ENERGY AND ENVIRONMENT

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Introduction

The World Resources Institute is located in Washington and is a non-profit policy research center funded mostly by private foundations, with some money from United Nations Environmental Program and some from EPA. There is also some support from a few foreign governments to work on projects such as improved natural resource management in Africa. I work in the climate-energy-pollution program.

I would like to begin by first posing a question to you all. What do the following countries have in common: the USA, Holland, Japan, England, Soviet Union, and France? The answer is they are all having international conferences on the global environment within a period of about one year, which tends to support the comment that environmental issues are making a comeback. I think they are coming back with a vengeance that is going to shake us all up.

In preparing for this, I was planning to tell you a little about what I think are going to be the direct effects of climate change on energy use and on aviation over the next couple of decades. But the more I listened to previous speakers, the more I was thinking that "business as usual"--as I heard it described--is not going to be the case at all. Things like global warming are going to affect us in profound ways with impacts on water supply, agriculture, resource management, wildlife, and energy supply. Energy is a $450 billion a year business here, and it is going to change pretty quickly if we are going to cope with climate change. I see a lot of turmoil over the next few decades because the problem will get progressively more threatening. I am not at all sure that the sort of evolutionary future that we have heard discussed here is actually going to be as evolutionary as one thinks. I think it is going to be much more revolutionary.

Greenhouse Warming Effects

Let me quickly run through for you some of the expected impacts of greenhouse warming and how they relate to our energy supply and how I think these impacts are going to affect aviation.

First of all, no one can say for sure that the effects of greenhouse warming have arrived, but there are a number of signs that are consistent with it. We know that the earth has warmed five to seven tenths of a degree Celsius over the past century though the average global temperature has not always gone up monotonically. The six warmest years of the past century have all occurred in the 1980s. Sea levels are rising at an accelerated rate. The depth to the permafrost is getting deeper suggesting that the earth at higher latitudes is warming. Canadian lakes are warming and, worldwide, glaciers are retreating. James Hansen of NASA's Goddard Institute for Space Studies says he thinks the greenhouse signal will be clear within the next decade.

Principal Greenhouse Gases. The five gases that people worry about most are carbon dioxide, ground level ozone, CFCs, Methane, and nitrous oxide. I think carbon dioxide (CO_2) is the one that will be of primary concern to aviation. Ground-level ozone is not so much a problem for airplanes. CFCs are not too relevant. Methane and nitrous oxide arise primarily from biological and natural sources (e.g. methane arises from coal mines, rice growing, cattle, and from the warming tundra. Nitrous oxide arises primarily from fertilizers and from forest clearing.)

CFCs, chlorofluorocarbons, are a class of inert, non-toxic but very stable compounds used in air conditioning, refrigeration, as cleaning solvents for electronic components, and as foam blowing agents. CFCs are depleting the ozone layer in the stratosphere, and they persist in the atmosphere for several hundred years. We are going to have to find substitutes which will be shorter lived. The CFCs are also very potent greenhouse gases in addition to being ozone depleters, and that is another reason why they are of concern.

If you look at the expected global warming from the buildup of these 5 gases, the trend is not at all encouraging. (See Figure 1.) CO_2 accounts for about half the global warming problem now. It will be about a third of the problem several decades from now. This projected warming does not take into account the Montreal protocol which should reduce the expected CFC warming. Nonetheless, the picture is one of permanent incremental warming each decade. This is going to affect things in ways not seen for tens of thousands of years.

How Transportation Contributes to Global Warming. Let's look at where the CO_2 is coming from in this country. The two biggest sources are electric utilities, the largest source at about a third of total emissions, and transportation, which is about 31 percent. With the virtual abandonment of nuclear power, the utilities are pretty much hooked on coal. And transportation is essentially 97 percent dependent on oil. No surprises there. Industry and buildings account for a smaller and diminishing fraction of CO_2 emissions. That is because the U.S. economy is becoming more electrified.

If you look at U.S. sources of energy and CO_2 you see that oil supplies about half of our fossil fuel energy and accounts for about half of our CO_2 emissions. Coal and natural gas account each for about a fourth of our fossil energy supply but coal accounts for a much larger fraction, about a third, of our carbon dioxide emissions. (See Figure 2.)

The reason for that is very straightforward. It is because of the high hydrogen content of the natural gas, and the relative lack of it in coal. A lot of energy is released from burning hydrogen when you use natural gas. If you take natural gas as 100 units of CO_2 per unit energy, then oil releases about 40 units more, and coal about 75 units more CO_2 than natural gas. This is the reason why natural gas is now being pushed as a substitute for coal in power generation; it releases much less CO_2 per unit of energy.

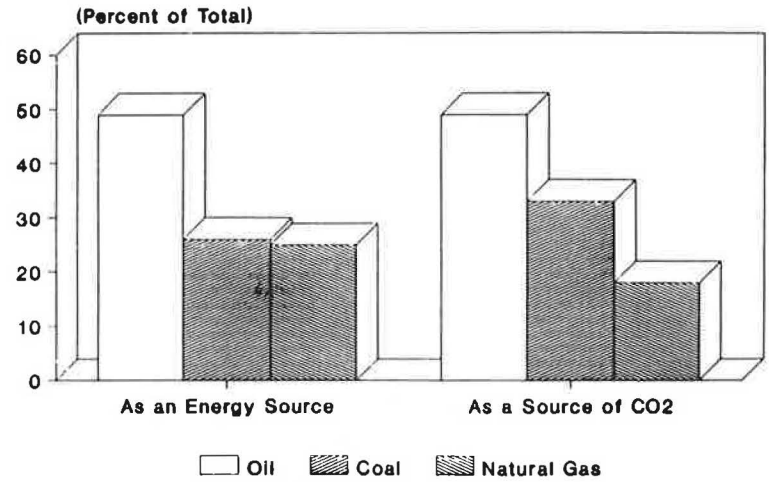

FIGURE 1. Fossil Fuel Sources and Carbon Dioxide Emissions

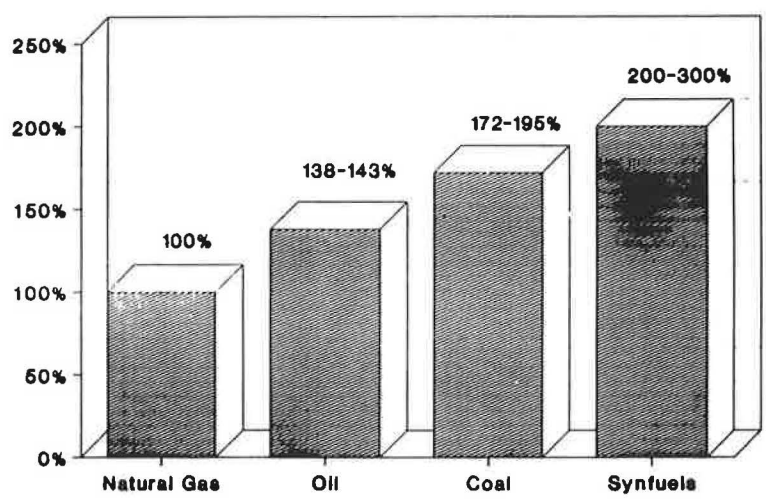

FIGURE 2. Relative Carbon Dioxide Emissions
(Natural Gas = 100)

If you look at the national emissions of CO_2 over the past 15 years, they basically reflect the price of oil. (See Figure 3.) Emissions went down after the first oil shock. As prices dropped, in constant dollars, emissions went up. In 1979, they started down again and, lo and behold, with low oil prices, they are have been going up again. So we have not done badly over the past 15 years but we must recall that the U.S. accounts for a fourth of global CO_2 emissions.

