The Effects of Global Warming and Sea-Level Rise on Coastal North Carolina

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Sea-level rise due to global warming is certain to cause significant changes in the world's coastlines. North Carolina, with 300 miles of open shoreline and 1700 miles of estuarine shoreline, will be one of the areas greatly affected by rising sea level. This article discusses the potential effects and policy implications of sea-level rise on coastal North Carolina.

Introduction

Increasing concentrations of greenhouse gases, principally carbon dioxide (CO_2), are certain to alter not only North Carolina's climate, but its physiography, ecology, and economy as well. Nowhere will the effects of global climate change be more pronounced than in coastal North Carolina.

In the last 180 years, global CO_2 concentrations have increased 20 percent, from between 260 and 290 parts per million (ppm) to 340 ppm, and 8 percent since 1958 alone (NRC, 1983). A doubling of atmospheric CO_2 concentrations is not only possible, but expected. Atmospheric levels of other greenhouse gases have increased as well. Methane increased 1 to 2 percent per year from 1970 to 1980, chlorofluorocarbons by about 0.6 percent over that same decade, and nitrous oxide by about 0.2 percent from 1975 to 1980 (WMO, 1982).

Global mean temperatures have increased 0.6°C over just the last century, consistent with atmospheric CO_2 increases over that period, and are expected to rise by no less than 1.5°C and perhaps by as much as 4.5°C by the year 2030 due to a doubling of atmospheric CO_2 concentrations alone (Charney, 1979). Increasing concentrations of other greenhouse gases could double the warming expected from increasing CO_2 concentrations (WMO, et al., 1982). Dr. James Hansen, director of the Goddard Institute for Space Studies, predicts that if current CO_2 levels double, the number of days per year with temperatures above 32.2°C (90°F) for representative U.S. cities will increase, as shown in Table 1.

Table 1. Days Per Year with Temperature Greater Than 90°F

City	*Average 1950-1980*	*Projected Average With Doubled CO_2*
Washington, D.C.	36	87
Omaha	37	86
New York	15	48
Chicago	16	56
Denver	33	86
Los Angeles	5	27
Dallas	100	162
Memphis	65	145

Source: J. Hansen, 1987

In North Carolina, a doubling of global atmospheric CO_2 concentrations would result in Raleigh's having an annual mean temperature of 19.2°C, greater than that of Dallas, Texas, today. Wilmington at 21.4°C would be as warm as Phoenix, Arizona, is now, and Charlotte would have an annual mean temperature of 19.6°C, approximately that of Jacksonville, Florida. Asheville would have an annual mean temperature of 17°C, fully 1°C higher than that of Mexico City, Mexico, today.

Increased global mean temperatures by themselves could engender a broad range of environmental and climatological impacts. Warmer temperatures in combination with increased concentrations of nitrogen oxides and hydrocarbons and enhanced ultraviolet radiation could result in elevated ozone levels, consequently increasing photochemical smog and related mortality and morbidity in urban areas. Temperate zone forests, already degrading due to air pollution, could be further stressed as increased temperatures accelerate the mechanisms causing the degradation. This forest degradation may, in turn, exacerbate eutrophication and acidification of downstream fresh waters. Agricultural production may be affected as well, with crop yields reduced a net 5 percent for every one degree centigrade rise

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in annual mean temperature (Dudek, 1987).

Potentially, the most devastating greenhouse effect will be the increased rate of sea-level rise due to thermal expansion of the ocean and more rapid melting of alpine, Antarctic, and Greenland glaciers. Various projections of sea-level rise and the relative contribution of the most significant sources to that sea-level rise due to a doubling of CO_2 levels (and the consequent increase in atmospheric and ocean temperature) are shown in Table 2.

