GLOBAL WARMING

Impacts on the Transportation Infrastructure

William R. Black

Climatologists and atmospheric scientists have been aware of the "greenhouse effect" for three quarters of a century, yet public concern over its potential negative impact—global warming—began only as recently as the 1970s.

Many analysts argue that it is highly unlikely that the transport sector will convert from its almost exclusive dependence on fossil fuel energy in the next 50 years. Because fully effective emission abatement is not a feasible option, the possible impacts of a warmer globe on the transportation infrastructure are discussed in this article.

The so-called greenhouse gases in the planet's atmosphere, which include carbon dioxide, nitrogen oxides, methane, and chlorofluorocarbons (*1*), allow incoming (shortwave) solar radiation to reach the earth and warm its land masses and waters. This warming of the earth results in the production of (longwave) heat radiation that would normally reradiate into outer space. It is fortunate that the greenhouse gases are less transparent for longwave radiation because this results in the retention of some of the heat in the atmosphere, making the earth warm enough for human habitation. Some scientists believe that if the concentration of greenhouse gases in the upper atmosphere increases, the planet will retain even more of the longwave heat radiation. It is for this reason that some refer to the greenhouse effect as the major cause of global warming. Its basic cause, however, will be the increasing concentration of greenhouse gases produced by human activity.

Although many atmospheric scientists believe that global warming has begun, perhaps an equal number are doubtful that it has or that it ever will. They note the limited knowledge, lack of definitive data, and need for more advanced models in this field. It is assumed here that global warming has begun. Some possible consequences of this potential climate change on transportation are now examined.

Impacts of Global Warming

In addition to increased temperatures, global warming could produce other changes. The sea level could rise as a result of thermal expansion of the oceans and partial melting of the ice caps of Greenland and Antarctica, causing low-lying coastal areas to flood. Perhaps the most significant impact would be changes in regional climates and associated increases and decreases in precipitation; the increases in temperatures could lead in some cases to a higher frequency of droughts and loss of agricultural productivity. These regional geographic changes are the least understood of the impacts anticipated.

Public awareness of the problems of global warming came about in 1988 after

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eight years of very warm temperatures and a drought in the summer of that year. The scientific community held conferences and seminars worldwide in 1988 and 1989 as it began to take another look at this problem and its potential ramifications. A similar reaction occurred after a major U.S. drought in 1977, but the difference this time was that researchers had access to improved global circulation models (GCMs) that would allow them to examine future scenarios.

These models are sophisticated and complex, but they also simplify the actual processes and leave out those that are less understood. For example, it is known that the oceans will absorb carbon dioxide, but it is not certain how this process works, and most of the GCMs do not include it. The models therefore have numerous critics. Nevertheless, they are commonly used to develop forecasts of future climate conditions under different assumptions. One of the frequently used assumptions—and there are many—is the 2 x CO_2 scenario (2, 3). This is a series of projections based on the assumption of a doubling of carbon dioxide (hence 2 x CO_2) in comparison with preindustrial levels by the year 2040. Taking that year as a target date, the models suggest a global temperature increase within the range of 1.5 to 4.5 degrees Celsius and an increase in sea level ranging from 0.3 to 1.2 meters. Regardless of the global temperature forecasts, it is anticipated that the smallest increases will occur near the equator and the largest near the polar areas. If the suggested ranges are accepted, policies should be put in place to deal with impacts on the transportation sector for the high end of the forecast range.

During the past couple of years, researchers have begun to examine the potential impact of global warming on different phenomena (4). The extent to which this problem will affect transportation is a subject of recent research and discussion. Although the focus of the following comments is transportation in the United States and Canada, the general (as opposed to regional) inferences also apply to other areas of the world.