If you break it down and look at the sector trends, you start seeing where the problem lies. (Figure 4.) The fastest growing source by far is electric power generation. Utility emissions have gone up substantially over the past 15 years. Right behind is transportation. As I said, emissions from buildings and industry have gone down. This trend reflects the electrification of the economy, the substitution of electricity for the direct use of fuels. Electric utilities are burning about 75 percent more coal now than they did 15 years ago, and if it were not for the increased use of nuclear power, we would be emitting far more CO_2 than what we do now.

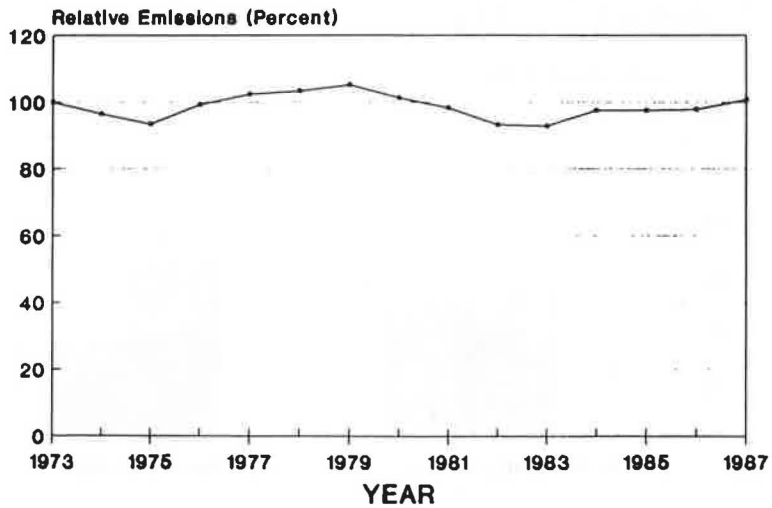

FIGURE 3. Total U.S. Carbon Dioxide Emissions
(1973 = 100%)

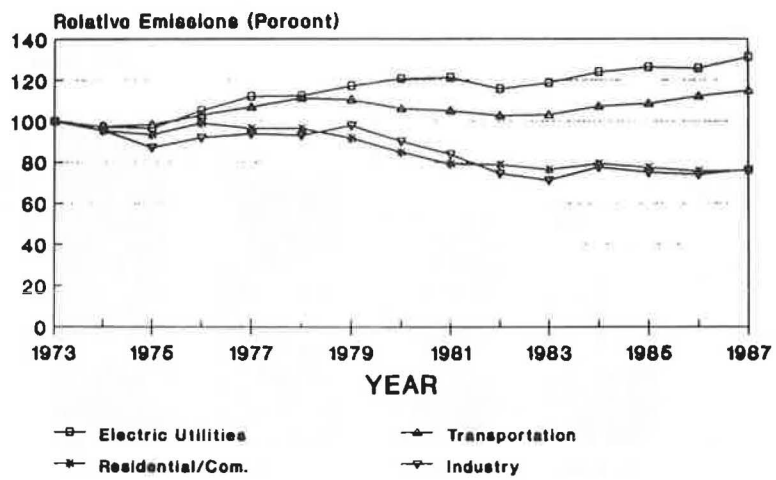

FIGURE 4. U.S. Carbon Dioxide Emission Trends
(1973 = 100%)

So transportation is, as you see, going up quite substantially. If you look at who accounts for the oil used in transportation you see that cars are the largest source, trucks are second, and planes are third. (Figure 5.) So airplanes are a part of the problem. Not the dominant source of the problem, but they are going to feel the impacts of policies to reduce CO_2 emissions.

If you look at total trends in oil use in transportation over the past 15 years, you see that oil demand has gone up, and it has come back down again. Aviation use -- and I am using jet fuel as the primary indicator for airplane fuel use -- has not changed very much. (Figure 6.) But if you look at trends over the past few years, you see that consumption is in fact beginning to rise, and that jet fuel demand has gone up by about 30 or 40 percent over the past few years. (Figure 7) So air transportation is not an insignificant part of the greenhouse problem.

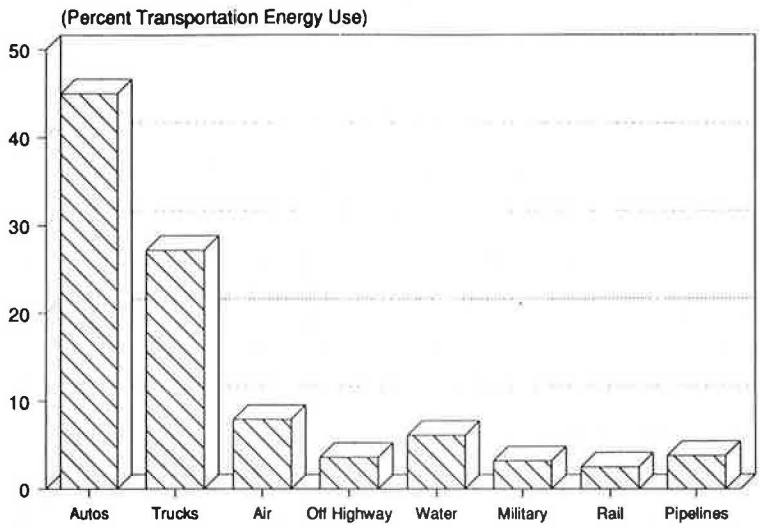

FIGURE 5. Fuel Use By Mode

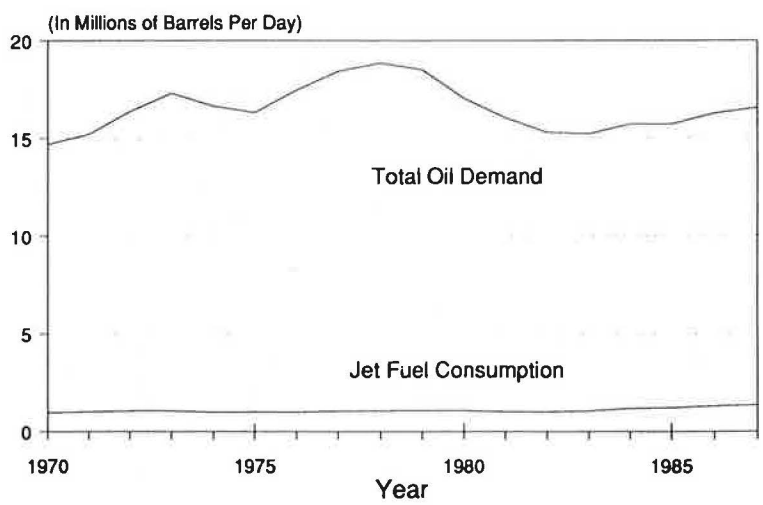

FIGURE 6. Trends in Jet Fuel and Total Oil Consumption in the U.S.