Table 2. Projections of Sea-Level Rise Due to a Doubling of CO_2 Levels (In Centimeters)

Author	*Thermal Expansion*	*Alpine Glaciers*	*Greenland Glaciers*	*Antarctic Glaciers*	*Total*
Revelle (1983)	30	12	12	*	70
Meier (1984)	-	10-30	-	-	-
Bindschadler (1985)	-	-	10-30	-	-
Hoffman, et al. (1986)	28-83	12-37	6-27	12-220	57-368
Thomas (1985)	-	-	-	0-220	-
Hoffman, et al. (1983)	28-115	§	§	§	56-345
NRC (1983)	-	10-30	10-30	-10-+100	

* 16 centimeters due to sources other than doubling of CO_2

§ glacial contribution assumed to be one to two times the contribution of thermal expansion

The general consensus is that a sea-level rise of 50-200 centimeters (1.6-6.6 feet) will occur over the next century. The U.S. Environmental Protection Agency estimates that a global sea-level rise of between 4 and 7 feet is likely by the year 2100 and may be as high as 11 feet (Hoffman, et al., 1983). Although there is substantial local variability and statistical uncertainty, average sea level over the past century has already risen approximately 30 centimeters relative to the coast of North Carolina (NRC, 1987). Accordingly, a sea-level rise in North Carolina of 5 feet by the year 2100 was selected as supportable for the purposes of this study.

Physical Impacts of Sea-Level Rise on Coastal North Carolina

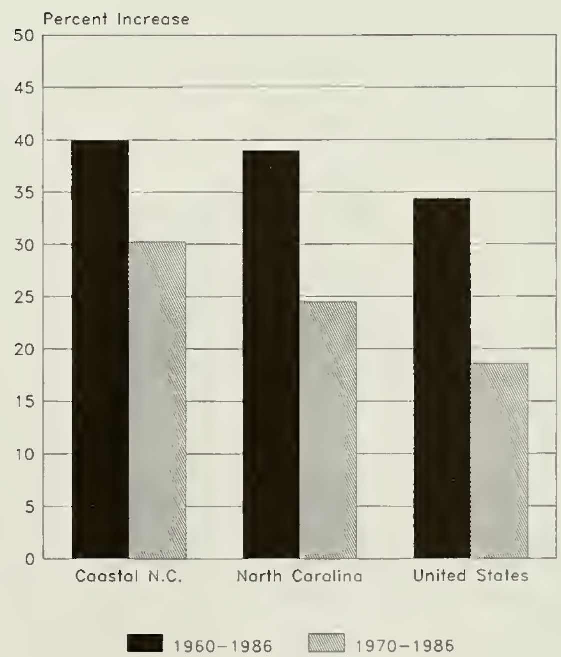
As sea level rises, shoreline retreat, flooding, and saltwater intrusion will increase. The magnitude of these effects and their environmental, social, and economic implications is a function of the physiography, topography, and population density of the areas impacted. By any method of accounting, the impacts of sea-level rise on North Carolina will be significant. Eastern North Carolina is characterized by over 300 miles of open ocean coastline and over 1700 miles of estuarine shoreline. Although the topography of the twenty-two coastal counties included in this study is highly variable, much of the area is low and swampy. Elevations on the barrier islands range from a few feet above mean sea level (msl) to 100 feet above msl for isolated hills, with many areas subject to overwash by storm surges. On the mainland, much of the area is lower than 20 feet above msl with a large percentage less than 5 feet above msl.

As Figure 1 shows, the permanent resident population of the coastal counties of North Carolina has increased dramatically since 1960. From 1960 to 1986, the populations of the United States and North Carolina have increased 34.4 percent and 39.0 percent, respectively, while the population of the twenty-two coastal counties increased 40.0 percent. From 1970 to 1986, the difference in relative population growth rates is even greater, only 18.6 percent and 24.5 percent for the United States and North Carolina, respectively, compared to 30.2 percent for the twenty-two coastal counties.

The increase in population in the twenty-two coastal counties has occurred primarily at or near the coastline, thus significantly increasing the population impacted by rising sea levels.

Given these geographic and demographic characteristics of coastal North Carolina, a five-foot rise in sea level could cause significant environmental, social, and economic impacts. Shorelines will retreat because lowlands will be inundated and land adjacent to the advancing sea will erode. May, et al., (1983) estimates that the average shoreline erosion rate in North Carolina over the past 40 to 50 years has been about 60 centimeters per year. In North Carolina, as well as along much of the Atlantic and Gulf Coasts of the United States, a 30-centimeter (1-foot) rise in

