Thoughts on the Future Of Transportation

Will it be

Or

Or Perhaps Both?

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The first version of this paper was drafted in 2000 when I was employed by the U.S. Department of Transportation's Volpe National Transportation Systems Center in Cambridge, Massachusetts. Although several agencies – notably the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) -- paid my salary during this time, I want to emphasize that the comments and opinions reflected in this paper solely reflect those of the author and not of any US government agency or organization. Any mistakes or errors are solely the responsibility of the author as well.

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Thoughts on the Future of Transportation

I. Introduction

Transportation is one of the most important, yet also one of the most overlooked activities within modern society. The efficient, affordable and rapid movement of people and goods from origin to destination is necessary to support many aspects of modern life; yet often it seems little thought is given to this topic until something breaks down. On the one hand, this can be taken as a positive sign of the success of our transportation system and its managers in meeting the daily needs of individuals and society as a whole in an unobtrusive manner. On the other hand, it can also mean that people are both unnecessarily surprised and befuddled when there are problems. And there will be problems; of that one can be confident.

In reality, millions of people across the globe spend a great deal of time, effort, expense and concern every day assuring that our transportation system functions as best as it can. Recent estimate suggest that – depending on how one defines the term, 'transportation' can account for as much as 10% of both the nation's workforce and total expenditures.[1] Transportation by its very nature has a profound impact on, and in turn is impacted by, a variety of other major societal and economic activities. These include energy supplies, costs and usage; environmental topics such as air and water pollution, global warming, and carbon emissions; local, national and international trade and employment patterns; land use decisions such as the placement of factories, warehouses, offices, shopping centers and residential communities; infrastructure investment; the development and application of technologies; and demographics. Thus, studying transportation and thinking about its current and future role in our society is in many respects a microcosm for thinking about our society and way of life as a whole.

This paper is written for those interested in thinking comprehensively about transportation, the role it plays and will continue to play in our life, and how this role may both change and be changed by the future. It provides a common starting point for a broad discussion of the topic of the future and transportation's constantly transforming role within it and points to a number of public policy issues that will need to be addressed. Section II of this paper discusses the general characteristics of future demographic and economic trends. Section III relates these trends to the safety, energy, environmental and economic aspects of transportation. Section IV describes how these trends will impact the major transportation market segments. Section V reviews the major technologies that hold the greatest promise for improving future transportation. Finally, section VI suggests some key questions to ponder on the future of transportation.

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[1] A lively academic debate on this topic has been underway for a number of years. For one example, see Michael Rossetti and Basav Sen, "A Complete Count of the U.S. Transportation Workforce", in <u>Transportation Research Record</u>, No. 1719, 2000, pp. 259-266.

This paper was assembled from a wide variety of published sources and discussions with a number of individuals focusing on the major social, political, economic, and technological factors that affect global systems such as transportation. Noted futurists were consulted and provided valuable insights and ideas.[2] It should be pointed out that this paper projects what could be called a '*plausible'* or *'probable'* view of the future. Catastrophic events that could significant alter the possibility of life on the planet or normal human evolution (i.e., World War III, famine, pandemic, asteroid impact, alien visitations, etc.) were deliberately excluded from consideration. There is, of course, no guarantee that these trends will actually develop as described here; or for that matter that one of these catastrophes may or may not happen. However, it does allow for the creation of a 'straw man' vision of the future for purposes of dialogue and discussion.

II. General Projections of Global Trends

Demographics*:* Depending on birth rate assumptions, the current (2006) world population of close to 6.5 billion will rise to about 8 billion in 2025, and about 9.1 billion by 2050. This population boom will create the basis for the evolution of future global trade patterns, manufacturing and overall economic activity. Growth rates, however, will vary. The developed nations and non-urban areas will have the lowest growth rate and developing nations and urban regions the highest rate.[3] In fact, almost all of the increase in population growth over the next fifty years will occur in the current developing world. Low fertility rates will keep the population of the current developed world constant at about 1.2 billion. Only immigration from the rest of the world will keep this number from falling further. More than 50 developed nations will probably be slowly losing population over the next fifty years. For example, by 2050 Italy, Hungary, Russia, Georgia and the Ukraine could all lose more than 20% of their current population totals. Of all developed nations, the United States will receive the largest population increase, due primarily to immigration.

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[2] Among the scenario collections researched were:

- Col. J. Engelbrecht et al, *Alternate Futures for 2025: Security Planning to Avoid Surprises*. April 1996, at http://www.au.af.mil/au/2025/monographs/A-F/a-f.htm.
- National Research Council, Aeronautics and Space Engineering Board (ASEB), *Maintaining U.S. Leadership in Aeronautics: Scenario-Based Strategic Planning for NASA's Aeronautics Enterprise*. Washington DC: National Academy Press, 1997
- The Millennium Project of American Council for the United Nations University, *1998 State of the Futures: Issues and Opportunities* and related reports at http://www.unmillennium.org/
- U.S. Department of Transportation, *ONE DOT Scenario Strategy Workshop*. April 1999, at http://stratplan.dot.gov/StratPlan/PlanProcess/Future.cfm
- Central Intelligence Agency, *Global Trends 2015: A Dialogue About the Future With Nongovernment Experts*. NIC 2000-02, December 2000, at http://www.odci.gov/cia/reports/globaltrends2015/index.html
- National Intelligence Council, Mapping the Global Future 2020, 2004, at http://www.cia.gov/nic/NIC_2020_project.html
- Final Report of the Joint Planning and Development Office (JPDO) Futures Working Group (FWG), August 2004 can be downloaded at http://www.jpdo.aero/FWG_reportout_ltr.html

[3] See the following section for a definition of the 'developed world' as 'Tier I nations'.

Another consequence is that the world's population will be an older population. The proportion of people over age 60 will grow from 10 percent, or 650 million, in 2000 to about 22 percent, or nearly 2 billion, in 2050.[4] According to one recent estimate, almost one-half of Germany's adults in the year 2030 will be over 65 years of age, compared to only one-fifth today. At the current German birthrate of 1.3 children per woman of child-bearing age, the total German population (without immigration) will fall from 82 million today to between 70 and 73 million in 2030, and the working-age population will fall from 40 to 30 million. With the same current birthrate as Germany, Japan's population will peak at about 125 million in 2005, and fall to about 95 million in 2050, without immigration. By 2030, one-half of Japanese adults will be over 65.[5]

Among the fastest-growing large nations of the future are the currently developing nations of Pakistan, Nigeria, Ethiopia and the Democratic Republic of the Congo. These nations are projected to roughly double their populations – or triple in the case of the Congo - in these fifty years. *(See Chart 1)*

Chart 1: Largest Countries by Population, 2005, 2025 and 2050

	2005		**2025**		**2050**	
Rank	**Country**	**Pop (M)**	**Country**	**Pop (M)**	**Country**	**Pop (M)**
1	China	1,316	China	1,441	India	1,593
2	India	1,103	India	1,395	China	1,392
3	USA	298	USA	350	USA	395
4	Indonesia	223	Indonesia	264	Pakistan	305
5	Brazil	186	Brazil	228	Indonesia	285
6	Pakistan	158	Pakistan	224	Nigeria	258
7	Russia	143	Bangladesh	194	Brazil	253
8	Bangladesh	142	Nigeria	190	Bangladesh	243
9	Nigeria	132	Mexico	129	D.R. of Congo	177
10	Japan	128	Russia	129	Ethiopia	170
	World	***6,465***	***World***	***7,905***	***World***	***9,076***

Source: United Nations, World Population Prospects: The 2004 Revision

Still a Divided World*:* It is also likely that the world's nations will continue to be roughly definable in three general categories – based on relative levels of technology, affluence, and life styles. These categories will be called 'Tier I', 'Tier 2', and 'Tier 3'. Currently they consist of:

- *Tier I* –OECD nations (Western Europe, US, Canada, Japan, Israel, Australia, New Zealand, Singapore, Korea, and Taiwan)

[4] Information in this paragraph is from the World Resources Institute, World Bank, and United Nations, *World Resources 1998-1999: A Guide to the Global Environment*, Oxford University Press, 1998, p. 143; and United Nations, *World Population Prospects, The 2004 Revision*, February 24, 2005 draft available at *http://www.un.org/popin/functional/population.html.*

[5] "The Next Society: A Survey of the Near Future", *The Economist*, November 3, 2001, p. 5. See also "Trends Now Changing the World: Economics and Society, Values and Concerns, Energy and Environment", *The Futurist*, January-February 2001, p. 32.

- *Tier II* –Eastern Europe, Russia, Southeast Asia, China, most of the oil-producing Middle East, most of Latin America, and Southern Africa

- *Tier III* –sub-Saharan Africa, South and Central Asia, and a few pockets in Latin America.[6]

<u>The Rise of 'Megacities'</u>*:* The bulk of the world's population will increasingly be found in major *megacities*, i.e., large metropolitan regions centered on one or more urban center and their suburbs with populations of about 10-20 million or even much more.[7] All three Tiers will have these megacities, but actual living standards and quality of life will vary immensely from one to another. Examples include:

- *Tier I* – New York, Los Angeles, Tokyo, Osaka/Kobe, Seoul, Paris, London, etc.

- *Tier* II – Mexico City, Rio de Janeiro, Sao Paolo, Buenos Aires/Montevideo, Cairo, Istanbul, Beijing, Shanghai, etc.

