

Role of Technology in Climate Change

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Analysis of the Role of Technology in Climate Change with Dynamic New Earth 21 Model

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Abstract

The purpose of the study is to make a comprehensive assessment of the technologies for limiting CO₂ concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. In order to conduct the assessment, the authors developed a large-scale energy system model Dynamic New Earth 21 (DNE21). In the framework of the energy model, the world is divided into ten regions so that it can explicitly evaluate the differences in regional economic and geographical conditions. The model can assess the various technological options up to the year 2100 through inter-temporal minimization of the total discounted energy system costs. The model takes into account the following categories of measures: energy saving in end-use sectors, efficiency improvement in energy conversion sectors, utilization of various less carbon-intensive or carbon-free energy resources, disposal and recycling of CO₂ recovered in the energy systems, and innovative system technologies especially with respect to hydrogen. The findings of the model analysis are summarized as follows: 1) it is economically optimal to reduce the CO₂ emissions in the latter part of the time horizon; 2) the CO₂ problem can not be easily settled by any single technological option; however, 3) if those options are reasonably combined with one another, there exists a great technological potential for CO₂ emission reduction to limit the atmospheric CO₂ concentration over the next century.

1. Outline of Dynamic New Earth 21 Model

Dynamic New Earth 21 (DNE21) model was developed on the basis of the New Earth 21 (NE21) model which was originally formulated by Y. Fujii (Fujii and Kaya 1993). DNE21 seeks the optimal trajectory of global energy system to evaluate the CO₂ mitigation technologies to cope with climate change. DNE21 is formulated with non-linear optimization techniques, and it has about 20,000 variables and 8,000 constraints. DNE21 minimizes the discounted present value of the total system costs distributed over the time range, whereas the cost minimization in the original NE21 is done for each time step; thus, DNE21 may incorporate a wider variety of constraints which include CO₂ emissions and atmospheric CO₂ concentrations limits, as well as various technological conditions in the energy systems.

In DNE21 the world is divided into ten world regions to take into account the economic and geographical differences among them: 1)North America, 2)Western Europe, 3)Japan, 4)Oceania, 5)Centrally Planned Asia, 6)Other Asia, 7)Middle East and North Africa, 8)Other

Africa, 9) Latin America, and 10) Former Soviet Union and Eastern Europe. The time horizon of DNE21 covers 1990-2100, which is represented by intervals of ten years until 2050 and 25 years thereafter.

2. CO₂ Control Technologies in DNE21

1) Energy conservation

DNE21 model evaluates energy conservation possibility by dividing the final demand sector into four categories by energy carrier type (gaseous fuel, liquid fuel, solid fuel, and electricity). Regarding the methods to describe energy conservation cost, one is called the bottom-up method by accumulating cost of individual technology and the other is called the top-down method by adopting the concept of price elasticity. In case of DNE21, while the bottom-up method is applied to energy supply side, the top-down method with price elasticity is applied to energy conservation on demand side. Cost of energy conservation is counted by integrating inverse demand function. The cost is interpreted as the loss of consumers' utility in welfare economics (see Figure 1). In DNE21, a set of potential energy demands, corresponding reference energy prices and price elasticities, are given as exogenous inputs for each final demand sectors.

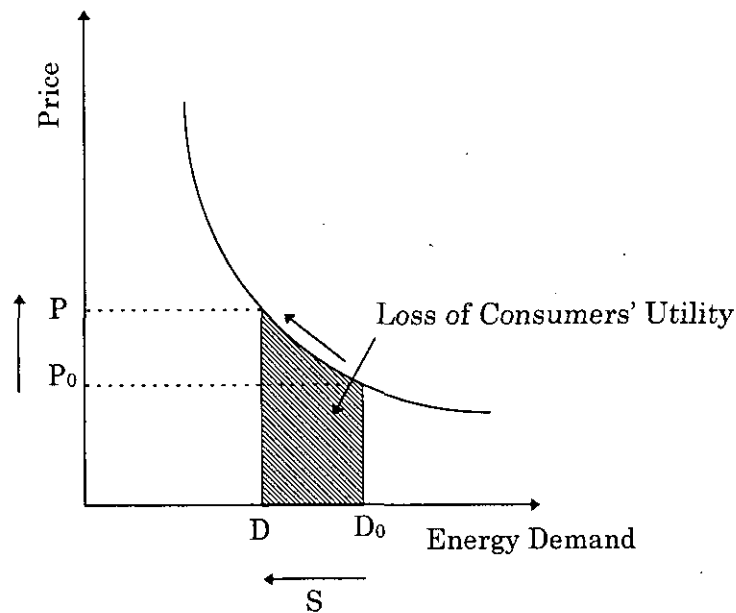


Figure 1: Energy Saving Costs Measured as a Loss of Consumers' Utility

2) Switching to less carbon intensive or carbon-free energies.