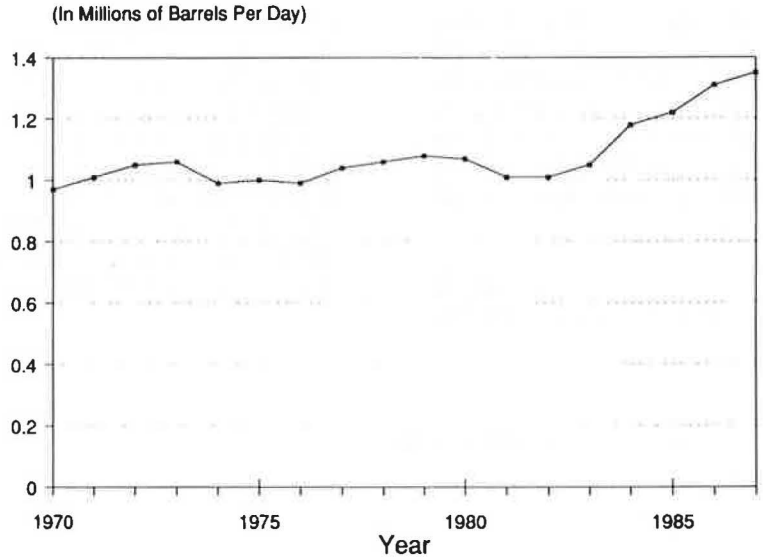

FIGURE 7. Jet Fuel Consumption

Impacts of Greenhouse Warming. Let me summarize some of the effects of greenhouse warming. I am going to describe some of the direct impacts of greenhouse warming on airports. These may be summarized as follows:

SOME EXPECTED IMPACTS OF GREENHOUSE WARMING

- **Higher temperatures, greater summer power demands, reduced cooling-water availability**
- **Worldwide shifts in rainfall patterns, monsoons, ocean currents, altered river flows, disruption of river and lake transportation**
- **Decline or loss of ecosystems that are unable to move or adjust to climate changes**
- **Dryer Midwest, Southeast, lower crop yields**
- **Sea level rise, erosion of beaches and coasts, damage to cities, ports, and other coastal structures, salt-water intrusion into coastal water supplies, flooding in low-lying countries, decline of fisheries with loss of coastal marshes and wetlands**
- **Stronger hurricanes, more weather extremes**
- **Melting of West Antarctic ice sheet (long-term threat) raising ocean levels many feet, submerging most coastal ports**

We can expect higher temperatures, shifts in rainfall patterns, a decline in ecosystems, and a rise in sea levels. Now, a lot of airports are at sea level: Hawaii, San Francisco, Boston, New York, so this is something you want to start thinking about. Sea levels 15,000 years ago were substantially lower than they are now because much of the northern hemisphere was covered with ice. As temperatures rose and the ice melted, sea levels rose and gradually levelled off. (Figure 8)

Figure 9 shows the recent trend in ocean levels. Sea levels are going up two to three millimeters per year. That does not sound like much, but it turns out that for every unit increase in the ocean level, the coast can erode back by a factor of 10 to 100. Coastal erosion, of course, may not necessarily apply to airports because of the way they are built.

The pluses on the chart indicate a rise in sea level and the minuses are decreases. There are two other factors reflected here besides the expansion of the oceans. There is subsidence due to oil and gas depletion, for example, off Louisiana where the sea level is rising, relatively, a centimeter a year. And there can also be coastal uplift from a glacial rebound which can give you the negative values. But by and large, the oceans are rising, there is no question about it, and there are the implications for airport planning.

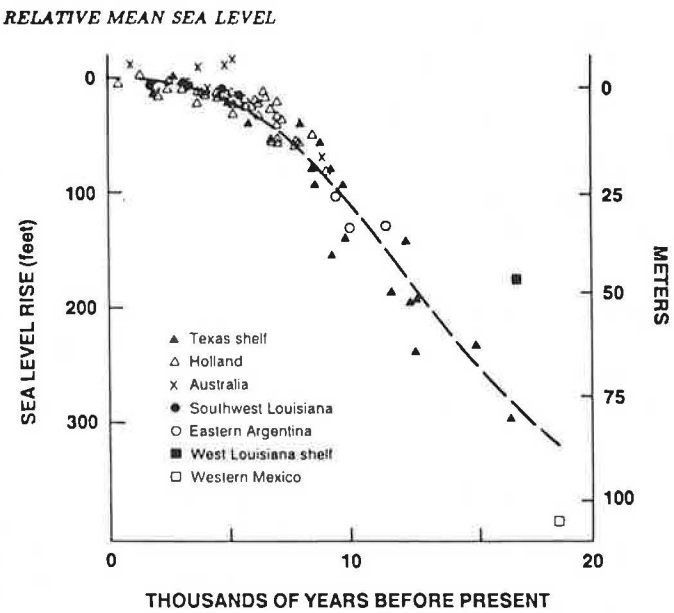

FIGURE 8. Sea Level Elevations vs. Time
(Obtained from Carbon 14 dates in relatively stable areas.
Adapted from Shepard - 1963)