Nature of the Impacts

For convenience, the effects of three different classes of global warming impacts on transportation are addressed: (a) temperature and precipitation; (b) water and sea level change; and (c) abatement. Temperatures will increase globally (although not in a uniform way) and precipitation may increase in some areas and decrease in others. Ocean levels will rise globally by a uniform amount, but inland waterways, rivers, and lakes will rise or fall as a function of changes in precipitation, runoff, and evaporation. Abatement impacts will result in technological changes or changes in use that will affect transportation as governments begin to address the problem of how to decrease greenhouse gas emissions. Extreme abatement strategies could lead to large economic and social impacts.

One or more of these impacts will affect each transport mode, but may not cause the major impact on transportation. Regional economic changes in existing patterns of production and consumption of fossil fuels that will result from increases in temperature, changes in precipitation, and long-term decreases in fossil fuel production will most likely produce the greatest impacts on transportation.

Major Impacts on Transportation

While occurring gradually, the impact of long-term global warming in North America could be a major disruption of the flow of goods and people caused by substantial changes in the volume of flow between exisiting origins and destinations. The exact location of these changes is not known, but some inferences are possible. Many scientists believe that there will be significant increases in temperature in areas such as the Great Plains, resulting in a northward shift of agricultural production. Many U.S. producers have been using aquifers to irrigate, but increases in temperatures will make this impractical in the short term and impossible in the long term. Although heat-resistant strains of different grains are being developed, it is unlikely that even they will be productive in the southern parts of the region. In addition to changes in agricultural production, U.S. regions specializing in fossil fuel production may


POLICANSKY

During next century, on low-lying islands of East Coast, such as this setting for North Carolina's Cape Hatteras lighthouse, sea walls may need to be constructed to keep roads clear of sea water.

experience significant changes in demand for their product as attempts to decrease carbon dioxide emissions begin.

Metropolitan areas in water-deficient regions of the United States will also feel the effects of global warming. In particular, areas of the U.S. Southwest may find that regional water supplies are insufficient to meet long-term needs. The construction of plants to desalinate ocean water in the coastal areas of these regions may offset this problem.

The northern part of the continent will also undergo significant changes caused by temperature increases. Canada expects significant increases in population settlement and agricultural production in the northern sections of all of its provinces (2). Researchers expect the existing highway and rail systems to expand to meet this need.

Streets and Highways

The most obvious impact of temperature and precipitation changes on highways will be the need to relocate some of them away from coastal areas to prevent inundation by sea level rise. In the near term these facilities will not necessarily become flooded because of sea level rise, but may flood during storm surges. Roads, streets, and causeways on some islands along the East Coast may need sea walls to keep out the ocean waters.

The potential problem is shown in Table 1. The table includes selected coastal cities of the United States along with their average elevation and tidal levels in meters and feet, both above mean tide. The third column of numbers represents the tidal level after the addition of the 1.2 meter rise in sea level. One of the problems with these data is that tides are not constant throughout the month and during the year; for example, Boston's high tide varies from 2.3 meters to 3.7 meters. In addition, the average elevation is not a good index of the threat from sea level rise because it often incorporates far more than the coastal area. In areas with little local relief (such as Atlantic City, New Jersey; Charleston, South Carolina; Gloucester, Massachusetts; and Miami, Florida) the index can be quite accurate. Adding the projected sea level rise to these figures illustrates the nature of the problem. If the possible surge activity that might accompany storms is taken into consideration, the need for measures to prevent the flooding of local roads becomes obvious.

TABLE 1 Average Elevation, 1990 Tide Height, and Estimated 2040 Tide Height for Selected U.S. Coastal Cities