Regarding fossil fuels (coal, oil, natural gas, etc.), cost increase resulting from exhaustion of resources by region was represented in the model. Without CO₂ control requirements, coal, whose cost increases less than the others, would be preferred. However, under the CO₂ restriction, natural gas, which produces less CO₂ per heating value, is preferred. As non-fossil energy except nuclear power, five types of renewable energy (hydropower, geothermal, forest biomass, photovoltaics and wind power) are to be considered. For these renewable resources, estimation of costs and resource availability is still not quite certain; however, they have been

assumed on the basis of the latest knowledge. The output of photovoltaics and wind power is intermittent, so in order to maintain the supply reliability of electric power system, the shares of these generation sources in the power system are to be limited lower than a certain limit considering load duration curve. However, the restriction is not applied to the electricity supplied to water electrolysis and electricity storage. In the study reported, the nuclear power capacity in the world is assumed not to increase beyond the level of 1000GWe.

3) CO₂ removal, disposal and recycle

With DNE21 model, chemical absorption process for flue gas of conventional power plants, and physical absorption process for gasification plant (using various fossil fuels and biomass), and integrated coal gasification combined cycle (IGCC) power generation, are considered as CO₂ recovery processes. As disposal sites for recovered CO₂, the following options are assumed: 1) Compressing to oil field for enhanced oil recovery (EOR); 2) Compressing to depleted natural gas well; 3) Injection into underground aquifer; 4) Ocean disposal (liquefaction and deposition on the seabed of deep ocean). The possibility of reusing a part of recovered CO₂ for methanol synthesis is also considered.

4) Other technologies: long distance transportation and IES

For constructing the optimal energy system in a global scale, we must take the importance of long distance energy transportation between world regions into consideration. DNE21 can deal with inter-regional energy transportation technologies for H₂, methanol, and recovered CO₂, as well as traditional fossil fuel transportation. DNE21 can also take into account the introduction of IES (integrated energy system), where we can convert carbon rich fuels into hydrogen rich fuels such as H₂, methane, and methanol; thus CO₂ emission can be reduced. Of course recovery of CO₂ which is produced in a process for this conversion must be considered as a prerequisite. DNE21 assumes the IES forming H₂, CO, CO₂ as common secondary fuel gases from each primary hydrocarbon fuels, then producing H₂, methane and methanol. CO₂ recycling, mentioned in the above paragraph, is incorporated in the IES (See Figure 2).