- *Tier* III – Lagos, Kinshasa, Nairobi, Teheran, Kalicut, Mumbai, Delhi, Dhaka, Karachi, etc.

Thus, much of the world's population will be living in a number of very dense urban environments scattered across the globe literally thousands of miles from each other. As the next century progresses, the Tier II and III megacities will be the largest and fastest-growing ones. *(See Chart 2)* These centers will drive the global economy. Many of the world's major trade and transportation corridors will connect these megacities to each other and to major sources of raw materials. Those megacities that cannot establish or maintain these corridors will inevitably suffer – both economically and in quality of life terms -- compared to the others.

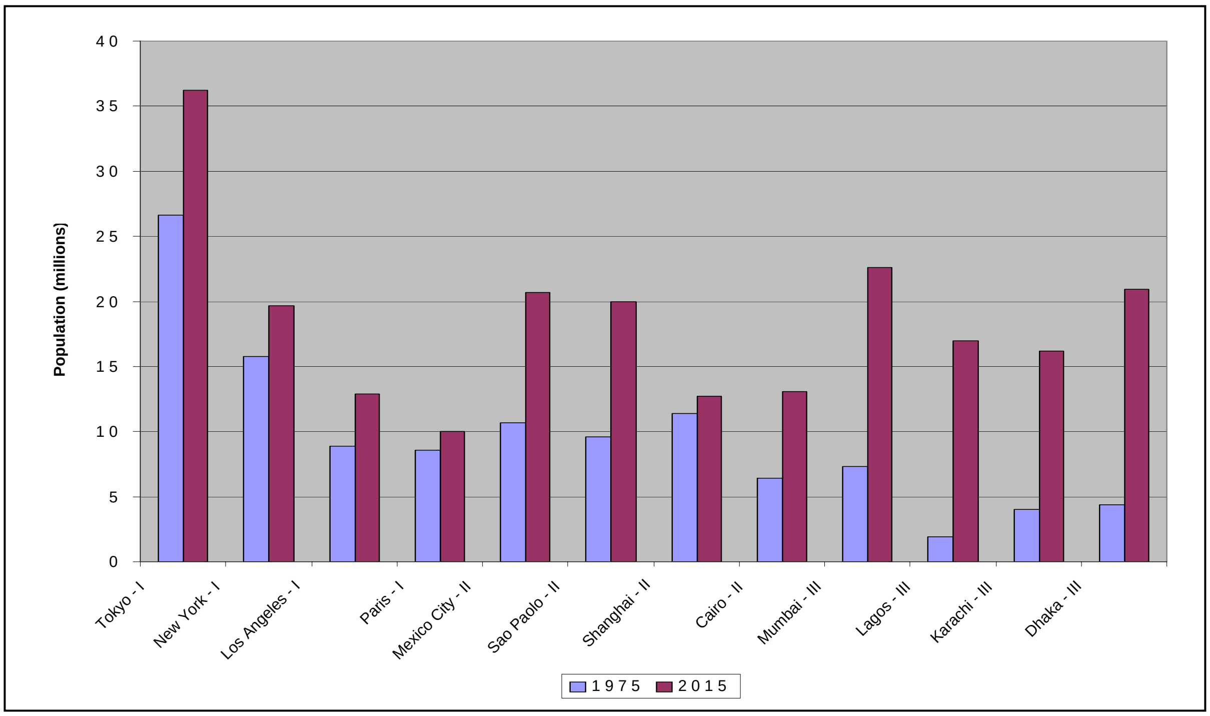
<u>Where Have All the Workers Gone?:</u> If current trends continue, the number of active workers for each retired person in developed nations will continually shrink to the point where these societies may be incapable of generating sufficient revenue to pay for adequate pensions and social services for a non-employed seniors population. This could have two major effects. First, it will encourage workers to postpone their departure from the work force, and even to continue working part-time after their formal 'retirement'. The value of pensions and senior benefits may have to be considerably reduced as well. This will also help to deal with the acute labor shortage that will be occurring in rich nations as their population totals stagnate or decline and the average age of their citizens continues to rise.

[6] India and Pakistan are on the borderline between Tiers II and III – they have significant industrial infrastructures and nuclear capabilities, but low overall per capita incomes of under $500 annually.

[7] These megacities have also been termed *conurbations.*

Second, as chronic labor shortages cut into their economic growth, developed countries will by necessity turn to immigrants to fill these vacant jobs. However, some will fear immigrants for 'diluting national identity'. Those countries with a tradition of welcoming and assimilating immigrants - such as the U.S., and Canada - will benefit from this trend. On the other hand, nations that have less experience with successfully assimilating immigration - such as Japan and parts of Western Europe -- may suffer a loss of economic growth as a result. And these nations cannot afford to miss out on this opportunity.

Chart 2: Expected Growth in Select World Megacities (by Tier), 1975 – 2015



Source: UN Population Division, World Urbanization Prospects: The 2003 Revision, 2004

The 'Trickle-Down' Effect: The features of Tier I countries can be expected to be replicated by Tier II countries with a time lag of 10-30 years or so, and by Tier III countries after a somewhat longer delay. For example, vehicle ownership levels in Tier I now will probably be seen in Tier II within the next 10-30 years. This is consistent with the recent history of vehicle fleets and total transportation volumes in these countries. For example, it took until 2004 for China has become the third largest auto market in the world behind the US and Japan, with annual sales of over 5 million units. It may surpass Japan (5.9 million units/year) by the end of the decade. At least sixteen foreign manufacturers now produce vehicles in Chinese factories and the nation doubled its inventory of modern motorways between 2000 (10,000 km) and 2004 (21,000 km). As The Economist summarized:

> This combination of soaring car ownership, frantic motorway construction and a booming economy evokes images of America in the 1920s, when the car transformed the aspirations of the middle class, and the 1950s, when the federal government built the interstate highways. Yet, in China's case, these developments have been compressed into just a few years.[8]

Intense Pressures on Land Use*:* As world population rises, it creates a concomitant increased demand for food, fuel, natural resources and finished products. The result will be intense competition for land, particularly when it is adjacent to these megacities. This will have two major impacts:

- It will be increasingly difficult to transform productive land near cities into urban districts or to find new rights-of-way for new transportation infrastructure; and

- Marginal land – such as Siberia, northern Canada, and desert regions – will need to be improved and made more productive. This will also require that transportation links to these more remote regions be extended.

In addition to land, there will likely be serious shortages of fresh water in many parts of the world, including those which are experiencing rapid population growth (such as Western US states like Arizona, Nevada and Utah). The cost of obtaining adequate and reliable supplies of fresh water could escalate, and armed conflict could even result over access to such vital resources.

New Regions to be Exploited*:* As pressures on finite land, water and mineral resources accelerate, new and much less hospitable environments will need to be exploited to answer these demands. These new techniques could include:

- Melting and transporting polar ice for drinking and irrigation;

- Intensive aquafarming for fish and plants;

- Deep sea/polar mining for minerals; and

- Deep seabed/polar drilling for petroleum and natural gas.

These will all require new means of extraction, processing and transporting these products, if in fact they prove to be feasible at all. In fact, the long-range transport of fresh water, including intercontinental and transcontinental shipments, may become a new and extremely important transportation market.

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[8] *The Economist*, 4 June 2005, p. 24. The sixteen companies are: DaimlerChrysler, Ford, GM, Peugeot, Fiat, VW, Hyundai, Daihatsu, Honda, Isuzu, Mazda, Mitsubishi, Nissan, Subaru, Suzuki and Toyota.

Bulk Stays Bulk, and Freight Stays Freight: Feeding, housing, fueling, and meeting the consumer product needs of an additional three to four billion people by 2050 will require the movement of significantly higher volumes of bulk freight than today. Much of this freight will also be moving longer distances, particularly as marginal lands become important sources of food and raw materials, and as trade between these scattered conurbations grows.

Regardless of the optimism of some that future freight will shift to lighter and smaller high value-added products, each new addition to the world's population stimulates an even greater demand for bulk freight. This includes everything from food, water and fuel to building supplies and construction materials, a vast array of consumer goods such as appliances, furniture and automobiles, and even the transportation of higher volumes of trash, rubbish and hazardous materials. According to one recent estimate, industrial societies currently use 80 metric tons of material each year to support a single person.[9]

Due to the nature of this freight – heavy and relatively low value-to-volume ratio – it will probably continue to be moved via the modes best suited to heavy transport – rail, pipeline and water. As globalization increases competition for resources and business, a highly efficient freight operational infrastructure will become essential, both to remain economically competitive and to satisfy the inexorably growing market for these products.

The Value of Time Grows: The total global market will be much larger than today, and will be additionally fueled by a continued overall rise in per capita incomes. This will be of particular importance in the Tier II and III countries as they start to attain the current Tier I living standards. This development will have two impacts on transportation:

- Demand for fast and predictable delivery of consumer goods, and for fast and predictable leisure and especially business travel, will significantly expand; and

- Competitive pressures on businesses will compel them to streamline and accelerate their entire logistics chains and lower costs as much as possible.

Decision-Making Moves Up -- and Down: At present, political sovereignty in a global context is vested in the nation. However, two distinct and somewhat opposing trends will act to shift this decision-making authority in opposite directions. First, many nations are increasingly devolving authority over certain topics (local governance, social welfare, housing, education, culture, etc) downward to regional or local levels (Canada to Quebec, Britain to Scotland) or even splitting into numerous independent states (Yugoslavia, the former Soviet Union).