CITY	ELEVATION[a]	1990 TIDE HEIGHT[b]	2040 TIDE HEIGHT[c]
Portland, Maine	7.62 (25)	1.49 (4.9)	2.68 (8.8)
Boston, Mass.	8.23 (27)	1.58 (5.2)	2.77 (9.1)
Gloucester, Mass.	3.35 (11)	1.46 (4.8)	2.65 (8.7)
New Bedford, Mass.	4.57 (15)	0.73 (2.4)	1.92 (6.3)
Providence, R.I.	24.38 (80)	0.85 (2.8)	2.04 (6.7)
New Haven, Conn.	12.19 (40)	1.10 (3.6)	2.29 (7.5)
New York, N.Y.	9.14 (30)	0.82 (2.7)	2.01 (6.6)
Atlantic City, N.J.	3.05 (10)	0.76 (2.5)	1.95 (6.4)
Philadelphia, Pa.	13.72 (45)	1.07 (3.5)	2.26 (7.4)
Baltimore, Md.	6.10 (20)	0.36 (1.1)	1.52 (5.0)
Norfolk, Va.	3.66 (12)	0.58 (1.9)	1.77 (5.8)
Charleston, S.C.	2.74 (9)	0.94 (3.1)	2.13 (7.0)
Miami, Fla.	3.05 (10)	0.52 (1.7)	1.71 (5.6)
San Diego, Calif.	12.80 (42)	0.94 (3.1)	2.13 (7.0)
San Francisco, Calif.	19.20 (63)	0.91 (3.0)	2.10 (6.9)
Astoria, Oreg.	5.79 (19)	1.37 (4.5)	2.56 (8.4)
Seattle, Wash.	38.10 (125)	1.80 (5.9)	2.99 (9.8)
Anchorage, Alaska	35.97 (118)	4.27 (14.0)	5.46 (17.9)
Juneau, Alaska	30.48 (100)	2.53 (8.3)	3.72 (12.2)

[a]Average elevation in meters (feet) (*10*). (Conversion from feet to meters by the author.)
[b]Tide height in meters (feet) above mean sea level on May 1, 1990.
[c]Expected tide height in meters (feet) above current (May 1, 1990) mean seal level.

Increasing winter temperatures will also result in other impacts: decreases in snow removal costs in the United States and southern Canada, and potential increases in these costs in the northern part of the Canadian provinces because of greater winter snowfall and more human activity in those regions (2). The areas less affected by snow should also see a decrease in chemical pollution caused by salt and other chemicals used for snow removal, possibly resulting in longer motor vehicle life because of less chemically induced rust. On the other hand, the likely introduction of these chemicals into the more pristine environments of Canada as transportation facilities expand northward may be harmful to those areas.

Higher summer temperatures will result in a different set of problems. The major automotive pollution episodes that occur in most cities during hot weather could certainly be aggravated by the extended length and intensity of the summer. The result will probably be calls for regulating the amount of driving, the length of the journey to work, or similar actions.

Longer and higher-temperature summer heat waves in the southern United States will result in "heat buckling" of highways. Higher temperatures may also begin to melt the permafrost beneath roads and highways in northern Canada and Alaska, causing subsidence. Recreational traffic volumes and accidents in Canada may increase as residents of the United States seek cooler summer retreats.

Water

Ocean transport will experience impacts resulting from both temperature increases and sea level rise (5). The major change caused by rising temperatures (aside from sea level rise) will be the melting of ice in oceans in northern regions. This will increase the length of the ocean transport season, raise the number of ice-free ports, and perhaps allow the movement of marine vessels along Canada's northern boundary. The latter will require outlays for navigational aids (such as lighthouses, ice breakers, and coast guard patrols) for the new shipping routes. Sea level rise will probably create the need for improvements in existing harbor and port facilities to handle higher tides.

Global warming will also affect lake and river transport, although in quite a different way from ocean transport. For North America, the major positive impact on inland water transport will be the decrease or elimination of water freezing in the St. Lawrence Seaway, which will allow use of this system during the entire year. Given constraints on the size of ships that can use the seaway, this may be the only way that the volume of traffic can be increased. The picture is not as bright for the Mississippi River system if the summer of 1988 is any indication. Decreasing water levels caused by drought in the central United States all but stopped commercial shipping on the river during that year. The response at the time was the dredging of a channel to allow barge movement. Long-term channelization of this system may be necessary if precipitation levels fall enough to warrant it.

An increase in winter navigation because of a decrease in ice should occur on the Great Lakes. However, because of the decrease in precipitation as well as the increase in evaporation, researchers expect that the level of the western lakes may fall. Canada is considering the construction of structures to maintain lake levels, but it is not clear how they would work (2). Without some system of water level maintenance, considerable dredging and port modifications will be necessary on the Great Lakes.