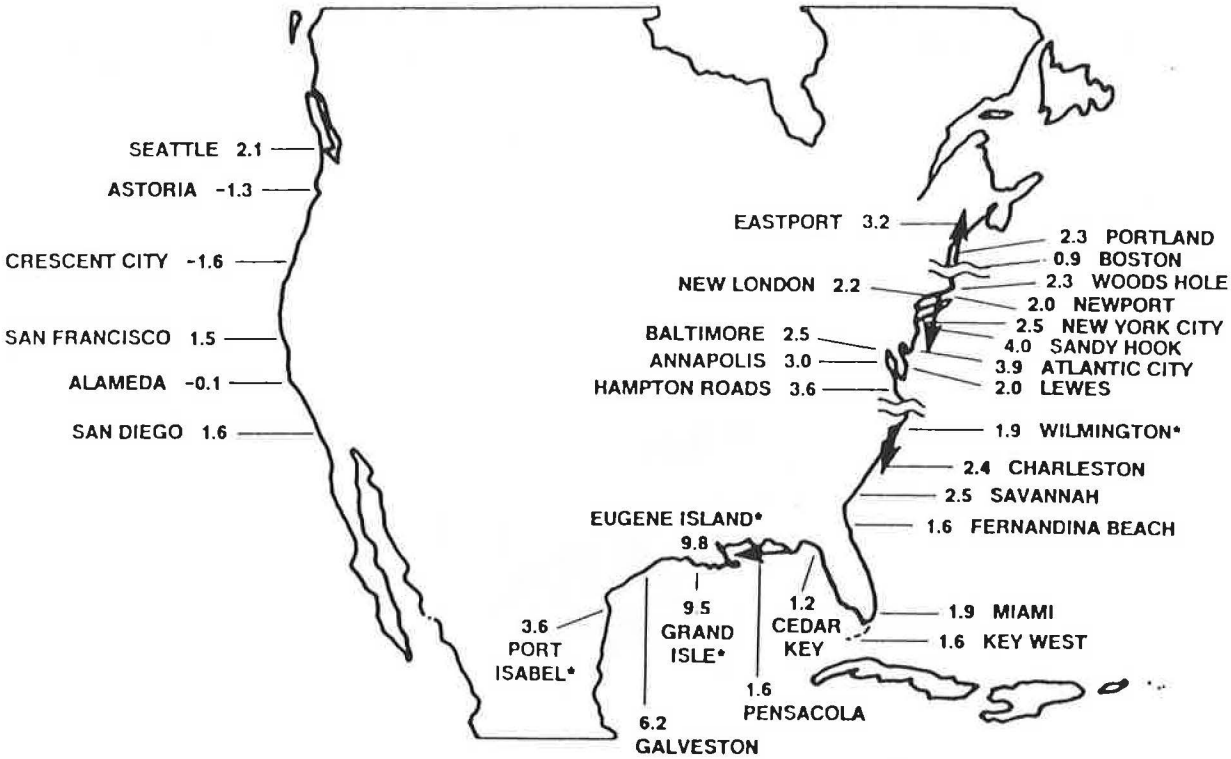

FIGURE 9. Local Relative Sea Level Changes*

*A summary of the present best estimates of local relative sea level changes along the U.S. continental coastline in mm/yr. The figures are based on the tide guage records over different intervals of time during the period 1940 - 1980.

Globally, the oceans have risen by about five inches over the past century and they are rising now two to three millimeters per year and accelerating. They could rise by four inches in the next 25 years and by up to one to three feet by the year 2100. Coastal airports are in low areas, and this has got to be taken into account in long-term planning. Some factors to consider are the following:

AIRPORTS AND SEA LEVEL RISE

- **Globally, oceans have risen by 5 inches over the past century. They can rise by 4 inches in next 25 years.**
- **They are now rising 2 to 3 mm per year.**
- **They could rise by 1 to 3 feet by 2050.**
- **Many coastal airports are located on low, filled-in land: Logan, LaGuardia, San Francisco.**
- **Rise of the sea level needs to be considered in long-term planning. Mitigation will be site-specific.**
- **There should be tide gauges at all major coastal cities with airports to monitor trends in sea level rise.**

One of the other effects of greenhouse warming is going to be an increase in tropical storms which will exacerbate the impacts of rising sea levels.

The last recommendation on the list is from a National Academy of Sciences report on sea level rise from about two years ago. They recommended that there be much more careful monitoring of sea levels at all major coastal cities, especially those with airports. By the way, rising oceans are going to have a big effect on places like Bangladesh and Egypt and other countries that are low. Holland is going to have to be very careful. I do not mean to downplay it, but the U.S. problem is not so big. We can cope with it.

Energy Security. When we get to energy supply and how it is going to be affected by greenhouse warming, I think we are getting into a much more interesting and much more rapidly changing problem than two millimeters per year of ocean rise.

About 42 percent of our energy supply is oil, and fossil fuels account for 90 percent of all our energy. (See Figure 10.) Our oil is increasingly being imported, and the underlying reason is very straightforward. We do not have much oil. The United States and Canada account for about 30 percent of world oil demand but have only about four percent of global oil reserves. Most of the world's oil is in the Middle East. (Figure 11)

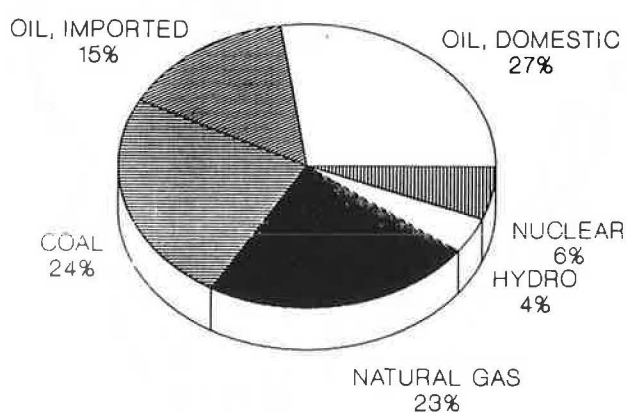

FIGURE 10. U.S. Source of Energy (1987)

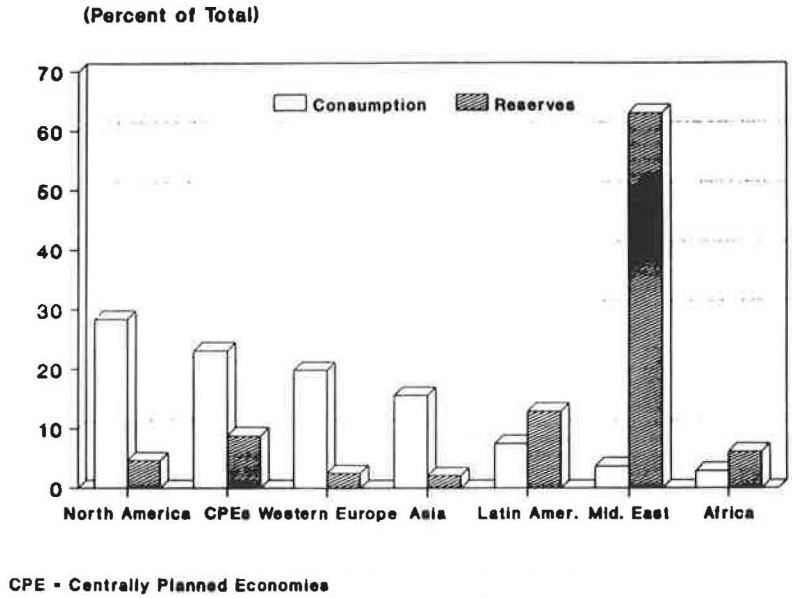

FIGURE 11. Global Oil Consumption and Reserves (1987)

Globally, OPEC has about two-thirds of global reserves. U.S. domestic production is declining and imports now account for 37.5 percent of our oil supply. (See Figures 12 and 13.) According to the Department of Energy, imports could reach 50 percent of supply by the mid-1990s, and they could be 75 percent by the turn of the century. I believe that OPEC will be back in control of world oil prices by sometime in the 1990s, simply because many of the other sources of oil such as the Soviet Union, are near their peak. Production from Prudhoe Bay also appears to be declining. The result is that more and more importers will be going to the same source, the Middle East.