[9] Presentation by Dr. Allan Hammond of the World Resources Institute at a NASA conference on May 16, 2001. Japan manages to use only 40 tons per person.

Second, however, there is also a consistent trend towards greater uniformity, harmony and standardization across nations to encourage and facilitate commerce and economic activities. The European Community (EC) and NAFTA are the most obvious examples. A number of transportation-related international organizations have already been formed to help establish such standards. They include the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO). This trend also coincides with the interests of multinational industrial and financial corporations, which seek to minimize national barriers to trade and investment.

In fact, several important global networks – the Internet and global funds transfer, for example – have already developed almost regardless of national laws or boundaries. Both serve extremely important needs, and both are difficult for one nation to limit or regulate even within its own borders. The growing importance and influence of megacities will further contribute to this trend, as a number of them (Seattle-Vancouver, San Diego-Tijuana, Buenos Aires-Montevideo, etc.) will cross national boundaries.

These trends will significantly impact decision-making and public policy. More and more individuals and groups will demand a role in the process, and will have means to hinder the process if they are not included. Achieving consensus on complex issues in transportation and other areas of life will probably become even more difficult than at present.

Businesses Get Bigger -- and Smaller*:* Economies of scale and global sourcing/markets will stimulate the continued evolution of very-large scale multinational industrial and financial corporations. These giants will have large production and distribution activities on several (if not all) continents and in most (if not all) conurbations. They will manufacture parts for a single finished product at varying locations throughout the globe, and ship them to one or more factories for final assembly. In transportation, this trend is clearly evident now in the merger of automakers from different continents (DaimlerChrysler) and the purchase of individual companies by another (Ford buying Volvo and Jaguar, GM buying Saab, Renault buying Nissan, etc); the continual consolidation of North American railroads into a few continent-wide companies; and the global partnerships between world airlines (Star, Oneworld, SkyTeam, etc).

At the same time, individuals will be empowered by wireless devices and 'e-commerce' to become "instant consumers" by ordering goods and services wherever they are and at any time of the day. This vast potential market will in turn generate significant opportunities for entrepreneurs to fill the many niches created by this global demand. It is likely that a large number of small (even one-person) companies will evolve, specializing in meeting the needs of these "instant consumers" through developing very close, ongoing relationships with their clients.

Combining these two trends may lead to a situation where the consumer custom orders an item, which is rapidly manufactured by a small, nearby, state-of-the-art factory and delivered directly to the consumer sooner than was ever thought conceivable. The world auto industry is already heading in that direction, as most new auto plants are relatively small (with an output of about 200,000 vehicles per year) and able to switch very flexibly between manufacturing different models.[10]

Can You Hear Me Now? Good! I'd like to order . . .

A somewhat different chain of thought suggests that the corporations of the future will be radically different from today. The primary contributor to this change will be the rise of the 'knowledge worker' - the person whose specific skills and expertise are necessary to provide a product or service. Since these individuals will essentially control the primary economic resource - knowledge - companies will go out of their way to accommodate their needs and wishes. [11]

At the same time, essential functions that used to be found only within the company - including IT services, human resources management, and even manufacturing - are increasingly being contracted out to outside firms and individuals who support the company but do not appear on its payroll. As this occurs, the actual 'company' increasingly becomes identified with its 'top management,' and *vice versa*.

In this situation, the most important task for top management in the future will be "to establish their organization's unique personality", including its "social legitimacy: its values, its mission, its vision."[12] They will spend increasing amounts of time on balancing the three major dimension of being an economic (profit making), human (workforce-friendly) and social (good neighbor) organization at the same time.

[10] "Special Report, Car Manufacturing: Incredible Shrinking Plants", ***The Economist***, February 23, 2002, pp. 71-73.
[11] "The Next Society", ***The Economist***, pp. 4, 8-11. See also ***The Futurist***, p. 34.
[12] "The Next Society", ***The Economist***, p. 18.

III. Impact of These Trends on Safety, Energy, the Environment and the Economy

Transportation Safety: Over 90% of all transportation-related fatalities are associated with motor vehicles. Even as the total travel volume has grown in recent years, both the U.S. highway fatality rate and the total number of annual fatalities have been steadily declining. Annual fatalities have decreased from a high point of over 52,000 deaths in 1970, to a range of 40,000 - 45,000 since 1985. The fatality rate has also dropped from a high of 5.7 fatalities per million vehicle-miles in 1965 to only 1.6 in 2000. *(See Chart 3).* Highway-related injuries have fluctuated between 3.2 million and 3.5 million annually throughout the 1990s.[13]

Despite these declines, however, steadily mounting volumes of traffic present a challenge to continuing this downward trend. If the fatality rate cannot be significantly lowered any further, it is likely that the total number of highway deaths in the U.S. will again start to increase in the future.

Most of the Tier I countries have, as with the U.S. example, managed to reduce total fatalities even as traffic volumes continue to grow. Among the reasons for these reductions are improved highway infrastructures, better signage and signals, enhanced safety features in vehicles, better traffic law enforcement, and public highway safety awareness and education campaigns.

However, the same situation does not hold for Tier II and III nations. The British Transport Research Laboratory (TRL) studies highway fatality and injury rates throughout the world. They estimated that during the 1980s alone a total of about 300,000 persons were killed and between 10 and 15 million were injured in highway crashes across the globe each year. In the years between 1968 and 1985, highway fatalities in Tier I nations fell by about 25%. However, during this same period they rose by 170% in Asian countries and more than 300% in some African nations. The World Health Organization (WHO) has determined that in 2002 highway accidents were the second-largest cause death for those between the ages of 5 and 29 worldwide. Of the 1.2 million highway fatalities per year across the globe, over 1 million occur in low and medium-income nations.[14]

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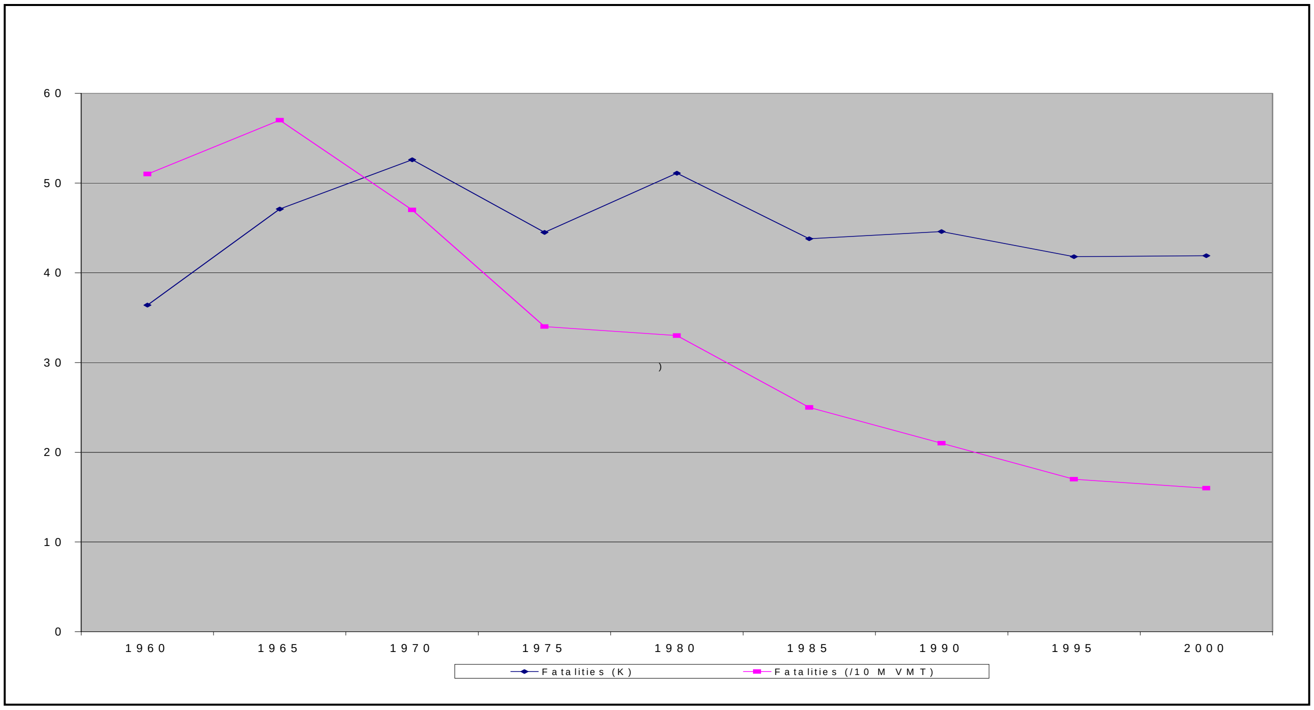
13 *Ibid*, p. 207.

14 TRL, *Towards Safer Roads in Developing Countries: A Guide for Planners and Engineers*, 1991; and Transportation Research Board Special Report 287, *Improving Road Safety in Developing Countries: Opportunities for U.S. Cooperation and Engagement*, Washington D.C., 2006, pp. ix, 1, 8.

Chart 3: U.S. Highway Fatalities and Fatality Rate: 1960-2000



Source: National Transportation Statistics 2004 at www.bts.gov.