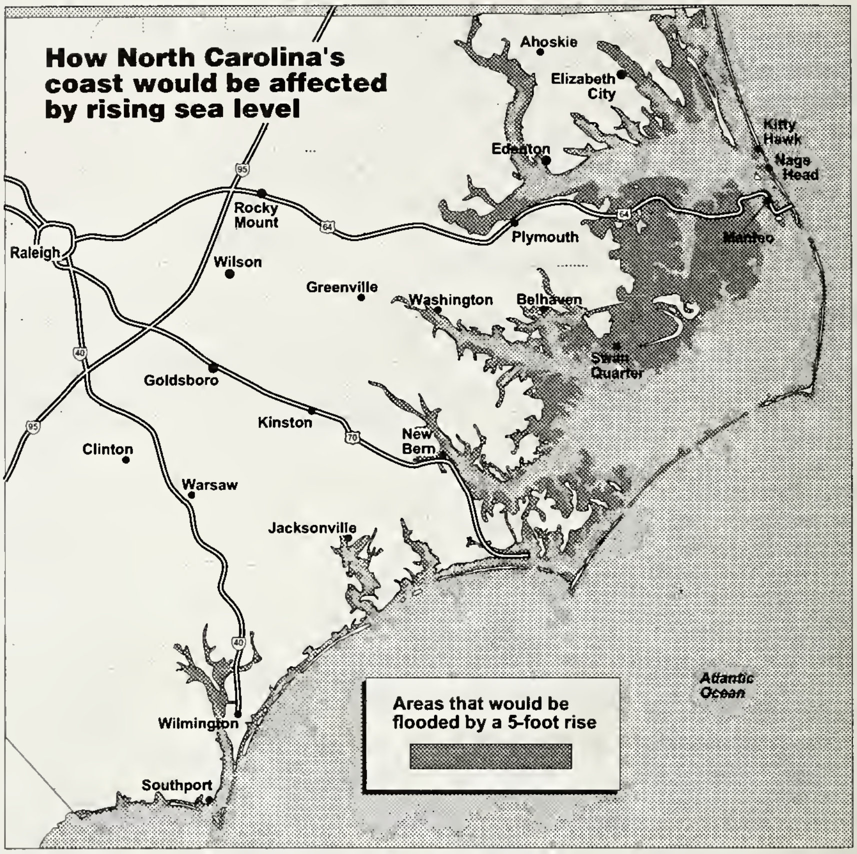
Figure 1. Population Growth Rate



Source: U.S. Department of Commerce

sea level would erode sandy beaches at least 30 meters (100 feet) and, perhaps, as much as 300 meters (1000 feet) (Hoffman, et al., 1983); therefore, a sea-level increase of 5 feet would result in a shoreward erosion of 500 to 5000 feet and would dramatically alter shoreline configuration.

A simple drowned-valley concept, in which preexisting topography along shorelines is considered fixed, can be utilized to conservatively model the resulting shoreline configuration as a function of sea-level rise (Kana, et al., 1984). The illustration to the right shows the changes in North Carolina's shoreline as a result of a five-foot rise in sea level using this model. Although the model is simplistic and does not account for the landward migration of barrier islands, it does serve to depict the dramatic implications of a five-foot rise in sea level. Utilizing the drowned-valley concept reveals that a five-foot rise in sea level would inundate over 1.23 million acres of lowlands, swamps, and marsh in North Carolina, ranging from just over 6000 acres in Chowan County to more than 260,000 acres in Hyde County. Nearly 73 percent of the total acres lost to inundation will occur in six of the twenty-two coastal counties (see Figure 2).



A five-foot rise in sea level would inundate 87 percent of Dare County, 75 percent of Tyrrell County, more than 66 percent of Hyde County, over half of Currituck County, and significant portions of many others (see Figure 3).

Lowlands not inundated will experience more frequent and severe flooding. Higher sea levels will engender larger storm surges and, because of beach erosion and deeper water, larger waves may impact further inland.

Much of the area subject to inundation by a five-foot sea-level rise is currently wetlands, including back-barrier marshes, estuarine marshes, and tidal freshwater marshes. Wetlands are vital to coastal recreation, to commercial fishing, to the maintenance of water quality, and as a buffer against shore erosion. The amount of wetland loss due to rising sea levels is highly speculative. Shoreline erosion will likely account for less than 1 percent of the marsh loss due to rising sea level because most marshes will have been long since inundated before erosion can take place (NRC, 1987).

A far greater cause of wetland loss due to rising sea level will be direct inundation and the formation of vast interior ponds resulting from tidal creek bank erosion and landward growth as the areas affected by tides expand. The amount of marsh loss due to anoxia and ultimate root death of marsh plants as rising sea levels outpace the ability of the marsh to maintain elevation could be catastrophic.