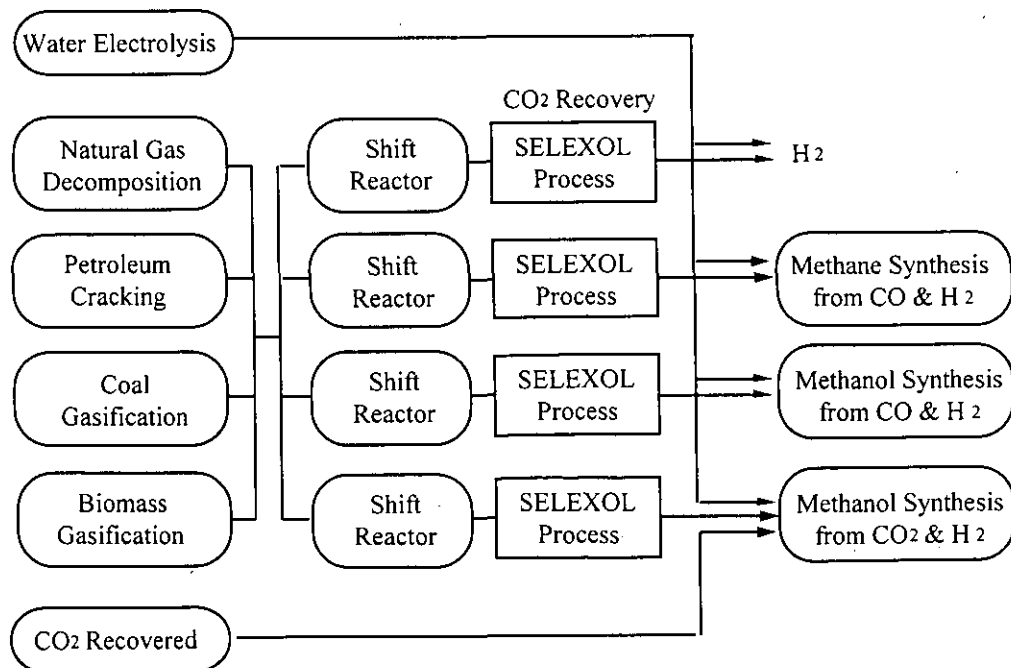


Figure 2: Assumed Integrated Energy System

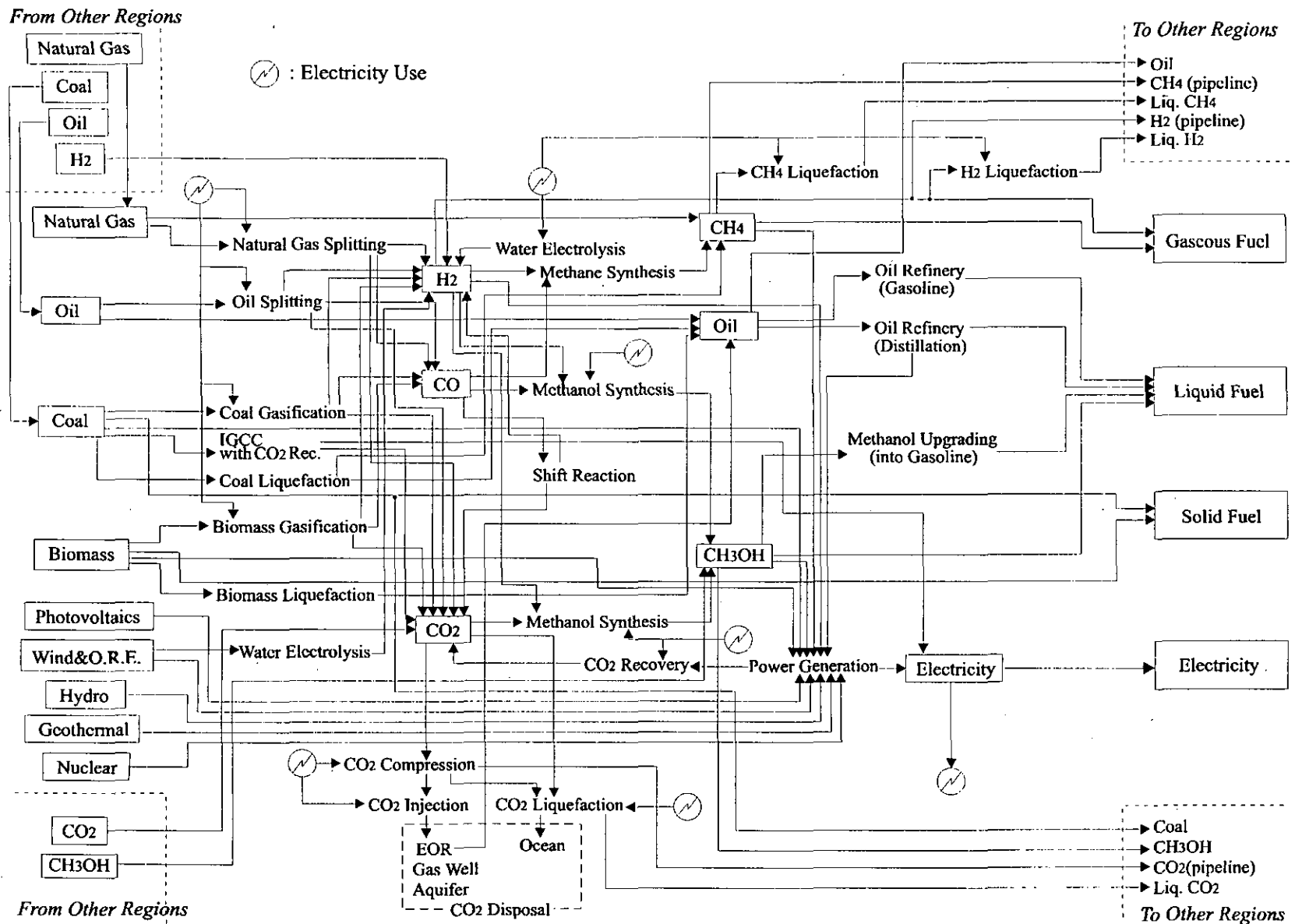


Figure 3: Energy Flow in DNE21 Model (for one region)