Let me tell you why I think the U.S. is not going to do much better in expanding its domestic oil supply. You perhaps know of M. King Hubbert, a well known geologist now retired from Shell and the U.S. Geological Survey. Hubbert observed some time ago that if you depend on a non-renewable resource, eventually you use it up. Figure 14 shows cumulative consumption of a non-renewable resource. As you use it up, the price rises and you have to substitute something else for it. If you plot U.S. lower-48 oil production it follows perfectly such a curve (See Figure 15.) The squares give you the actual data for U.S. cumulative oil production for the lower 48 states. They lie perfectly on a logistic curve. If you take the derivative of this curve you get annual production.

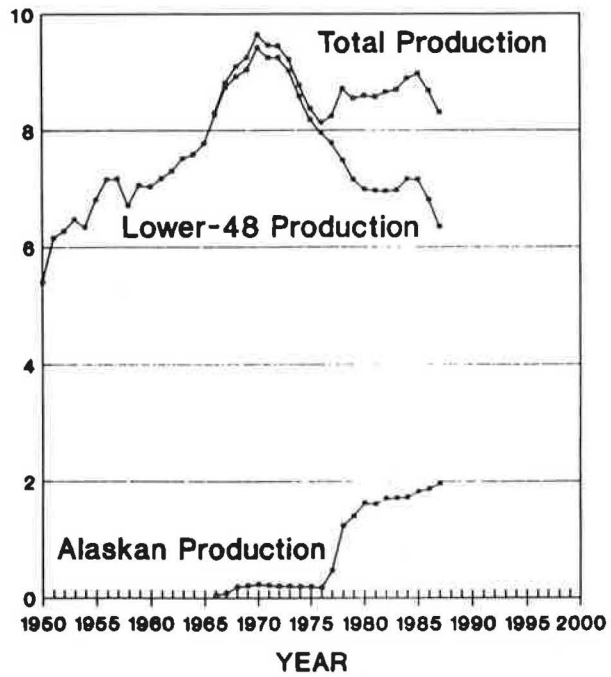

FIGURE 12. Trends in U.S. Oil Production (in Million of Barrels per day)

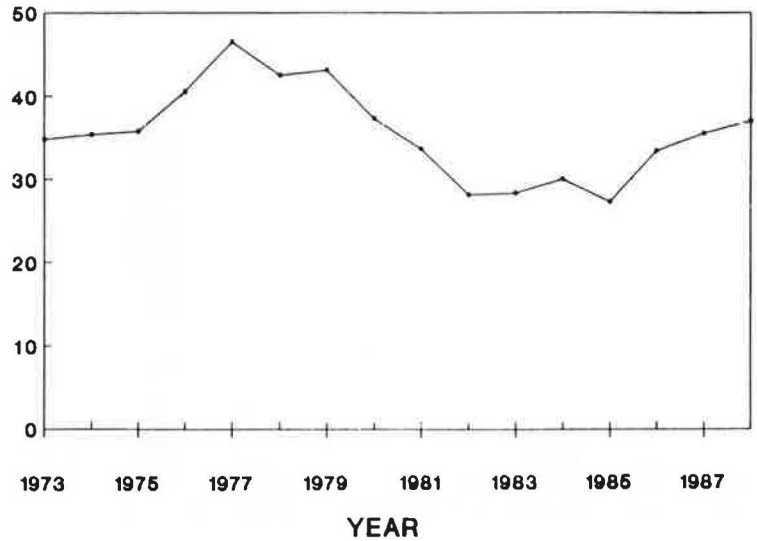

FIGURE 13. Trends in U.S. Oil Imports
(Percent of Total Supply)

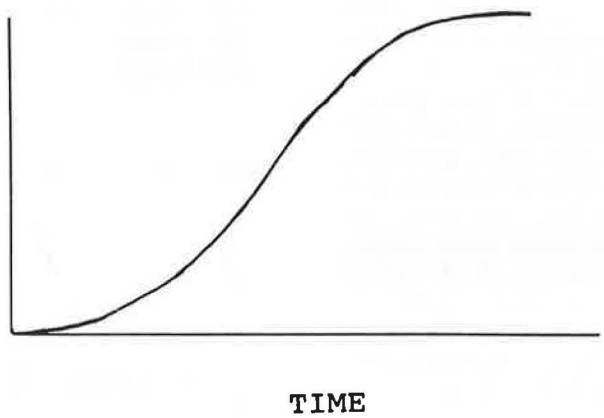

FIGURE 14. Cumulative Consumption
of a Non-Renewable Source

U.S. oil production continues to decline. Production in the lower 48 peaked in 1970. It has gone down even more rapidly with the recent drop in prices. (See Figure 16.) Many of the small oil wells, so-called stripper wells, have been closed down and will not be reopened.

One of the participants pointed out that if an import fee were imposed, as has been proposed several times, it could change this whole picture.

MacKenzie responded that during the 1970s, the price of oil was high. The United States drilling effort tripled between 1973 and 1981. Yet, the United States could not even maintain constant oil reserves. With higher prices you will get the oil out faster but I do not think you are going to get significantly more out in the long run. You are not going to turn around this curve of declining production. Production in the lower 48 is going to continue declining. Alaskan production has helped. But production from Prudhoe Bay also appears to be declining, so total domestic production is going to continue to drop. More incentives and more drilling may temporarily slow it down, but certainly is not going to reverse it. Looking to increased domestic oil production is not a long-term solution to this problem. We are going to have to find replacements for oil.