An exploding level of vehicle ownership and use, rapid urbanization, and unplanned growth all contribute to this rising fatality and injury rate in Tier II and III nations. The amount and condition of the physical infrastructure cannot keep pace with this growth, traffic laws and driver education are not well established, and driving becomes more dangerous. Since vehicle ownership and traffic volumes are projected to expand rapidly in these nations, the consequence could be an unprecedented level of motor vehicle-related deaths and injuries. The World Bank projects that highway fatalities in low and medium-income nations could increase by 80% between 2000 and 2020 even as they fall by 30% in high-income nations.[15] If this outcome cannot be avoided, Tier II and III nations may face a difficult choice: either devote high levels of resources to improving road safety, or accept these consequences as the unavoidable price of economic progress.

Fortunately, this situation provides a promising opportunity for the developing nations. By importing the lessons learned by the previous experiences of developed nations in successfully reducing these rates and applying the same improvements in signage, safer vehicles, law enforcement and public education, the developing nations could avoid the typical spikes in highway accidents and injuries that have usually accompanied rapid motorization.

15 *Improving Road Safety in Developing Countries*, p. 10.

Energy*:* In 2002, transportation accounted for about 27% of all U.S. energy consumption (27 out of 98 quadrillion BTUs). About 97% of all transportation energy consumption was petroleum-based fuels, and transportation consumed 67% of all petroleum used in the US.[16] As population grows and living standards evolve, an increase in energy consumption is inevitable. In addition, Tiers II and III nations will be moving into an era of even higher petroleum consumption as their economic development parallels the late 20th Century in Tier I. Larger and more affluent populations will spur a demand for more vehicles, more roads and rail lines, more seaports and airports, etc. Oil consumption in both India and especially China has been growing rapidly since the 1990s as manufacturing and infrastructure construction have proceeded at very high rates in both nations.

This will create an intense global demand for more petroleum. Prices are likely to rise. Conflicts between nations and regions may erupt over access to increasingly valuable oil reserves. Meanwhile, Tier I nations will likely be further pressured to start shifting away from petroleum energy sources for transportation, which will spur the development of alternative transportation fuels and propulsion systems.

Although exact calculations vary somewhat, most experts agree that the total world output of conventional oil will peak around 2020 at approximately 35 billion barrels per year, and then begin a long-term decline. However, according to a recent paper prepared for the U.S. Department of Energy,[17] the world's unconventional petroleum reserves of natural bitumen, extra-heavy oil and oil shale are many times larger than conventional oil reserves. The largest deposit of natural bitumen – also known as tar sands or oil sands – is found in the Canadian Province of Alberta, while the largest extra-heavy oil deposits are in the Orinoco Belt in eastern Venezuela. Together, these two areas contain the equivalent of 3,600 billion barrels of oil in place and account for almost 90% of the world's known reserves of these substances. Nearly two-thirds of the world's known oil shale is found in the U.S., concentrated in the states of Wyoming, Colorado and Utah. And even though extracting and processing fuels from these deposits can be expensive and dirty, the fact is that it is already being done on a massive scale by multinational energy companies today.[18] *(See Chart 4)*.

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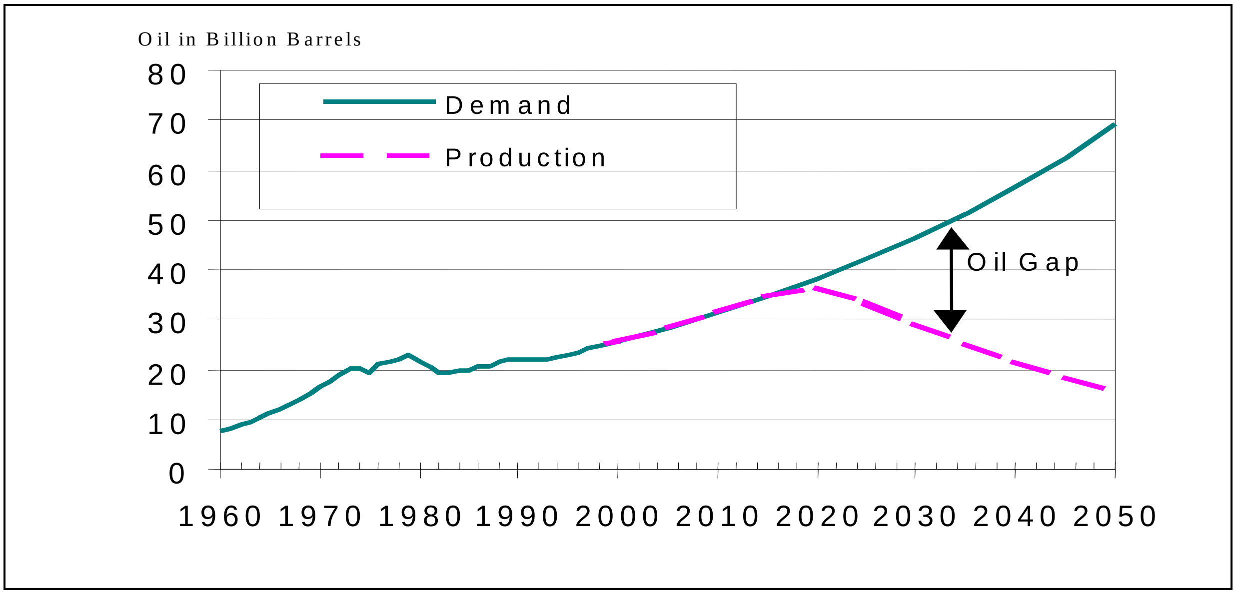
[16] *Transportation Statistics Annual Report*, September 2004, pp. 156, 312. Primary non-petroleum transportation energy sources were electricity (transit and Amtrak) and natural gas (pipelines).

[17] Alicia Birky (National Renewable Energy Lab), David Greene (Oak Ridge National Lab), Thomas Gross (DOE), David Hamilton (DOE), Kenneth Heitner (DOE), Larry Johnson (Argonne National Lab), John Maples (Trancon Inc.), James Moore (TA Engineering Inc.), Philip Patterson (DOE), and Steven Plotkin (Argonne National Lab), "*Future U.S. Highway Energy Use: A Fifty Year Perspective*", prepared for the Office of Transportation Technologies, U.S. Dept. of Energy, December 4, 2000 draft, 35 pp.

[18] World Energy Council web site, Survey of Energy Resources section on '*Oil Shale'* at http://www.worldenergy.org/wec-geis/publications/reports/ser/shale/shale.asp. See also "Canada Pays Environmentally for U.S. Oil Thirst, *Washington Post*, May 31, 2006; and "For Venezuela, a Treasure in Oil Sludge", *New York Times*, June 1, 2006.

Chart 4: Projected Total Conventional Oil Production, 1960-2050



Source: Birky, Greene et al "Future U.S. Highway Energy Use: A Fifty Year Perspective", prepared for the U.S. Dept. of Energy, December 4, 2000 draft, p. 5.

Other nations with significant oil shale deposits are Morocco, Turkey, Thailand, Israel, Jordan and Australia.[19] Liquid fuels can also be derived from other carbon sources, including coal, natural gas and methane hydrates, which are methane molecules encased in ice crystals found on sea beds and under permafrost land.[20] *(See Chart 5).*

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[19] World Energy Council web site, Survey of Energy Resources section on '*Natural Bitumen and Extra-Heavy Oil'* at http://www.worldenergy.org/wec-geis/publications/reports/ser/bitumen/bitumen.asp.

[20] The description of methane hydrates is from John Maples, James Moore, Philip Patterson and Vincent Schaper (National Renewable Energy Lab), "*Alternative Fuels for U.S. Transportation*", submitted to Transportation Research Board (TRB) A1F06 Committee on Alternative Transportation Fuels, 2000, p. 5.

Chart 5: Remaining World Fossil Fuel Reserves (In Billion Barrels of Oil Equivalent)

Fossil Resource	Reserves	Resources	Additional Occurrences	Total
Conventional Oil	1,100	1,063		2,163
Unconventional Oil	1,340	2,460	13,370	17,170
Conventional Natural Gas	1,030	2,050		3,080
Unconventional Natural Gas	1,410	1,890	2,840	6,140
Hydrates			137,500	137,500
Coal	7,350	17,570	20,860	45,780
Totals	12,230	25,030	174,570	211,833

Source: "Alternative Fuels for U.S. Transportation", p. 13.