Expected sea level rise in next century requires substantial investments in existing harbor and port facilities to contend with higher tides.

Rail

As is true of highways, many rail lines skirt the coastal areas of North America, and relocation of some of these lines may be necessary, particularly on the East and Gulf Coasts of the United States. Permafrost may underlie portions of rail lines built in the vicinity of Yellowknife and the Great Slave Lake in Canada's Northwest Territory and sections of the Alaskan Railroad. As noted for highways, the thawing of this permafrost will cause ground subsidence and require major rehabilitation of track and rail facilities.

Changes in the rail system of North America are likely as Canada expands the density of its system in the midwestern provinces and the United States decreases the density of branch lines in the lower Great Plains. In each case, the primary cause of these changes will be transport market shifts caused by temperature increases that affect agricultural productivity.

Rail rapid transit systems in areas such as New York and Boston may encounter some difficulties because of sea level rise. Most of these problems will be manageable without major capital outlays.

Air

In several cases, local authorities built airports on once-swampy coastal areas of North America filled for this purpose. Logan Airport in Boston and National Airport in Washington, D.C., are examples. As a result, these areas may not be high enough above sea level to withstand surges from major ocean waves during stormy periods. Such situations may also require the construction of sea walls.

Canada expects increased contact with the northern areas of its provinces because of new development and the bulk of this will most likely be undertaken by float planes. Such aircraft, which are popular in Canada, will have a longer season of use with decreases in the period when northern lakes are frozen.

Jet aviation may experience some regulatory pressure because of the emission of greenhouse gases. The extent to which the industry can respond with "cleaner" fuel will determine the size of this problem. At the same time there is growing concern that jet aircraft may be contributing to high-altitude cloudiness from contrails, which may also enhance global warming (6).

Abatement

Many of these impacts and changes appear to reflect a willingness to surrender to the inevitable. Although halting the buildup of greenhouse gases from the transport sector is also an option, it no longer appears to be a feasible solution. Abatement in the sense of slowing the rate of increase is still possible even though it is extremely difficult to get developed countries to agree on curtailment measures. Any action taken to reduce future emissions will doubtless meet with equal opposition from developing countries because of their wish for further economic growth. In effect, high emissions from developing countries may offset any abatement action taken by developed nations. At worst, the increase in emissions from these emerging nations may result in an increase in the global emissions trend. Nevertheless, the introduction of various abatement practices over the next few decades is anticipated as governments attempt to ensure that the impacts described here are worst-case scenarios, and not significant understatements of the possible impacts.

Abatement actions or policies in the transport area include shifts to alternative fuels, changes in mode use, increases in vehicular operating efficiency, and conservation measures. These would, without a doubt, involve high social costs.

Shifts to Alternative Fuels

Transport accounts for 27 percent of global energy used, with virtually all of this derived from petroleum. Energy for transportation in the United States accounts for 27 to 30 percent of all energy consumed. The range difference is explained by whether the secondary use of energy (usually in the form of electricity) to power electrified rail lines of the northeast United States and metropolitan rail rapid transit systems is included.

Most U.S. transport energy comes from fossil fuels, and this sector accounts for about 34 percent of the greenhouse gas emissions. Existing nuclear and hydroelectric power sources, which account for about 12 percent of total U.S. energy production, do not release greenhouse gases.

Because of the importance of transportation fuels in greenhouse gas emissions, it is reasonable to look at the extent to which switching to alternative fuels could reduce these emissions. One such fuel is methanol. The most probable source (feedstock) for methanol production would be natural gas. This would result in emissions that would differ little from the use of gasoline. Using coal as a feedstock would roughly double greenhouse gas emissions. Methanol or ethanol production can use biomass; the following comments related to ethanol are also applicable to methanol derived from lignocellulosic biomass (e.g., wood, wood waste, or other agricultural residues).