5) Energy flows in DNE21

Figure 3 illustrates the energy flow of DNE21 model. The flow in the figure represents one region; ten of these regional flows are linked to comprise the whole global model.

3. Scenarios for Model Analysis

The following three cases of simulations were calculated with DNE21 model, while the results are tentative and being reviewed for update (MITI 1996): 1) Business as Usual Case (without limitation of CO₂ emission, energy demands are fixed to the IPCC IS92a scenario); 2) Technology Development and Transfer Normal Case (CO₂ concentration in the atmosphere is controlled at 550 ppm in 2100, energy demands are adjusted by price increases from the IS92a scenario); 3) Technology Development and Transfer Accelerated Case (CO₂ concentration in the atmosphere is controlled at 550 ppm in 2100; growth rates of energy demands are reduced by 0.5%/year from the IS92a scenario; with the assumption of increase in end-use energy efficiencies; several technological performances are assumed to be improved from those in the Business as Usual Case).

4. Overview of the Results

The results are shown in Figures 4, 5, 6, and 7, from which following observations are derived:

1) Ba U (Business as Usual) Case

When no countermeasure towards CO₂ emission reduction are conducted, the share of coal in primary energy supply increases remarkably because of its low price. Therefore the total CO₂ emissions also increase, and will be five times as large as the present level in 2100.

2) Technology Development and Transfer Normal Case (550 ppm in 2100)

To meet the constraint of CO₂ concentration in the atmosphere without acceleration of technology development and transfer, the composition of primary energy is diversified, with increased shares of various renewable energies and natural gas being the highest share in 2100; the energy demand decreases because of increases in energy prices; and CO₂ recovery and disposal technologies play a very important role in reducing CO₂ emissions, particularly in the latter part of the next century.

3) Technology Development and Transfer Accelerated Case (550 ppm in 2100)

In meeting the CO₂ concentration constraint with accelerated technology development and transfer, the shares of renewable energies, particularly that of photovoltaics, increase significantly. As a result of the combined effects of the assumptions of cost free end-use energy efficiency improvements and the improved technological performances, CO₂ emission reduction is achieved without severe cost increase in this case.

The findings of the model analysis are summarized as follows: 1) it is economically optimal to reduce the CO₂ emissions in the latter part of the time horizon; 2) the CO₂ problem cannot be easily settled by any single technological option; however, 3) if those options are reasonably combined with one another, there exists a great technological potential for CO₂ emission reduction to limit the atmospheric CO₂ concentration over the next century.