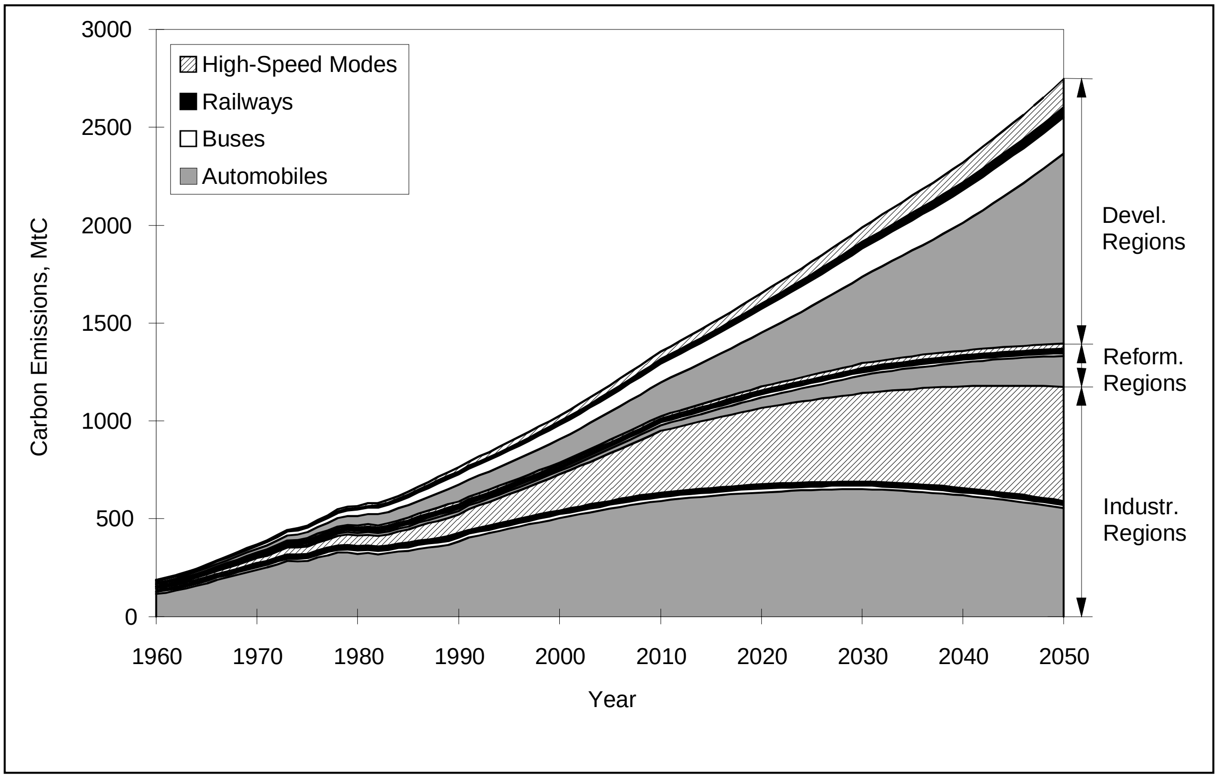
Many of these technologies are not new. Both Nazi Germany and Apartheid South Africa maintained large-scale programs to convert coal to conventional liquid fuels to overcome a lack of access to crude oil. Australia, Brazil, Canada, Estonia and Venezuela currently produce oil from these sources. There are some technical challenges to this process, including the need for large amounts of natural gas and/or water. Finally, ethanol and methanol fuels and fuel additives can be produced from biomass such as agricultural crops and waste and forestry products. At a crude oil price level of about $30 to $35 per barrel over a sustained period of time, however, tapping these unconventional sources could become economically feasible.[21] This would enable the U.S. to achieve energy independence for carbon-based fuels, bringing significant benefits to the nation's balance of payments and national security posture.

The Environment, Greenhouse Gases and Global Warming: Thus, it would seem that the world will likely not run out of carbon-based fuels by 2050. Unfortunately, the environmental consequences of continuing to rely on such fuels for that long may be unsustainable. Increasing worldwide petroleum consumption immediately raises concern over the health of the global ecosystem. If current trends continue in the U.S., for example, petroleum fuel consumption could double between 2000 (8 million barrels/day) and 2050 (16 million barrels/day). The impact of spills and runoff on the land and water quality, and the impact of emissions on the atmosphere, will both be staggering. Annual carbon emissions from these fuels will more than double: from the current 300 million metric tons to more than 800 million metric tons in the US alone by 2050.[22] Total global carbon emissions could more than double from about 1 billion

[21] *"Alternative Fuels for U.S. Transportation," p. 12.*
[22] U.S. Department of Energy, Office of Transportation Technologies, *2050 Transportation Paper: An Analysis of Several Scenarios That Significantly Reduce Oil Use by U.S. Highway Vehicles in 2050*, unpublished draft paper of September 29, 2000, p. 16.

metric tons of carbon in 2000 to more than 2.5 trillion metric tons in 2050.[23] *(See Chart 6).*

Chart 6: World Passenger Travel Carbon Dioxide Emissions, 1960-2050



Source: Schafer and Victor, 2000.

Even significantly increasing vehicle fleet mileage and/or moving to non-petroleum fuels will not start reducing total carbon emissions until at least after 2020.[24] Since the U.S. currently is responsible for one-quarter of all world carbon dioxide emissions,[25] we may come under intense pressure from other nations to make significant reductions in these levels. Meanwhile, transportation fuel continues to be a major contributor to poor air quality. Transportation is the source of 35% of total U.S. volatile organic compound (VOC), 47% of oxides of nitrogen (NOx), and 66% of carbon monoxide (CO) emissions.[26] As vehicle usage climbs, these levels will rise along with them.

At some point, it is inevitable that the world will seriously confront this continuing degradation of the atmosphere. The Rio de Janeiro (1992) and Kyoto (1998) global summits did establish the stabilization and eventual reduction of greenhouse gases as a common global goal. The Kyoto Protocol, in particular, called for the U.S. to cut greenhouse gas emissions to 7% below 1990 levels by the year 2010. It is extremely

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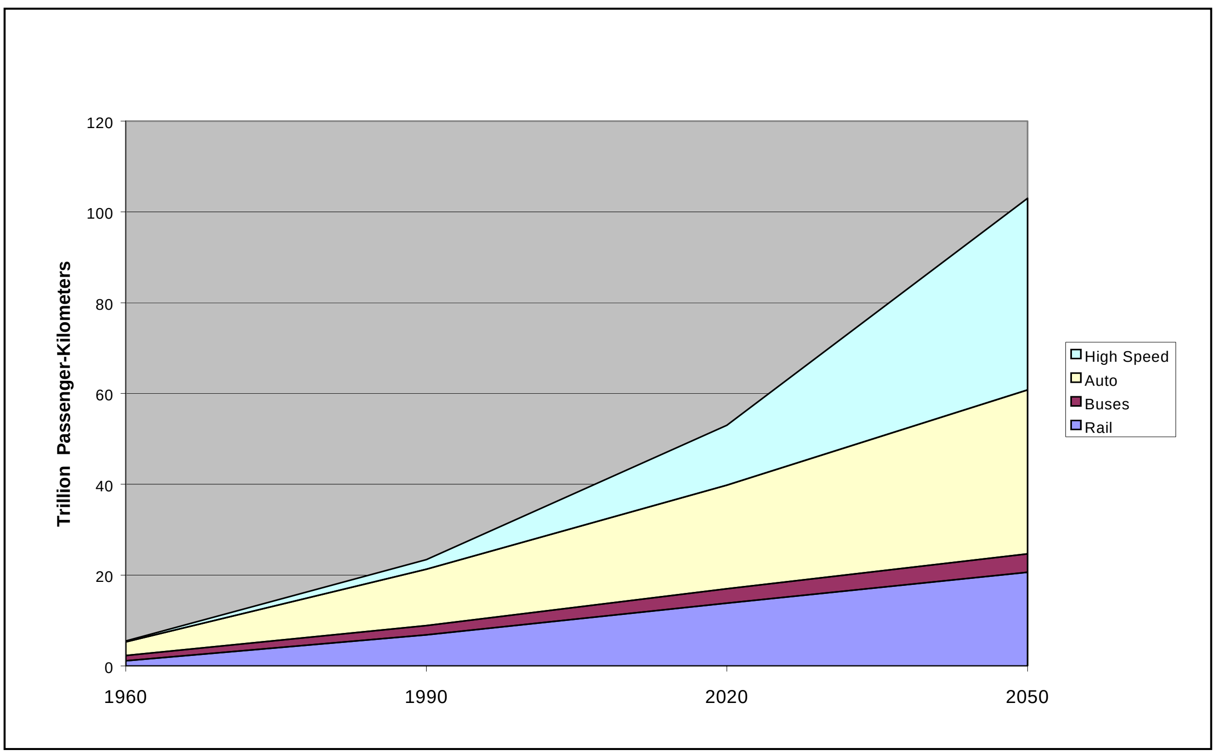
[23] Presentation by Andreas Schafer, September 2000.
[24] *Ibid, passim.*
[25] *Ibid*, pp. 9-10.
[26] *Transportation Statistics Annual Report*, September 2004, p. 118.

doubtful that this goal could be met, either in 2010 or at any conceivable time in the future, without a massive shift in transportation fuels away from our current dependence on petroleum.

Transportation and the Economy: There have been numerous projections of national and global transportation demand, each one based on a specific set of conditions and assumptions. What is common across all of these exercises – except for those that posit a major world crisis in the near future -- is that the overall volume of both passenger and freight movements is definitely heading upwards.

One recent estimate by Andreas Schafer and David Victor projects total world passenger travel from 1960 out to 2050 based on two constants: first, that individuals at all levels of economic development have a personal *travel time budget* of about 1.1 hours per day; and second, that the average speed of personal travel increases with income. This approach suggests that total passenger kilometers will more than double between 1990 and 2020, and will double again by 2050 to hit 103 trillion passenger kilometers in that year. *(See Chart 7).* It is interesting to note that more recent research by Dr. Schafer suggests that total per capita miles traveled tends to plateau and even diminish at the highest income levels.