Compressed natural gas is already in use in parts of Canada, New Zealand, and Italy. It is considerably cleaner than gasoline in hydrocarbon and carbon monoxide emissions, but only about 10 percent cleaner than gasoline in carbon dioxide emissions. Potential leaks of natural gas, primarily as methane, during production, distribution, or refueling could offset the slight advantages from its use in decreasing global warming (4).

Ethanol is likely to use biomass as a feedstock. At present this biomass is produced from corn and sugar cane, and this causes some concern about competition with food production. It is also not clear what changes may occur in the availability of these crops. The dominant production region for corn is a drought-prone area of the Midwest, and the major production region for sugar cane is the Mississippi Delta area, which may experience problems with sea level rise. These points aside, carbon dioxide emissions from ethanol are less per mile than gasoline, but total emissions are a function of the distillation process used for ethanol production and the efficiency of biomass production.

Electricity has potential as a transport fuel because it has virtually no emissions. However, if electricity production uses oil, coal, or natural gas, it could end up as a far less attractive option. Widespread use of nuclear energy for electricity production given existing technology and public opinion does not seem likely. If added to this are the limited range of these vehicles, lower speeds, and recharge periods of up to eight hours, the likelihood of electric vehicles helping to reduce future greenhouse gas emissions all but disappears.

Hydrogen-powered transport vehicles hold some promise as a partial solution to the greenhouse gas problem. Combustion of hydrogen produces water vapor and certain oxides of nitrogen that may increase global warming, but less than other gases. Production of hydrogen would require electrical power. Most assume that this power will come from solar energy. So the viability of hydrogen as a "cleaner" transport fuel awaits the development of solar energy as an electrical production method because most other production techniques have the drawbacks already noted. [See DeLuchi et

AMTRAK

Relocation of highways and rail lines in coastal areas would be a probable response to expected sea level rise.

al. (7) and Saricks (8) for further discussion of these fuels.]

In summary, alternative fuels do not seem to offer much potential for a significant reduction in greenhouse gas emissions in the near future. Vehicular transport is increasing annually and there is a slight possibility that the use of certain alternative fuels could offset what would otherwise be an annual growth in greenhouse gas emissions from the transport sector. Reducing these emissions below current levels seems unlikely, and considering the global increase in transport emissions, the use of alternative fuels will probably do little more than slightly delay the process of global warming.


BALDERSON INC.

Global warming is expected to decrease snow removal costs in the United States, but increase such costs in Canada.

Mode Shifts

Methods of implementing a policy of shifting riders from personal automobiles to mass transit include the use of exclusive bus lanes, charging higher bridge tolls for low-occupancy vehicles, taxation of parking facilities and gasoline resulting in higher charges for automobile use, rationing gasoline, and providing high-quality transit service. Unfortunately, most urban areas do not have a transit system that attracts riders to mass transit.

Proposals for high-speed rail passenger service offer alternatives to some of the current air passenger travel in North America. High-speed rail is a viable alternative in selected areas such as the West Coast, the Northeast, and perhaps along a New York-Chicago corridor. However, a high-speed North American rail system would generate construction costs far beyond those considered realistically in the near future.

Increased Vehicle Efficiency

Numerous ideas are circulating about increasing the operating efficiency of major transportation modes. It has been observed that such increases in efficiency will decrease greenhouse gas emissions. Among the ideas are more streamlined automobile bodies, improvements in automobile tires, or automotive engines designed to use fuel more efficiently. The list goes on. Although some argue that efficiency improvements would add substantial reductions of emissions, in the opinion of the author the most reasonable changes have been implemented during the last 10 years. Also, there is a belief that increases in travel will offset any further decreases in emissions caused by efficiency changes.

Air transport made significant strides in reducing emissions per passenger during the 1980s. This appears to have resulted from a combination of more passengers on fewer planes, abandonment of service to nonviable markets, and significant improvements in engine performance.