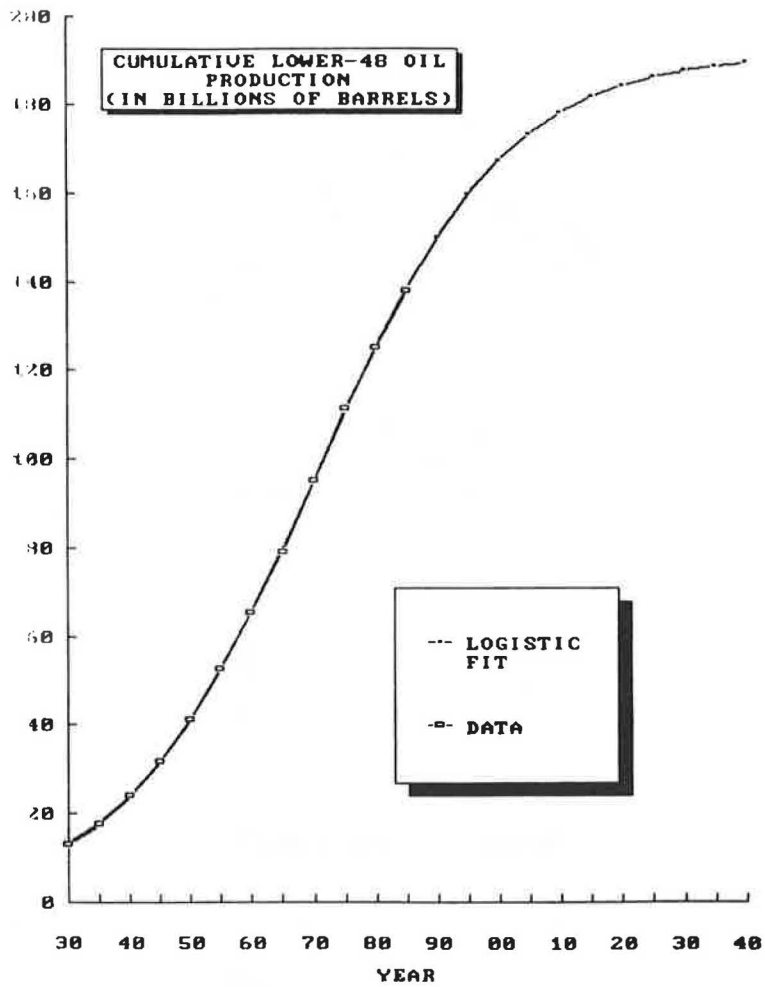

FIGURE 15. Cumulative Lower 48 Oil Production (Billions of Barrels)

Where do We go From Here?

The pressures to reduce CO_2 emissions worldwide are going to increase over the next few years. If you just ask the question, "by how much would the world have to reduce CO_2 emissions to stabilize atmospheric CO_2 levels?", it is probably 50 percent to 80 percent. There is a lot of scientific uncertainty there about how much CO_2 is going to stay in the air versus going into the oceans. But there is already international discussion about adopting a global goal of a 20 percent reduction in CO_2 emissions by 2005. We are a long way from there now with emissions from transportation and utilities going up. And this is why I believe the kind of discussion we have heard today--that things will be very evolutionary and that prices are going to stay low--is just not realistic.

With regard to global oil resources, you ask "how much oil is likely to be pumped from the earth using existing technologies?" that is, without going to tar sands and the like. If you look at the estimates that have been made over time, you find a range of estimates that are entirely subsumed within the Rand Corporation's estimate of 1,600 to 2,400 billion barrels. (See Table 1.) Of this, the world has already consumed about 600 billion barrels, so we still have a lot more oil to pump before we reach the half-way point. Even so, if you fit a logistic curve to cumulative world oil consumption you find that global oil data followed such a curve up to the 1973 embargo.

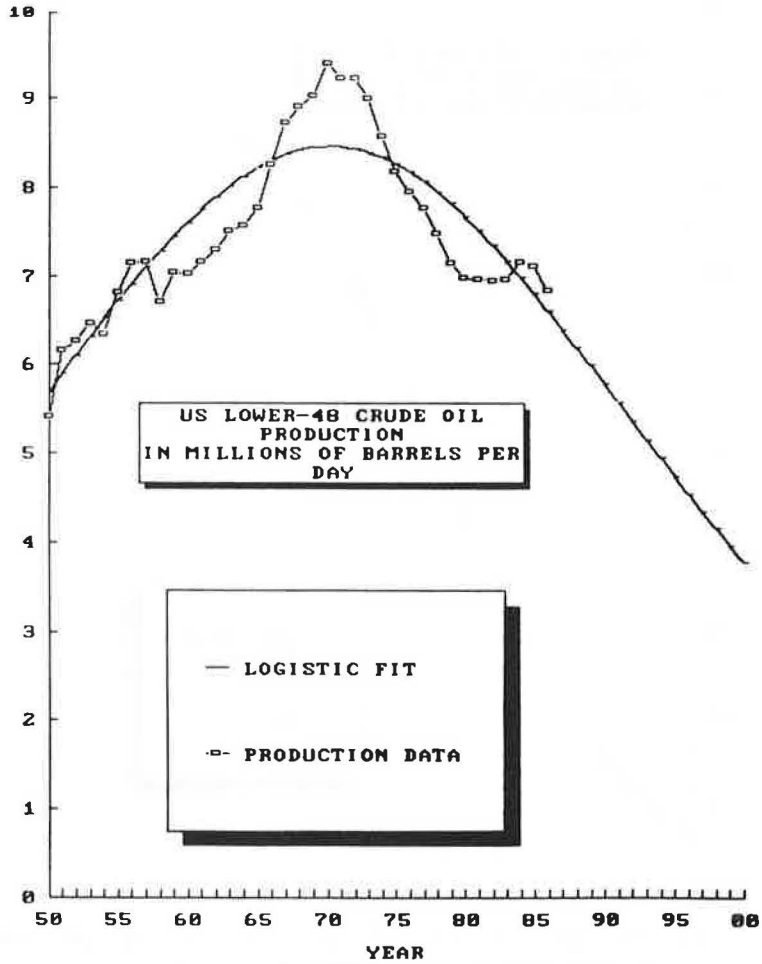

FIGURE 16. U.S. Lower 48 Crude-Oil Production
(Millions of Barrels Per Day)

Using the Rand estimates for the asymptote one concludes that -- absent the 1973 sharp rise in oil prices -- world oil production would have peaked sometime in the early part of the next century.

TABLE 1. ESTIMATE OF ULTIMATE RECOVERABLE GLOBAL CRUDE OIL

SOURCE	ESTIMATE (Billions of Barrels)	DATE OF ESTIMATE
Masters et al. (USGS)	1744	1987
Riva (Congressional Research Serv.)	1721	1987
Nehring (RAND)	1600-2400	1982
BP	2290	1980
Halbouty, Moody	2128	1979

As it is, of course, oil consumption dropped way down as a result of politically set high oil prices. Recently, with the weakening of the cartel and its inability to hold prices up, world oil demand is going up again. As a result the world production curve has probably been shifted several decades further into the future. Nonetheless, the message is clear that the mid-point of the oil era is only a matter of decades away. Please note that I am <u>not</u> saying that we are running out of fossil fuels; there is still a lot of carbon in the world in the form of coal. But I think that there is not going to be a whole lot more oil found outside of the Persian Gulf and that in our children's lifetimes, if not in ours, global oil production will peak out. (See Figure 17.)

All of this, I believe, has important implications for our use of fuels. In the short term we have got to make far more efficient use of energy. I say this recognizing that airplanes have already become much more efficient. The two consuming

sectors now posing the biggest problem, where major changes are going to occur, are power generation and transportation. In light of both global warming and the finiteness of global oil resources, we are going to have to turn to new energy technologies such as hydrogen or electrically powered vehicles, certainly for ground transportation. I just do not see any alternatives for the longer term.