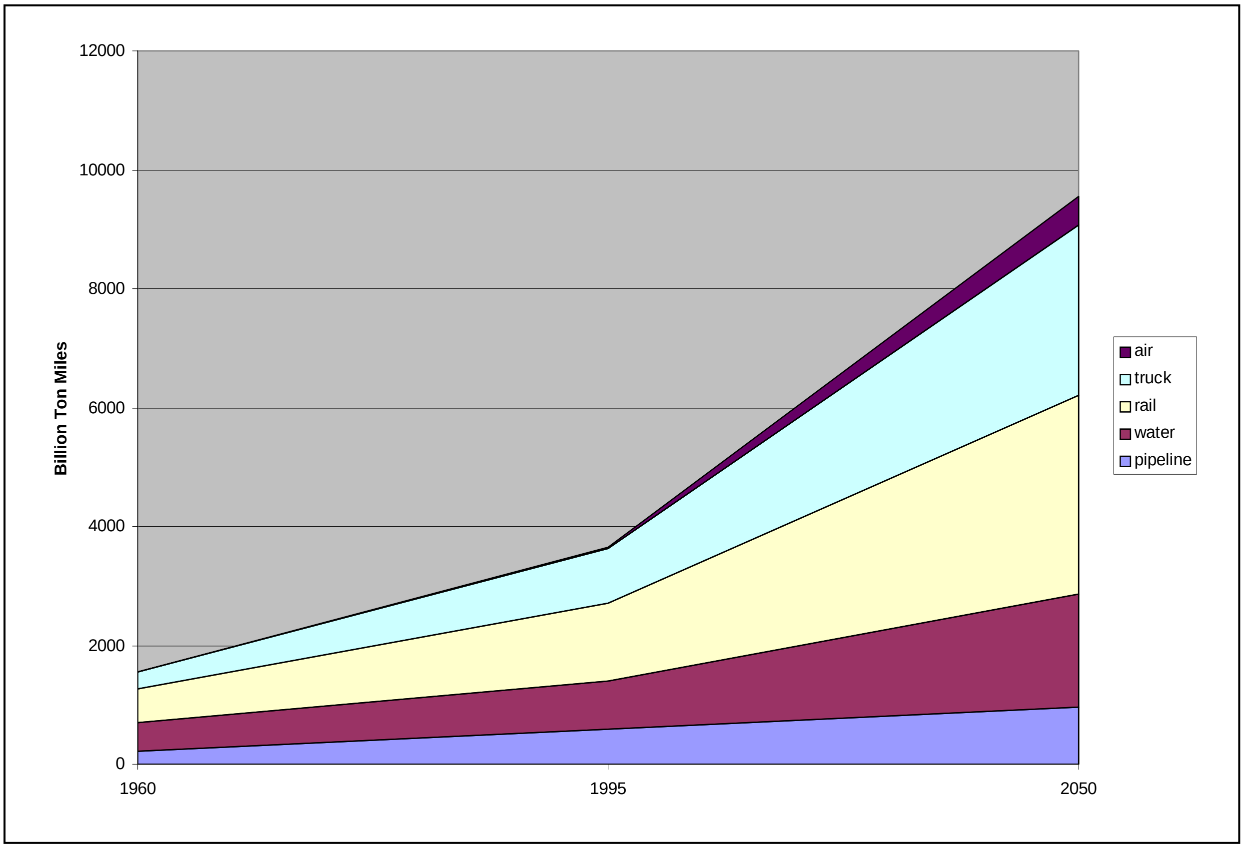
Chart 7: World Passenger Volume 1960-2050



Source: Schafer and Victor, "The Past and Future of Global Mobility", Scientific American, October 1997, p. 39.

A similar analysis of U.S. domestic freight projected demand out to 2050 based on the fact that total freight volume has risen at twice the rate of population over the past forty years. This trend is projected to continue into the future as well. A recent Boeing Corporation projections for 2004-2023 put worldwide GDP growth at 3% annually, passenger traffic growth at 5.2% annually, and cargo traffic growth at 6.2% annually over this twenty-year period. [27] This approach posits a similar tripling in freight demand from 3.2 trillion ton miles in 1990 to 9.5 trillion ton-miles in 2050. *(See Chart 8).* These projections suggest that total transportation volume may see a four-fold increase by the year 2050. The consequences of this type of growth on congestion, safety, the environment, energy, land use and living patterns will be truly profound.

Chart 8: U.S. Domestic Freight Volume 1960-2050



Source: M. Safford, 2000.

[27] Boeing Commercial Airplanes, *Current Market Outlook 2004: World Demand for Commercial Airplanes* at http://www.boeing.com/commercial/cmo . The Airbus *Global Market Forecast 2004-2023* at http://www.airbus.com/media/gmf.asp reaches similar estimates of 5.3 per cent annual passenger growth and 5.9% for cargo.

IV. Impact of These Trends on Transportation Markets

A. Long Distance Passenger Transportation

Demand for long-distance travel (trips of more than 1000 miles) will increase, driven by population and economic growth and rising personal affluence. This growing volume of travel will be especially apparent between the large megacities, each with tens of millions of inhabitants, scattered across the globe. The only feasible solution for rapid travel between continents will still be aviation. However, every survey of future global air travel foresees an inevitable saturation of existing airports and major constraints to additional growth occurring within a very short time.

One solution may be coastal airports for supersonic/hypersonic aircraft that will fly oceanic and polar routes between the major population centers. Another concept would be to build new airports offshore, as the Japanese had proposed to do with Kansai airport in the early 1990s. Dutch transport officials, in fact, are considering building such an airport in the North Sea several miles off the Dutch coast.[28] Costs and environmental concerns, however, could make such projects both controversial and difficult to accomplish.

Another alternative is channeling aviation growth into the existing smaller regional airports surrounding a major hub. This trend can already be seen in areas such as New England, where Providence, Manchester and Bradley (Hartford-Springfield) airports already are becoming alternatives to Logan. New large-scale airports could also be constructed in remote areas specifically to serve as transfer points in a global 'hub and spoke' network. High-speed surface networks – whether steel rail, maglev or another concept -- could feed passengers to and from these airports. Due to the well-known noise issues with SSTs, transcontinental aviation (i.e., NY to LA) will probably have to stay subsonic. It may also face competition from long-distance high-speed surface systems.

It may also be possible to make better use of the existing airport infrastructure. In addition to the large commercial aviation facilities, there are over 16,000 general aviation (GA) airports in the US that can be used by smaller aircraft. This nationwide network means that it is possible for a small group of passengers to travel directly from one point to another, bypassing commercial aviation and the hub-and-spoke system. New technologies are being developed to exploit this network, including new small 'executive jet' aircraft concepts for faster, more efficient and less polluting travel. Depending on the cost and availability of such aircraft and the capabilities of the future air traffic control system, general aviation could meet a growing segment of this market demand. NASA has an active Small Aircraft Transportation System (SATS) program

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[28] Presentation by Wilbert de Kok of the Dutch Ministry of Transport, Public Works and Water Management at the Volpe Center, Cambridge MA, September 27, 2001

exploring the contribution this type of service could make to meeting future travel demand.

Eventually (closer to 2050), hypersonic commercial aircraft may start to appear. This technology would offer much faster flights, but there are a number of technological, cost, safety, health and environmental issues that must be resolved first.

B. Intercity Passenger Transportation

Demand for shorter trips, especially between major cities, will increase for the same reasons cited above. High-speed rail networks and general aviation are alternatives over short and medium distances (up to perhaps 1000 miles). Due to safety and operating issues, a high-volume, high-speed passenger rail network would probably have to be separated from the freight rail network, and both would ideally have no (or as few as possible) at-grade road crossings. Land use pressure also suggests that these new networks would have to be accommodated within current long-distance rights-of-way as much as possible, which considerably limits the number of feasible new routes.

As mentioned above, a new generation of smaller jets could increase travel volume between cities. It is also possible that tilt-rotor aircraft, helicopters, or even a new concept of personal aircraft could augment conventional fixed-wing aircraft in this market. High-speed ferries can also be a viable alternative in areas where navigable waterways are available.

Without major technological breakthroughs, highways will probably remain the primary mode for short and medium distance intercity travel. Increasing road congestion, however, could stimulate a shift by some customers to other means such as air, rail and waterways. Highway traffic will probably still consist of some advanced type of passenger and freight vehicles (autos, buses and trucks), but with different fuels and propulsion systems starting in Tier I countries and 'trickling down' to the other countries over time. The recent growing popularity of hybrid vehicles in the U.S. and high-mileage diesel engines in Europe are examples of this trend in action. As Intelligent Transportation Systems (ITS) applications are introduced to highways, benefits such as better safety, higher speeds, and more capacity will result.

In the early 21st Century, Tier II and later Tier III nations will likely pass through the same motor vehicle cycle as Tier I nations did in the late 20th Century. As incomes and populations rise in these regions, a literal explosion of 'conventional' motor vehicle production, ownership and usage is almost inevitable. In fact, the shift in motor vehicle manufacturing from Tier I to Tier II nations and the rapid growth of motor vehicle ownership in Tier II-III nations was already underway in the late 20th Century. In Europe, for example, most new motor vehicle factories are being built in Asia and the former Communist states of Eastern Europe to take advantage of significantly lower labor costs. However, even as these new factories spring up across the developing world, the ultimate ownership and management of these facilities often remains with the existing global auto companies and the target market for the output is often the developed world. *(See Chart 9)*. It is also interesting to note that both Boeing and Airbus are increasingly entering into co-production or supplier agreements with aircraft companies in China, the former Soviet Union and other nations in these regions to supply both component and entire sub-sections of their latest aircraft models. Part of the motivation for these agreements is to decrease the costs of the final products, and part is to help encourage these nations to purchase the final products as well.[29]

Chart 9: Representative New Auto Factories Locations and Ownership

Where Will the Next Hyundai Come From?