The possibility does exist to decrease the demand for some personal transportation through substitution of communication. The United States has one of the most advanced and efficient telecommunications systems in the world, capable of voice, data, visual image, and computer file transmission. Nevertheless, the growth of several express mail services in this country has occurred during the past decade almost in contradiction to communication capabilities. Communication will continue to play a minor role in decreasing the level of demand for transport.

Conservation Measures

It should be possible to decrease greenhouse gas emissions from the transport sector through conservation. The gasoline shortage of 1975–1976 demonstrated that the United States is capable of conserving fuel and therefore decreasing emissions. However, without a visible problem it appears that the need to conserve rapidly disappears. Global warming is not currently viewed as a significant enough problem by most individuals to yield a successful conservation program.

Conclusion

In the examination of one of the more extreme scenarios of global warming, it has been assumed that little, if anything, will be done to control the emission of greenhouse gases during the next 50 years. Although some might say such an assumption is unrealistic, it is also unrealistic to assume that abatement measures started in the year 2025 will have any impact on the problems outlined here.

Although it may be argued that global warming needs further study before governments act to lessen its possible impacts, the scientific community is beginning to discuss adapting to those impacts (3). Global warming, with its rising temperatures and sea levels, dropping lake levels, droughts, and disturbance of existing commodity flow patterns for grains and fossil fuels, could have a serious effect on the transport sector. Avenues for abatement of these impacts do not seem to offer much hope for control of the total problem, but research must continue in this area. To mitigate the likely impacts on all sectors, something must be done to lessen the trends in greenhouse gas emissions.

Within the field of transportation research it is not too early to begin more detailed studies of the probable impacts of global warming and adaptation to those impacts. This is consistent with the national transportation statement released this year (9), which states that it is the federal transportation policy to "participate in national and international review of and research on transportation-related environmental issues, such as global climate change."

NRC Panels Support Global Change Research Program, Urge Development of Integrated Global Observational Strategy

The federal government's plan to better understand natural and man-made influences on global environmental change—including changes in global temperature and climate, atmospheric composition, oceans and biosphere, and the earth's energy balance—represents "unprecedented" interagency cooperation and "reflects the priorities established by the scientific community" for global change research. These conclusions were reached by two panels of the National Research Council and published in a report requested by the White House Office of Science and Technology Policy.

The proposed program of observation, computer modeling, and other research is seen as a first step that requires initial heavy investment in the Earth Observing System (EOS), the space-based part of the program that provides long-term observations "essential" to global change research. Maintaining a balanced, long-term program will require substantial growth in funding for process studies and computer modeling. The program could also benefit from development of an overall strategy for integrating observations made from space with those made from earth.

Plans for EOS currently include the placing of two large platforms, EOS-A and EOS-B, in polar orbit. The report supports the development of EOS-A, but suggests that some instruments planned for EOS-B could be flown on several smaller, independent satellites, possibly launched earlier. This change would make the EOS system more responsive to goals set by the scientific community, the report states. Noting the complexity of the mission, the report also recommends more comprehensive contingency plans in case of instrument or satellite failure.

NASA plans a number of other missions before the first EOS satellite is scheduled for launch in 1998. The report recommends that these missions should go forward even if the first EOS launch is delayed by budget constraints.

The U.S. Global Change Research Program (USGCRP) mechanism for maintaining and integrating the diverse data needed for global change research is the EOS Data and Information System (EOSDIS). The scope and complexity of this system "far exceeds that of any existing civilian data management system," according to the panel.

Both panels stressed that thorough review and oversight by independent scientists is crucial to the success of the USGCRP.

The panel that reviewed the USGCRP was chaired by John A. Eddy, University Corporation for Atmospheric Research, Boulder, Colorado. The panel that reviewed EOS in the context of the USGCRP was chaired by D. James Baker, Jr., Joint Oceanographic Institutions, Inc., Washington, D.C.

The report of the panels, The U.S. Global Change Research Program: An Assessment of FY 1991 Plans, *is available for $15.00 (prepaid) from the National Academy Press, 2101 Constitution Ave., N.W., Washington, D.C. 20418 (telephone 202-334-3313 or 1-800-624-6242).*

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