II, p. 1.26

4.5 Conclusions

This chapter concludes the following:

- Oil and gas resources are smaller than that of coal, and this creates pessimism about oil and gas prices, generating forecasts that they inevitably increase. But if the present trend of increasing gas and oil reserves continues, oil and gas prices will stay at the present level except for the vacillation by world wide events, and oil and gas will replace coal with high carbon tax.

- Coal is virtually unlimited in its resource and more evenly distributed geographically than oil and gas. This makes coal stable in supply and price, which is important for utilities' fuel choice.

- Oil and gas sometimes need to be and sometimes can be used directly for end uses, and usually direct use is more efficient than going through electricity energy form. To increase overall energy efficiency as well as avoiding instability in fuel supply and fuel price, application of oil and gas should be limited to special cases such as peak load, supplemental fuels at plant start up and shut down or where a plant is built in an urban area and local environmental concerns are too strict for other fuels or available space for fuel storage is limited.

- Since generating electricity is the only way of converting the plentiful and stable energy coal resources, it should be promoted with careful to local, regional and global environmental concerns as a reasonable use of natural resources.

- Technologies are commercially available so that coal is clean enough to be accepted to the public and still competitive with oil and gas. It will, however, never be competitive if used with a facility for the removal and disposal of CO_2.

- Tradeoffs among minor greenhouse gases like CO_2 v.s. CH_4, CO_2 v.s. N_2O should be carefully compared in choosing process of fuel and technology. However, both global warming by these minor greenhouse gases and global warming potential (GWP) are too uncertain to take into account in calculating tradeoff for such choices.

- Global warming should not be used to promote nuclear, because nuclear has its own and potentially more serious problems like safety, waste management and proliferation issues yet to be solved.

- High cost is the constraint for renewables in most cases. However, even if the cost is reduced each renewable technology has its own environmental impacts, many of which have not been quantified yet.

- Efficiency improvement is always good whether global warming is true or not. Financial schemes needed to urge utilities investment to improve efficiency. An energy price tax (not carbon tax) will best fit such purposes as well as encouraging efficient use of energy by end-users.

5. Conclusions and recommendations

The paper concludes and recommends as follows:

Conclusions:

- Global warming should not be given higher priority in energy and environmental policy than other more serious issues.

- The CO_2 emissions rate is not an appropriate index, and setting a CO_2 target of an arbitrary level misdirects energy and environmental policy.

- Energy consumption is the index that should be set as the standard or target, and population growth rate and economic growth rate should be given significant difference in energy consumption.

- Energy security and price stability has a higher priority than global warming.

- Concern about global warming should not be used to promote nuclear, because nuclear has its own and potentially more serious problems like safety, waste management and proliferation issues yet to be solved.

- Each renewable technology also has its own environmental impacts many of which have not been quantified yet.

- Efficiency improvements are always good whether global warming is occurring or not. Financial schemes are needed to urge utilities investment to improve efficiency. An energy price tax (not carbon tax) will be the best fit for this purpose, as well as encourage efficient use of energy by end users.

Recommendations:

Do's

- Appropriate population growth rate in developing countries needs to be sought and actions to be taken to meet the goal.

- An appropriate economic growth rate should be sought to develop and sustain the world's limited energy and environmental resources.

- Energy efficiency always needs to be improved to conserve limited energy and environmental resources.

- Energy and environmental policies which encourage incentives to improve efficiency need to be sought.

- Research should be continued to reduce uncertainties in the scientific and economic analysis of global warming.

- Utility industries should choose energy sources and technologies so that stable and reasonable price of electricity can be supplied at locally, regionally and globally acceptable environmental levels.

Don'ts

- Do not use the global warming to promote nuclear, renewables, or fuel switching

- Carbon tax should not be introduced because it unnecessarily distort energy choices.

- Do not give high priority in CO_2, CH_4, N_2O emission rate when selecting among fossil fuels.