Rising sea level will also increase saltwater intrusion into groundwater, rivers, and estuaries. It is estimated that the salt-

Figure 2. Percent of Total Area Inundated Per County

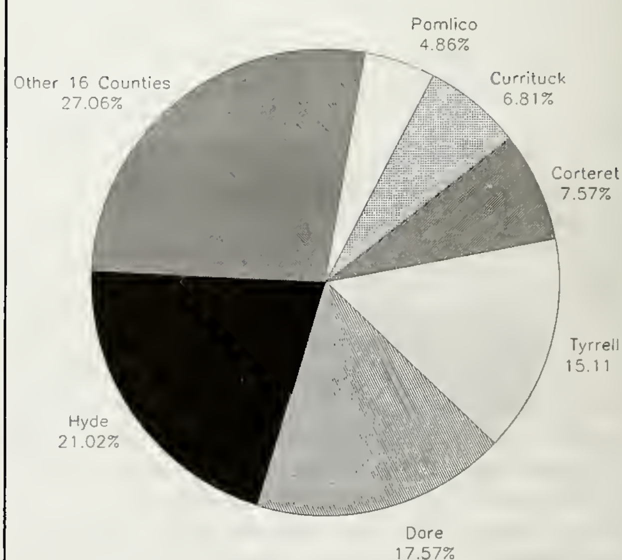


Figure 3. Area Inundated by a Five-Foot Rise in Sea Level

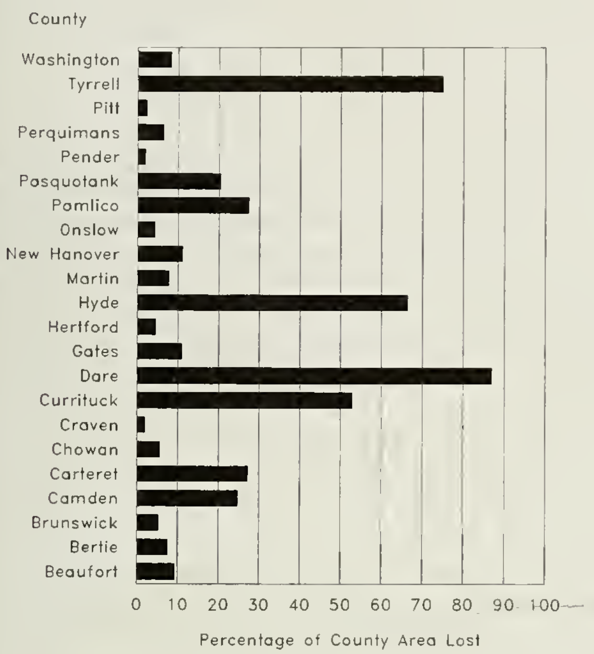
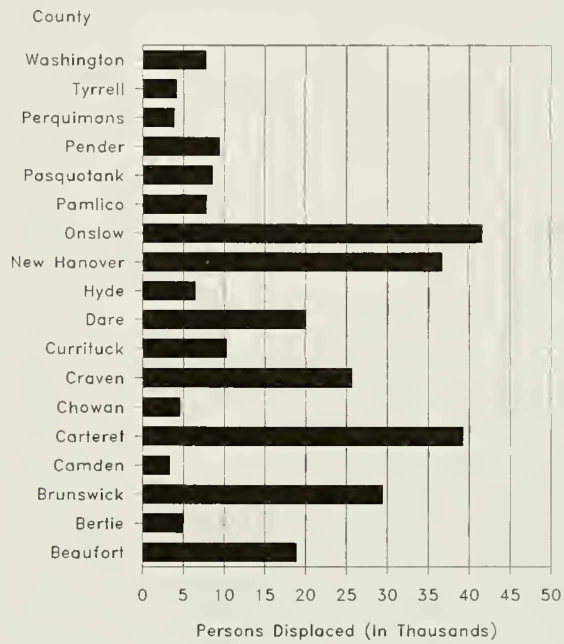