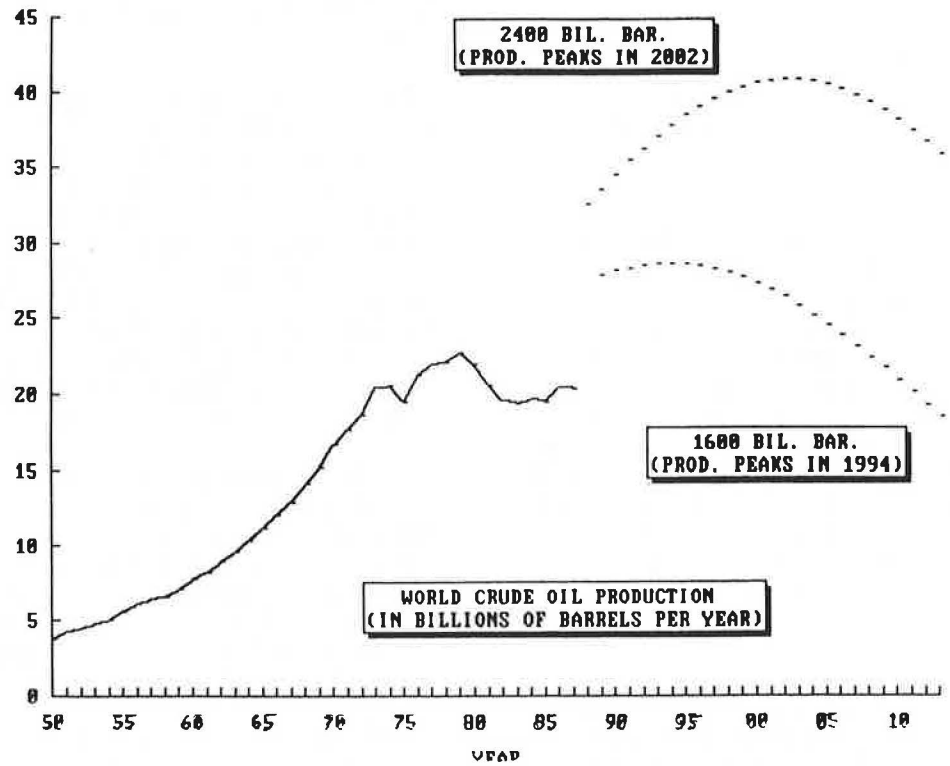

FIGURE 17. World Crude Oil Production
(Billions of Barrels Per Year)

Of course this does not mean that we have to eliminate all uses of oil and other fossil fuels and maybe aviation is exactly where we want to continue using them because it may be difficult to develop alternatives. In this case perhaps the problem will not be so severe for the air transportation industry.

Alternate Fuels. We should begin to move to non-fossil energy technologies, particularly, (1) hydrogen and/or electrically powered vehicles, and (2) renewable (PV, wind, etc.) and second-generation nuclear technologies for electric power generation. Hydrogen, the development of which is being explored in Germany, Canada, and the Soviet Union, is a good candidate to become the aviation fuel of the future. Hydrogen, of course, can be made using non-fossil sources such as nuclear power or solar energy.

Given the need to drastically cut CO_2 emissions, it is imperative that we start a transition to new, non-fossil energy sources. The renewables -- such as photovoltaic cells -- are well known but still expensive. They also need storage because they are intermittent. Second generation nuclear power plants are another possibility. These would be power plants with passive safety systems, ones that do not have all the reliability and sensitivity problems of the present generation of light water reactors.

Conclusion

Let me summarize by saying that the direct impacts on airports from sea level rise should be fairly small. A gradual rise in the sea level can be engineered against as long as you keep track of and monitor trends. The big changes from global warming are going to be in the economic conditions that will arise as we attempt to cope with rapid change. We should have begun to adapt some time ago. With a few more summers like the past one we can expect more nations of

the world to turn more attention to this problem. Either we start planning or we are going to leave a very unpleasant climate for our children. And it will get progressively worse. There is no sign it is going to level off, unless all the climate feedback loops just happen to be negative, which seems unlikely.

The majority of feedback loops may, indeed, turn out to be positive: the clouds, the melting of arctic ice, the release of methane from the tundra, and the rest of it. At any rate, I think that the social changes are going to be much more revolutionary than evolutionary, and there are going to be a lot of changes in the use of the fuels -- much less use of coal, more use of natural gas as a transitional fuel, and a greatly accelerated attempt to introduce non-fossil energy sources. We consume far more fossil fuels than we need to. With five percent of the world's population we account for 25 percent of the world's CO_2 emissions. I do not see any way we are going to convince the third world, the developing countries, to cut back on their emissions until we do so ourselves. The United States has a real responsibility to take the leadership in controlling our energy appetite and developing new energy alternatives.

Discussion

Comment: Does the recent announcement on the cold fusion experiment in Utah, indicate that this may be an important alternative energy source?

Mr. Mackenzie: Fusion is an energy source, and you can make hydrogen with it, but we do not have to wait for fusion for alternative sources of energy. There are solar thermal power plants already operating in California. They are building them with 80 megawatts capacity, and the newest one is expected to produce power at eight cents per kilowatt hour. Photovoltaic power plants can produce competitive power at peak periods. Certainly, new sources are not going to be as cheap as before. At the same time, we must recognize that traditional energy prices have been subsidized by unpaid environmental costs. It has not yet sunk into our psyche that we have to incorporate these unpaid social costs into the price of fuels. The greenhouse problem is well known and has been since the 19th Century. We still have not started to incorporate it into our long-term planning.

Comment: We, the human race, do not learn from past mistakes, and this presentation is an example of it. Malthus, a few hundred years ago, predicted some dire things in the first edition. Luckily, in the second edition he learned a little. Also in the last century, Jevons did funny projections and concluded that in 50 years we are going to run out of coal. We have more coal now than we know what to do with. Thirty years ago in 1954, we were told that we had about 30 years of oil left, but today, the experts are saying we have 45 years.

Mackenzie: Some years ago experts said that U.S. lower-48 oil production wouldn't peak in the foreseeable future, and when Dr. Hubbert said in 1957 that it would peak around 1969, he was laughed at. As we now know, he was right on the money and production peaked in 1970 and has been declining since, despite the rise in world oil prices and a tripling in exploration. At issue is not the reserves-to-production ratio, usually cited as so many years of oil left. The important date is the year of peaking. That is the time when you must have ready new, replacement energy sources.

Comment: Where does it say that the United States should be 100 percent independent in everything? We have at least, in the world, 50 years of oil by today's standards. If in 12 months the fusion does not happen, it will happen in 30 years. Then we will have a lot of oil and we will say, "what will we do with this stuff?" It is the same story. It is the Club of Rome over again.

MacKenzie: You miss the point I was trying to make, namely, that we are not just running out of oil in a matter of decades but that we are going to be constrained in our use of it by a real problem. When President Bush entered office the National Academy of Sciences wrote him a letter saying that this was the most serious problem that they were aware of, that basically the physics is irrefutable, that it demands international attention. If you have some refutation of their argument, I would like to hear it. We are going around with a business-as-usual attitude when it is not business as usual at all.