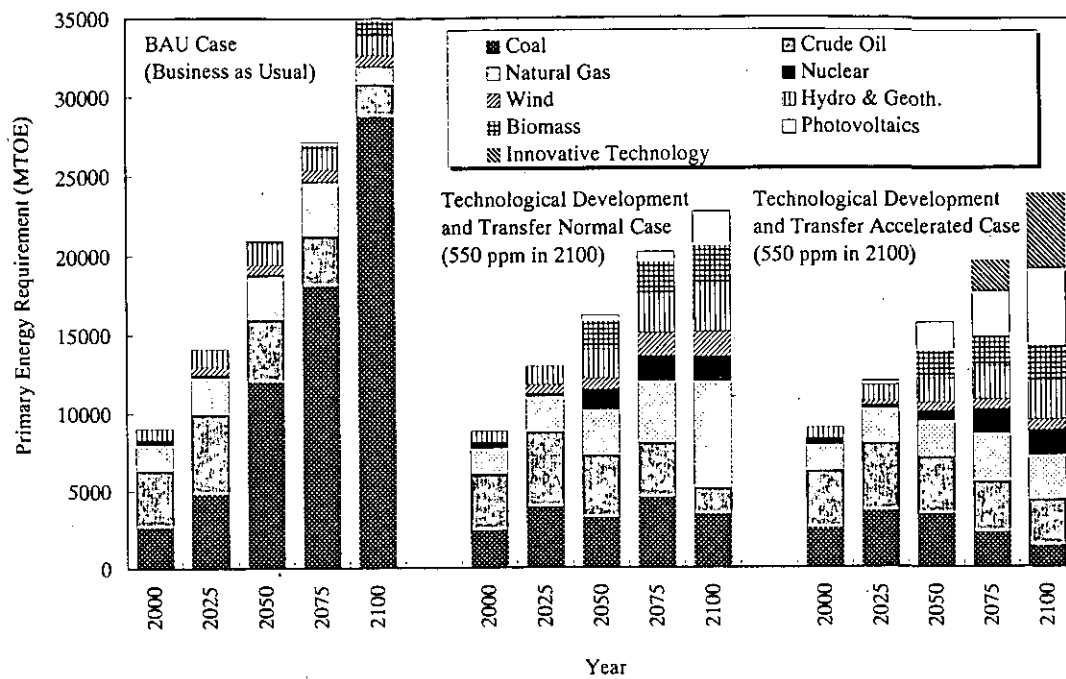


Figure 4: World Primary Energy Requirements

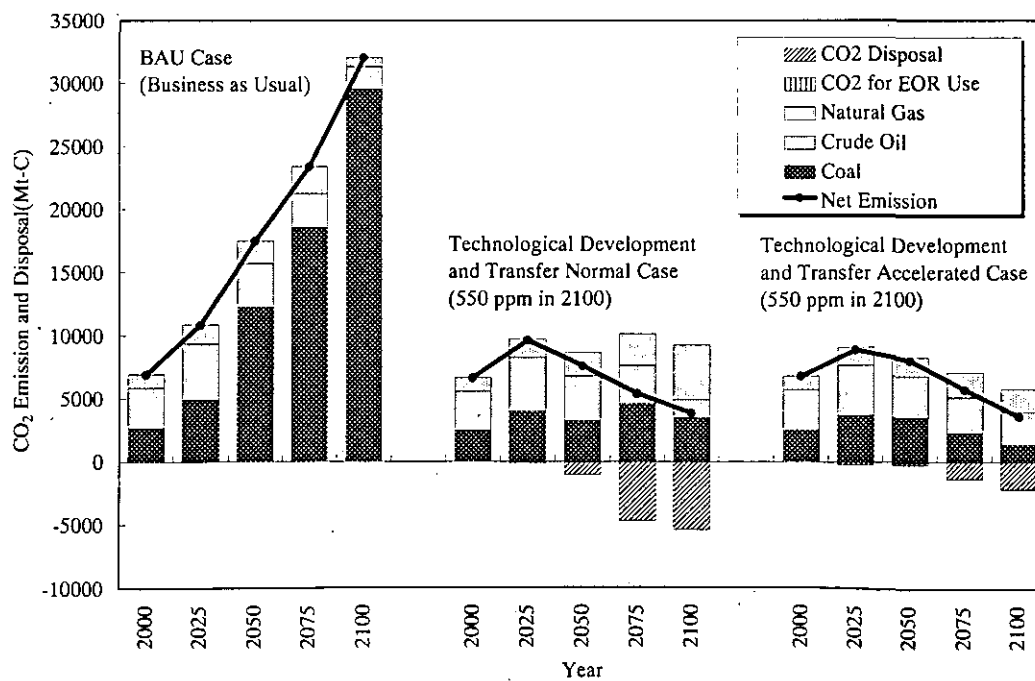


Figure 5: CO₂ Emission and Disposal

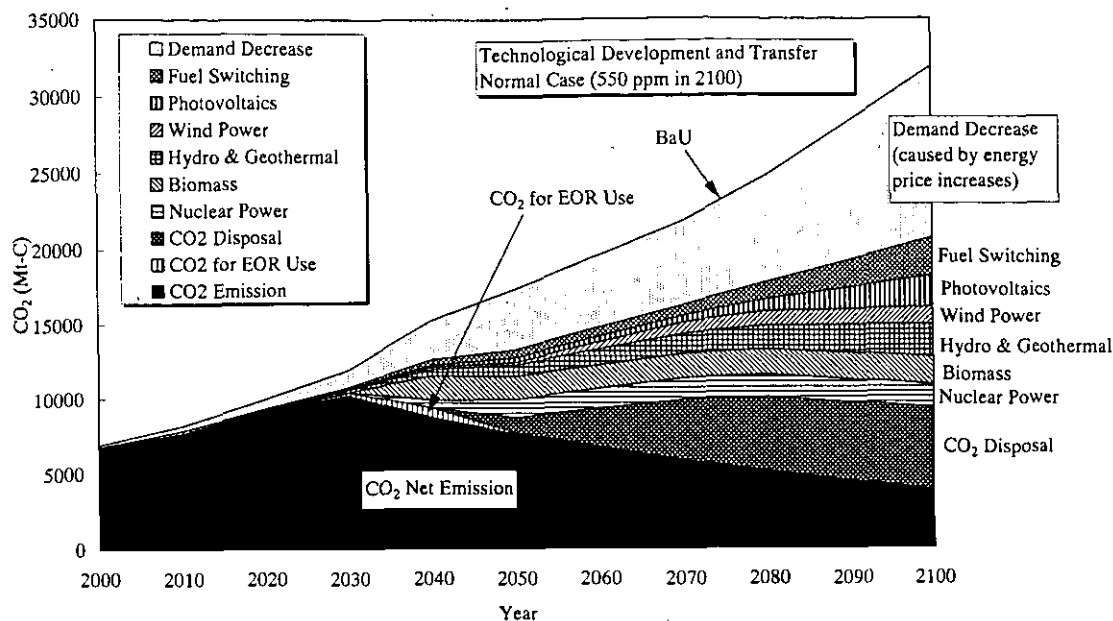


Figure 6: CO₂ Emission Trajectory in Technological Development and Transfer Normal Case