Figure 4. Population Displaced by a Five-Foot Rise in Sea Level



water wedge through estuaries and tidal rivers could advance as much as 1 kilometer for every 10 centimeter rise in sea level (NRC, 1987); therefore, a five-foot sea-level rise could push the saltwater wedge almost 10 miles further upstream, posing significant threats to local water supplies and freshwater ecosystems. Evidence of this saltwater-wedge migration due to sea-level rise may already be available. In its report entitled "Salinity and Bald Cypress (Taxodium distichum)," the North Carolina Division of Environmental Management cites a study by Hackney and Yelverton attributing the decline of an extensive area of cypress and gum trees along the lower Cape Fear River to increasing salinity or tidal flooding associated with sea-level rise and channel dredging at the mouth of the river (DEM, 1987). Many forested wetlands in the lower portion of the river have already been converted to brackish marsh. Hackney and Yelverton (1987) believe that the process of cypress decline and marsh replacement will continue as sea level rises.

Economic and Social Impacts of Sea-Level Rise on Coastal North Carolina

Because humans seem to have a predilection for building on or as near to water as possible, perhaps the predominant impact of sea-level rise will be on man's cultural establishment rather than on the natural environment, especially given the dramatic increase in population at and near the coast. Using the average assessed value per acre for each of the twenty-two coastal counties, the value of the 1.24 million acres inundated by a five-foot sea-level rise can be conservatively estimated to be approximately $1.86 billion. Utilizing data developed by the N.C. Division of Emergency Management, et al. (1987), it is estimated that a five-foot rise in sea level would displace more than 282,000 permanent residents in eighteen of the twenty-two coastal counties (see Figure 4), or about 44 percent of the 1986 coastal population for those eighteen counties.

Public Policy Options in Response to Sea-Level Rise

Given the potential economic impact and social disruption attendant to a five-foot sea-level rise, one can anticipate that man's response to this phenomenon will be aimed at protecting what has already been built. Consequently, the environmental impacts of man's response to sea-level rise could be greater than the impacts of sea-level rise itself. It must be remembered that the coastal ecosystem is in a natural, dynamic equilibrium. As sea level rises, erosion will attempt to restore that equilibrium. If left unimpeded, sandy beaches will move landward, and marshes and wetlands will be reestablished further inland. Marshes and wetlands will be reestablished at a slower rate than they are destroyed by rising sea level, however, and will be less extensive. Of course, these natural processes will not be left unimpeded. Existing cities, harbors, highways, and other infrastructure, including erosion-control structures, already pose significant physical barriers to this natural restoration of the equilibrium and, given the potential societal impacts, natural restoration would not be socially or politically acceptable.

In general, the two options available in response to sea-level rise are protection, either by beach nourishment or by coastal armoring, or retreat. The coastline of The Netherlands testifies to the fact that it is technically possible to protect areas against sea-level rise; however, once a strategy involving diking, drainage, and artificial shoreline stabilization through beach nourishment or construction of dams, groins, sea walls, and the like is adopted, vested interests will demand its continuation regardless of the cost. By any standards, these costs, in either economic or environmental terms, will not be trivial. Diking and embankment, while relatively simple processes, can themselves cause profound environmental changes and can entail many, usually undesirable, hydrologic and morphologic effects. Drainage canals must be constructed and, because the beneficial effects of flooding are lost, irrigation facilities may have to be provided. Additionally, natural tidal drainage systems will have to be replaced by lift pump drainage. Hydraulic loading on coastal structures such as breakwaters, bridges, and water intakes/outlets will be increased by rising sea levels, requiring that such facilities be reinforced or adjusted. Adding to this concern is the prospect of overtopping and erosion of solid-waste landfills, waste pits, lagoons, and disposal sites in low-lying areas, which will enhance leaching of pollutants from such facilities into surrounding surface and ground waters.

While the spectre of widespread bulkheading, damming, diking, and pumping is truly fearsome, structural protection is almost always technically possible and, in the short term, even necessary; however, in those areas where the long term cost of protection or the environmental damage engendered by it is unacceptable, retreat from the shore will be advisable. Retreat, which will occur either gradually in keeping with some orderly plan or catastrophically as a result of coastal storms, can be accomplished (1) by moving buildings as the shoreline advances, (2) by allowing buildings to be destroyed by storms and the debris removed, or (3) by precluding the construction of buildings near the shoreline in the first place. North Carolina's moving setback requirement for construction projects on the beach based on annual erosion rates is a technically simplistic, but politically progressive, example of the latter. In addition to the anticipatory land-use planning inherent in North Carolina's construction setback requirement, Howard, et al. (1985), recommend that the retreat option also include a cessation of shoreline stabilization efforts and removal of coastal stabilization structures that threaten public safety as well as structures undermined by the sea.