Comment: I think you are both right. We did not run out of oil, but the price went up, and the price is still with us. We are still paying, in real constant dollars. We are actually paying less, but the effect on airlines and air passengers and airports and aircraft manufacturers was traumatic for those five or six years during the 1970s. Although there is still plenty of energy, it affected all of our jobs and what we do so I think you are both right. We need to monitor these.

Comment: What are the prospects of a tax on oil to reduce the carbon dioxide output.

MacKenzie: It is not likely. The country does not want to be taxed; it prefers to be regulated.

Comment: We are having a lot of environmental damage. That seems fairly clear. But the important question, with the industry is how that is going to affect them. Unless there are real restrictions, most likely in the form of a tax on the use of carbon based fuels, it is unlikely that there is going to be a major change in industry consumption because there are no incentives.

MacKenzie: There is a major international review of the greenhouse problem called the Intergovernmental Panel on Climate Change. It is supposed to release its findings in about a year and there will be a lot of pressure for an international protocol to reduce CO_2 and other greenhouse gas emissions. It may or may not affect the airline industry. There is enough oil that if the price goes up, they can still use it. What occurred to me this afternoon was that the kind of quiet business growth that is imagined here will not likely occur. It will be very different if we have to go through major changes in our energy resources to severely decrease CO_2 emissions. If you look at what it would take to reduce CO_2 emissions, it is formidable problem.

Let me give you an example. People have been talking about least-cost planning on the part of the utilities. This means paying the utilities, giving them incentives, to go in and install efficient new lights and other highly efficient electrical equipment in all our buildings. A number of studies have concluded that if you do most things that people can think of, you can just about imagine holding electricity kilowatt-hour sales even while supporting maybe 2.5 percent GNP growth. That is a long way from reducing emissions by a few percent per year, which will be needed to meet the goals that are being discussed. It is going to take even more aggressive kinds of programs and I do not know what they might to be. But it suggests that we are in the calm before the storm.

Comment: I do a lot of flying and notice more turbulence in the air. Is there is any projection on the actual climatic conditions that will prevail in the future. We may have all the oil but if we have to sit in turbulence for seven hours every time we go somewhere, it may not be as pleasant. For example, some areas of Canada, this winter was one of the windiest, believe it or not, on record, and it has an impact on aircraft operations.

MacKenzie: The models are not really good enough to answer that question. The models divide the atmosphere into boxes, typically of 200 miles on a side, so they do not have a lot of detail. Climatologists do not really know what is going to happen to clouds. Changes in clouds are not incorporated into existing models. It is a very complex issue. The feeling is, though, that there will be more weather extremes. It would be interesting to see an analysis done to determine whether a trend of such extremes can be observed.

Comment: The secret of success is going to be whether the new technology will become commercially feasible. Supporting research and making some of these solutions commercially feasible will help. Superconductivity, for instance, promises to (in some respects) make electricity generation, storage, and transmission very much more efficient. This could reduce the huge loss in transporting energy from the point of generation to where it is used. In the transportation field, the application of superconductivity to maglev (magnetic leviation) and then to levitated transportation systems offers something that will equal or beat an airplane within a 500-mile range at an energy cost of about 25 percent of what an airplane uses. With such technology, energy can be generated by non-fossil fuels. Things like that are on the brink of commercial feasibility.

MacKenzie: The problem is not only developing new technology. The problem is with our institutions. We continue to build more and more highways, and create more urban sprawl. We are just locking ourselves more and more into a sprawled, decentralized way of life, totally dependent on the automobile, and one that is just going to make it harder and harder to cope with the problem.

If you look at where the oil is being consumed, maglev will be just a very small part of the solution, at least in the near term. The problem is the large number of cars and trucks that are out there and that are changing only very slowly. The newest cars today average 27.5 miles per gallon. Even so, the national fleet average has moved from about 13 mpg up to only 19 mpg over 15 years because of the slowness in turning over the stock of vehicles. We do not have decades and decades. We are committing the world to a permanent increased warming of about a half a degree Fahrenheit per decade. By 2030, the Earth will be committed to warming as much as 9 degree Fahrenheit, a temperature rise which was

sufficient to take the Earth from the last ice age to the warmest period known to man. It is a major issue that is going to move very quickly. It will require a rapid response, not a kind of a laissez faire, "wait until it all happens and then we will worry about it" kind of attitude, which is unfortunately the way we tend to deal with these problems.

TECHNOLOGY

John White,
National Aeronautics and
Space Administration

The technologies emerging over the next decade will provide the basis for the next generation of aircraft whether they come about through evolutionary changes in derivative aircraft of the current generation, conventional new aircraft, or revolutionary new designs with significant new capabilities. Technology developments will also allow for significant improvements in air traffic control capabilities.

Air Traffic Control

New ATC technologies being considered for use within the coming 10 to 15 years include precise four-dimensional navigation and guidance systems, improved capability for the transfer of weather, traffic, and ground information to the flight crew, and computerized controller aids for optimum aircraft spacing and sequencing. For the very near term, the Traffic Alerting Collision Avoidance System (T/CAS), now being evaluated, will provide aircrews with onboard capability for detecting and avoiding potential mid-air collisions. By 1991 the FAA will require aircraft that carry over 30 passengers, to be equipped with T/CAS. These capabilities will help accommodate the substantial growth in air traffic that is expected to occur in the future. Air travel should also become more convenient in terms of reduction in unanticipated ATC delays, and maintaining on-time departure and arrival schedules.

Subsonic Aircraft

In an evolutionary fashion, the aircraft manufacturers will continue to introduce new subsonic transport aircraft that will incorporate major technology advances in aerodynamics, structures, propulsion, and systems.

The most apparent change to the vehicle may well be the introduction of new propulsion systems incorporating advanced turboprop technology. General Electric has recently tested a gearless, counter-rotating unducted fan advanced turboprop engine, and Pratt and Whitney/Allison/Hamilton Standard are developing an advanced, geared, counter-rotating turboprop engine. Both Boeing and Douglas are currently investigating aircraft designs using these propulsion systems. The timing of their introduction will depend on economics as influenced by fuel prices.

In aerodynamics, further gains in cruise performance and efficiency are expected from new airfoils, fuselages, and nacelles, which incorporate advanced technology for improved laminar flow control and high-aspect-ratio wing designs. The ability to achieve the contour of these airfoil shapes, and at the same time reduce weight, will be realized by advanced composite materials which are anticipated to be used as primary structure in wing and fuselage designs for the next generation aircraft.

Flight control systems using power-by-wire technology will replace the heavier hydraulic and cable systems. These designs offer potential improvements in direct operating cost (DOC) of 25 percent relative to current jet transports, particularly those that were introduced 10-20 years ago. These same technology advances are also applicable to future generations of improved general aviation or commuter aircraft.

A major technology driver will be operating and equipment cost, as affected by fuel prices, maintenance, and manufacturing techniques.