Model	**Built in?**	**Affiliation?**
Dacia	**Romania**	***Renault* owns**
Maruti	**India**	**Indian Govt/*Suzuki* Joint Venture**
Lada	**Russia**	***Fiat* started, *GM* now markets in Europe**
Proton	**Malaysia**	***Mitsubishi* helped start**
Seat	**Slovakia**	***VW* owns**
Skoda	**Czech Republic**	***VW* owns**

Source: Safford, 2005

Actually, the recent increase in output in Tier II nations is noticeably higher than in Tier I producers. As this greatly expands transportation mobility and accessibility, however, it will also put great strains on the infrastructure, environment, land use and energy supplies. The impact on petroleum supplies, prices and availability must be monitored carefully to avoid serious consequences for the global energy and environmental situations.

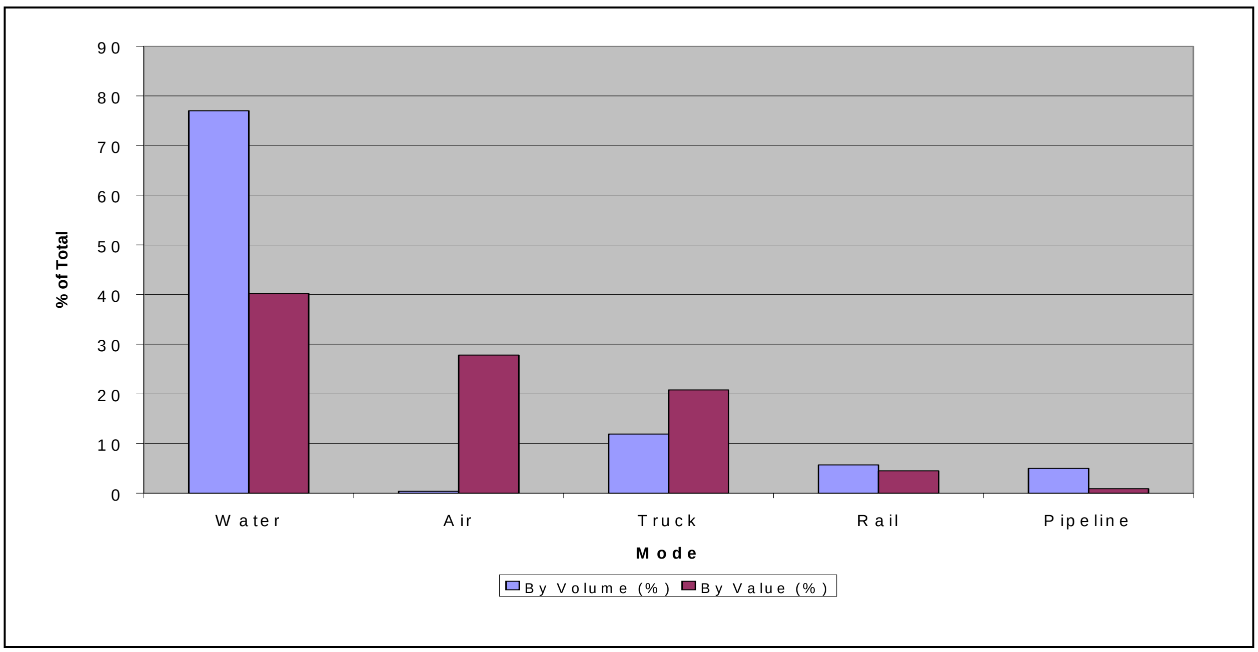
C. *Long Distance/Intercity Freight Transportation*

[29] For example, see "Boeing Deals for Supplies from Russia, *New York Times,* August 12, 2006.

Demand will increase significantly, for shipments of both low weight/high value finished products and the traditional bulk shipment of raw materials. This demand could spur a separate network of freight-only airports as well as high capacity freight aircraft. High-speed rail could also compete for these trips up to about 1000 miles or so.

It is interesting to note that, as of 1997, air carried only 0.4% of U.S. imports and exports by volume, but 28% by value. *(See Chart 10)*. As the U.S. economy moves increasingly towards the production of low weight/high value goods, airfreight can be expected to grow in importance. At present, almost one-fifth of airfreight value is electronics and computers, with significant quantities of transportation parts, precision instruments, pharmaceuticals, and fresh produce.

Chart 10: Carriers of U.S. International Goods Trade, 2001



Source: BTS, US International Trade and Freight Transportation Trends, 2003.

For bulk, a freight rail network based on the current infrastructure but with higher average speeds and reliability may be developed. For transoceanic bulk shipments, for which ships will continue to carry the majority of trade by volume, higher speed freighters using innovative hull designs and propulsion methods are likely, as is the deployment of 'mega-carrier' container ships and improved automated cargo handling systems to load and unload ships more rapidly. However, these larger vessels require new ports or major enhancements to existing ports to accommodate their much larger sizes and freight volumes. In fact, the largest container ships in service now cannot enter U.S. ports fully laden and even bigger ships are on the drawing boards.

In addition, there is potential for increasing waterborne intercity domestic freight, especially along coasts and on inland river systems. In Northern Europe, where landside congestion has precluded creation of significant rail and highway corridors, cargoes that had been moved by truck and rail are increasingly returning to coastal ship and inland barge transport.

D. *Urban Passenger and Freight Transportation*

Urban transport will probably be the area with the most intense demand growth. The densely packed megacities will put extreme pressures on the current infrastructures for both moving very large numbers of people and delivering a much higher volume of goods locally. Each city will need to develop its own specific land use patterns, but denser concentrations of population are inevitable.

Given the large footprint of the current urban transportation infrastructure, very little ground level addition to this system seems possible. Possible alternatives include: going underground for greatly expanded subway systems to carry people and goods; building a new guideway above the ground over existing rights-of-way for maglev/light rail/monorail-type systems; exploiting existing infrastructure such as rail and waterways; and/or ITS. Among the latter possibilities are true traffic management, in which individual vehicles are actually routed and directed centrally and the drivers' role is minimized, and demand-response systems that can rapidly dispatch and direct transit vehicles.

The idea of moving urban freight underground is not new. Between 1906 and 1959, the Chicago Tunnel Company operated a freight service under downtown Chicago using sixty miles of two-foot gauge track and electric rail cars to deliver freight to various buildings.[30] Currently, the Netherlands is developing a concept termed the Underground Logistics System (OLS in Dutch) that would run between freight terminals at Schiphol Airport - the nation’s major international gateway - a nearby freight rail station and a warehouse next to a major highway. This system, which would eventually grow to 24 kilometers, would thus connect air, road and rail modes. Prototype vehicles for this system are currently being tested at the University of Delft. About $14 million has already been budgeted for OLS research; building the entire system is estimated to cost about $300 million.[31]

V. Future Technologies and Transportation

Technology's Role Expands: An essential factor to remember when discussing possible transportation 'futures' is that the existing physical infrastructure has slowly evolved over decades of incremental additions and improvements. Recent large-scale transportation projects – the Boston Central Artery/Tunnel ('Big Dig'), the 'Chunnel' under the English Channel, etc. – have taken several decades from inception to

[30] Additional information is available at http://membres.lycos.fr/fdelaitre/Chicago.htm and http://www.ameritech.net/users/chicagotunnel/tunnel1.html. In 1992, these tunnels flooded when the Chicago River poured in through a crack caused by pile driving.

[31] Information provided to the authors by the Royal Netherlands Embassy, Office of Transportation, Washington DC in April 10, 2000

completion. The global transportation vehicle fleet -- motor vehicles, ships, locomotives, aircraft, etc. -- also represents a massive financial investment in equipment that can mostly remain operational for several more decades. Thus, to a certain extent, transportation operations will be constrained to utilizing these existing physical assets for many years to come. For example, Boeing recently estimated that two-thirds of the world's current commercial aircraft fleet will still be operating twenty years from now.[32] This means that much future transportation investment – particularly in the next decade – may tend to focus on enhancing the capacity of existing physical assets rather than building infrastructures and vehicles based on new technological advances. In addition, there are sections of the current physical infrastructure – such as certain bridges, shipping channels, docks, locks and dams – that will require renovation or replacement regardless of these new technologies.

The current trend of embedding new technologies into the operations and management of transportation will continue, and accelerate. This same trend will also be noticeable in most other areas of life as well. The actual transportation process will continue to be increasingly automated, to the point where many (if not most) aspects of it may seem to occur in the absence of human intervention. This will be facilitated by the continuing evolution of computer and communications components and networks, as well as by the enormous amount of information that can be generated, communicated and processed in real time by these systems.

Information Technology (IT): IT is based on automation and computers – hardware, software, networks, operating systems – and people trained to use them effectively. In addition, telecommunications is becoming an integral part of these applications. It is in fact the merger of computers and telecommunications that enables these improvements to occur and generate the benefits that they do. Thus, 'IT' incorporates computer services and telecommunications, as well as the trained and skilled staffs to operate them and the technological consequences of their continued evolution. Among the most important examples of the application of IT to transportation are Intelligent Transportation Systems (ITS) and its various derivations in the different transportation sectors, and the Global Positioning System (GPS).