The decision of whether to retreat or protect will necessarily be based on many factors, not the least of which should be the impacts of one particular community's selected strategy on neighboring communities. In the final analysis, however, intense emotionalism, parochial politics, and false economics can be expected to drive the decision making process.

Recommended Actions

Need North Carolina do anything in light of the projected rise in sea level? Can anything be done? The answer to these questions is a resounding yes, but the timing of the state's response will in large part determine its effectiveness. In the short term, North Carolinians will be confronted with the classic dilemma of having to make decisions in the face of awesome uncertainties. The dilemma is this: Should the state take actions now at the risk of incurring economic costs that might later prove to have been unnecessary, or should the state wait for more conclusive information, thereby running the risk that any actions taken later, if still possible at all, will be more costly? Certainly, extremism must be avoided, but so too must delay in policy development. The risk of waiting to form policy until there is complete scientific certainty may be too great and, at the very least, may preclude some policy options that otherwise would have been available.

History shows that decision makers for the most part react only to discrete, clearly recognizable events and rarely to slow cumulative developments. In the case of sea-level rise, reticence on the part of decision makers will be understandable, since any selected strategy, ranging from full protection to full retreat, will have significant and widespread environmental, social, and economic impacts. Marshalling public support for the selected strategy will be difficult, since many of the effects of global climate change will not be clearly evident to society as a whole for at least several years. In fact, the first and perhaps one of the greatest challenges facing policy makers and scientists is to sensitize people to what is occurring and to the difficult choices that must be made.

North Carolina will experience many of the projected impacts associated with global climatic change, for example, impacts on agriculture, forestry, water and air quality, and coastal infrastructure and ecosystems. Accordingly, North Carolina has the responsibility and the opportunity to exercise national leadership in dealing with these phenomena. At a minimum, the state can and should take the following actions:

1. Initiate a risk assessment program to determine the sensitivity of North Carolina ecosystems, agriculture, silviculture, and infrastructure to a wide range of potential climatic changes. This program would include a survey of coastal topography to define those areas most vulnerable to sea-level rise.
2. Enhance research and monitoring of the state's climate.

3. Require development in North Carolina's coastal areas to take into consideration the predicted rise in sea level:
   a. Allow building next to a marsh and anywhere below the five-foot elevation only with the understanding that if sea level goes up, buildings must be moved. This approach would overcome constitutional questions regarding unlawful taking of property and, if sea level did not rise, would avoid costs of overreaction. North Carolina currently does not allow building in the marsh, but construction immediately adjacent to the marsh is permitted; therefore, as sea levels rise, inundated marshes would not be replaced.
   b. Require all project proposals on the coast to consider the various sea-level rise projections and specify what will be done pursuant to each of the projections.
   c. For those coastal projects requiring an Environmental Impact Statement (EIS), require the EIS to to consider the implications of sea-level rise.
   d. Give priority for clean-up to those hazardous waste sites subject to sea-level rise.
4. Assess the environmental, economic, and social implications of climate change in North Carolina and formulate mitigation policy options that are periodically reviewed and updated.
5. Diagnose and periodically reassess the economic, social, and political disruption likely to be caused by the effects of global climate changes, particularly sea-level rise, in North Carolina, and make preparations to mitigate them. Gubernatorial veto authority may be necessary to ensure an adequate and effective response to the implications of global climate change from a coordinated, statewide perspective and as a defense against the plethora of local legislation, aimed at parochial needs, which will be competing for limited resources.

These recommendations, while necessary, are admittedly defensive and reactionary, aimed at addressing the symptoms of climate change, particularly global warming. A concomitant, proactive response to global warming is not only possible but, in the long term, essential. Ultimately, emissions of CO_2 must be reduced through (1) a sustained energy conservation program, (2) a gradual transition from fossil-fuel generation of electricity to alternative sources of energy, including invigoration of the nuclear power industry, and (3) a reduction in, if not an end to, global deforestation. It is unlikely that any measures taken now will reduce the global warming expected within the next few decades; however, whatever steps can be taken to limit global warming should be effected as quickly as possible, if for no other reason than to slow the rate of global warming to provide additional time to study the issues, and thereby make better informed decisions. □

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