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Appendix 1. CH4 v.s. CO2

Comparing CO2 reduction by conversion of fuel from coal to gas, with allowable increase of CH4 emission of natural gas use. How much leakage at transportation and end use of gas is calculated.

Assumptions:

Emission at production sites: coal mine and gas well is equal amount to produce the same amount of final energy use. (Probably over simplified assumption)

1 quad of coal produces 0.025 GtC of CO2
1 quad of natural gas produces 0.015 GtC of CO2
(DOE, Sep. 1991, p. xxxix)

Plant efficiency at the best coal fired power plant (PFBC): 40%
Plant efficiency at the best natural gas power plant (CC): 45%

Global Warming Potential (GWP) of CO2 = 1
Global Warming Potential (GWP) of CH4 = 11
(Direct only, 100 year time horizon, IPCC, 1992, p. 15)

Heat Value of Methane: 56,000 kJ/kg

Calculations:

Coal emit twice as much CO2 as gas to produce the same amount of electricity, because of higher carbon content and lower plant efficiency as follows:

CO2 emissions from **coal-fired** power station to produce 1 kwh;

$\underline{0.025} \times 10^9 \times 10^6$ (gC) / $1.055 \times 10^{18} \times \underline{0.4}$ (J)

$= 0.025/0.422 \times 10^{-3}$ (gC/ws)

$= 0.0592$ (gC/kws)

$= 0.0592 \times 3600$ (gC/hwh)

$=$ <u>213 (gC/kwh)</u> $= 213 \times 3.67$ (gCO2/kwh) $=$ <u>782 (gCO2/kwh)</u>

CO2 emissions from **gas-fired** power station to produce 1 kwh;

$\underline{0.015} \times 10^9 \times 10^6$ (gC) / $1.055 \times 10^{18} \times \underline{0.45}$ (J)

$= 0.015/0.475 \times 10^{-3}$ (gC/ws)

= 0.0316 (gC/kws)

= 0.0316 x 3600 (gC/hwh)

= 114 (gC/kwh) = 114 x 3.67 (gCO2/kwh) = 417 (gCO2/kwh)

Therefore, if coal-fired power plant is converted into gas-fired power plant, CO_2 reduction will be:

782 - 417 = 365 (gCO2/kwh)

This correspond to the allowable methane leakage of:

365 (gCO2/kwh) / 11 (gCO2/gCH4) = 33 (gCH4/kwh)

when methane's GWP or 11 is used.

To produce 1 kwh of electricity with 45% efficiency plant, methane required will be:

1 (kwh) / 0.45 = 3600 /0.45 (kJ) = 8000 (kJ)

8000 (kJ) / 56,000 (kJ/kgCH4) = 0.143 (kgCH4) = 143 (gCH4)

Therefore, allowable methane leakage percentage of methane consumed will be:

33 / 143 = 23 (%)

Conclusion: 23% allowable.

If indirect effect of methane to global warming is as large as the direct effect and with positive sign (IPCC, 1990 shows 24 in 100 years horizon), then this conclusion will be reduced to around 10%.

Appendix 2, N_2O v.s CO_2

How much N_2O emission allowed to get even global warming potential to compensate the reduction by efficiency increase?

Assumptions:

Global Warming Potential (GWP) of CO_2 = 1
Global Warming Potential (GWP) of N_2O = 270
(Direct only, 100 year time horizon, IPCC, 1992, p. 15)

Efficiency increase from conventional coal-fired power plant: 10% (relative value)

CO_2 concentration in flue gas: 15%
Critical N_2O concentration in flue gas: N ppm

Calculation:

CO_2 emission will be decreased 10% by the efficiency increase. Both CO_2 and N_2O have molecular weight of 44, therefore, either the volume flow or mass flow give the same results.

$$N \times 10^{-6} \times 270 = 0.15 \times 0.1$$

$$N = 15000/270 = 55.5 \text{ (ppm)}$$

Conclusion: Around 50 ppm of N_2O emission will be allowable to get the same global warming potential, when 10% efficiency increase is expected.