(Reductions from that of BaU case by technological option)

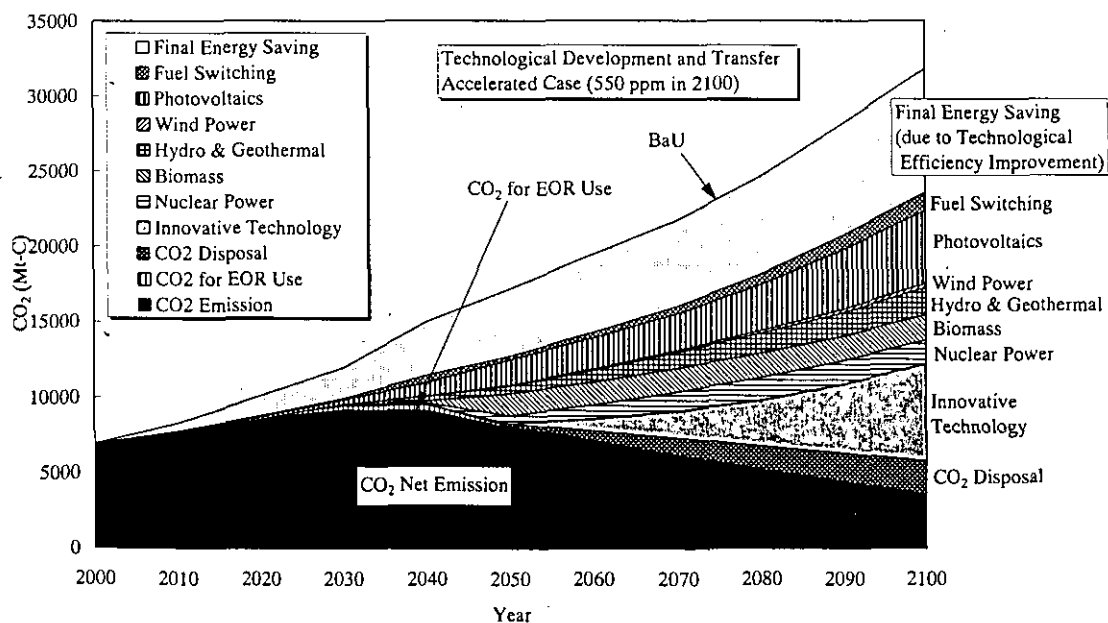


Figure 7: CO₂ Emission Trajectory in Technological Development and Transfer Accelerated Case
(Reductions from that of BaU case by technological option)

References

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