ITS and GPS*:* It is nearly impossible to envision the next several decades without including the rapid proliferation of both ITS and GPS applications throughout transportation. ITS began in the late 1980s as the "Intelligent Vehicle-Highway Systems" (IVHS) program. It envisioned the continuing application of information and communications technologies to the management and operation of individual transportation vehicles, vehicle fleets, and traffic management systems. Since then ITS has expanded to become a major technological endeavor which receives several hundred million dollars of federal funding annually, and a significantly higher investment by state and local governments and private sector companies. More than 25 specific ITS 'user services' have been identified in a variety of categories. These include:

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[32] Boeing Commercial Airplanes, *Current Market Outlook 2001*, June 2001, p. 13.

- *Vehicle Control and Safety*. Also known as the *Intelligent Vehicle Initiative*, activities include developing collision avoidance, vision enhancement, driver condition monitoring and related applications that will warn drivers of dangerous situations, recommend corrective actions, or even assume partial control of the vehicle (autos, trucks and buses) to avoid a collision.

- *Traveler Information*. By applying advanced IT technologies, real-time traffic and traveler information can be gathered, analyzed, and made accessible to drivers, operators and passengers via a range of media – radio, telephone, variable message signs, kiosks, the Internet, etc.

- *Electronic Payment*. The use of paperless financial transactions – such as electronic invoices, 'smart cards', 'e-tickets' and 'e-money' – can save considerable time and ensure greater financial accuracy in transportation transactions. A number of toll roads, for example, already use vehicle-mounted electronic transponders to allow motorists to pass through toll plazas without stopping to make payments.

- *Telematics*. Reliable two-way communications between separate vehicles and between vehicles and the roadside is the basis for a wide range of successful ITS services. These range from electronic toll collection and emergency notification to driver information and vehicle/fleet management systems.

- *Transportation Management*. Combining computers, telecommunications, and positioning systems enables both real-time tracking of individual persons, packages and vehicles, as well as traffic management centers to operate consolidated ITS services in metropolitan areas.

- *Commercial Vehicle Operations*. Long-range trucking operations can benefit significantly from services that enable trucks to minimize the number of stops they need to make. This can be accomplished through such services as weigh-in-motion, automated vehicle identification, electronic credentials from multiple jurisdictions (including international border crossings), and onboard and roadside vehicle safety inspection and monitoring.

- *Public Transportation*. Many of the vehicle and fleet-based ITS services can also be implemented for transit fleets, particularly buses and demand-response vehicles.

In addition to these road and transit applications, ITS-type systems are being developed and deployed in other modes as well. The Department of Transportation's Marine Transportation System (MTS), for example, is incorporating IT applications such as Vessel Traffic Services (VTS), Physical Oceanographic Real-Time Systems (PORTS) and Electronic Navigational Charts (ENCs) to improve the productivity, safety and security of the nation's shipping. US railroads are implementing Positive Train Control (PTC) systems that use navigation, communication and information technologies to run trains at faster speeds yet closer together. This can significantly increase the volume of traffic that a rail line can handle in any given period of time.

The Federal Aviation Administration's National Airspace System (NAS) is a prime example of real-time traffic management that depends on advanced information and communications technologies to manage thousands of flights simultaneously over the continental United States. All freight modes are using ‘tagging and tracking’ technologies to monitor the location and movement of packages and containers. Finally, traveler information and electronic payment systems can benefit passengers and shippers in all modes.

The Department of Defense originally developed the GPS concept as a means of enabling pinpoint weapons delivery on targets over great distances. GPS consists of a constellation of geosynchronous satellites continually transmitting precise location and time signals. By reading and analyzing several of these signals at the same time, an electronic GPS receiver can determine its location with far greater accuracy than was previously possible. It was soon realized that this capability could also be useful in many other fields, ranging from search and rescue and navigation to tracking the location of non-military individuals and objects anywhere on the globe. Similar European (Galileo) and Russian (GLONASS) systems are also been deployed.

GPS is now extensively used by the private and commercial sectors, including all modes of transportation. In the process, it also spawned a new consumer electronics market. Accurate, hand-held GPS receivers can now be bought nearly anywhere for under a hundred dollars. This real-time position location, tracking and navigation capability is being combined with other technologies such as ITS and personal communications devices (PCDs) to provide greatly enhanced services.

<u>Telecommunications</u>: The impact of the emerging global personal wireless communications networks on transportation, as on other aspects of daily life, is bound to be profound. One likely outcome is an increase in real-time information available to transportation users, along with the ability to request demand-response services from any location. Even now, many PCDs include cellular telephone, wireless Internet and e-mail capabilities. This may help stimulate the expansion of transit, paratransit and taxi/limousine services. PCDs with GPS-type capabilities can also act as personal locators. Freight customers could also use PCDs to help them track and locate shipments, and even re-route or re-prioritize goods in transit.

Tele-conferencing, tele-commuting, e-commerce and virtual reality applications may replace actual passenger transportation in a number of circumstances for both business and pleasure. How people react to these time and cost savings, however, or whether they would prefer these substitutes to face-to-face interactions, remains to be seen. Ironically, it may lead to an actual increase in travel and tourism as people replace one reason for making a trip with another one. This trend has already been noted in previous travel surveys.

Finally, this inevitable embedding of IT into transportation will give issues of information security and information assurance a much more prominent role. As transportation increasingly relies on information and communication systems and technologies, it also grows more vulnerable to their disruption. To be truly useful, we need to maintain the *integrity, availability, validity, accuracy, accessibility, timeliness, and privacy* of both these systems and technologies and of the information and knowledge that they manage. If one or more of these attributes is compromised, transportation services will be degraded. Ensuring that these high standards are met will require major efforts and a significant allocation of resources. Not doing so, however, could expose the entire transportation enterprise to unacceptable degradation. Thus, significant efforts must be made to assure the security both of this information and of the IT systems and networks that transmit it.

New Fuels: The need for new non-petroleum based transportation fuels will become even more acute as demand for oil grows. Much research is currently under way, but the definitive 'next fuel' is still to be determined. Among the known candidates are electricity, alcohol, methane, natural gas, ethanol, and hybrids (with or without petroleum). Practical fuel cells for motor vehicles will probably emerge early in the 21st Century. They are already being tested on automobiles, trucks, and buses. These may also be implemented in rail locomotives and ships.

At the present time, the motor vehicle industry is developing several alternate fuel vehicles for possible mass distribution. In the U.S., both Toyota (Prius) and Honda (Impulse and Civic) have recently introduced gas-electric hybrid vehicles, selling about 15,000 vehicles each year. The 'Big Three' manufactures (Ford, GM, DaimlerChrysler) have announced similar programs to introduce their own hybrid models over the coming decade. GM, for example, plans to bring out Chevrolet Equinox and Malibu and Saturn VUE SUV hybrids by 2005. In announcing this program, GM President and CEO G. Richard Wagoner said, "Although today's hybrid market represents relatively low volumes, we are well-positioned to meet any market demand that may develop. In fact, if consumers were to select the hybrid option on all of the models included in our multiyear plan, it could eventually exceed one million vehicles" annually.[33] There are a few prototype hydrogen fuel cell vehicles available, and this power source may ultimately offer the most effective alternative to petroleum fuel. Locomotives, ships and even small aircraft powered by fuel cells are also being explored.[34]

Meanwhile, existing systems are being continually improved. For a number of years, NASA and aircraft engine manufacturers such as General Electric and Pratt and Whitney have been engaged in developing newer, quieter and more efficient aircraft engines. NASA's Ultra Efficient Engine Technology (UEET) Program, for example, will

[33] "GM commits to hybrid gas-electric technology", ***Providence Journal***, January 22, 2003, Automotive Section.
[34] An *Aviation Week and Space Technology* article of September 9, 2002 (p. 26) discussed a $315,000, 3 to 6 month contract Boeing received from the U.S. Defense Advanced Research Projects Agency to design a fuel cell-based aviation propulsion system. The goal is to produce an energy source for extremely long-endurance -- at least two weeks -- unmanned surveillance or communications relay aircraft that could lift a 250 pound payload.

receive about $30 million between FY 2002 and 2006. One of the goals of the UEET program is to reduce NOx emissions by using lean-burning jet engine combustors. Researchers have been able to reduce the noise generated by jet engines by increasing the size of bypass fans – used to increase fuel efficiency – and redesigning the fan blades. They are also investigating other advanced technologies to reduce engine noise and emissions, such as active noise control via electronics and computerized control of engine functions.[35] Additional reductions in fuel usage and total emissions can be gained through improved aerodynamic efficiency, reductions in aircraft weight through using advanced lightweight alloys and composite materials, and increasing aircraft load factors.[36]

These advances could do much to ease the demands transportation places on the world's petroleum production. As a corollary, the environmental degradation attributed to petroleum fuels should also ease significantly. However, due to the need to phase in new vehicles into the existing inventory over time, this will not make a significant impact for at least 10 to 20 years.

Nanotechnology and Advanced Materials: The potential for nanotechnology – the building of devices and materials at the atomic and subatomic levels and the exploitation of the novel physical properties at this scale -- is only now just beginning to unfold in transportation and other possible areas. Its potential is still undefined: however, many observers believe it could have a profound impact in a wide range of applications.

Likely nanotechnology applications in transportation include:

- Embedded sensors in vehicle and infrastructure materials and components that can monitor and communicate real-time conditions and identify – and perhaps even automatically respond to -- maintenance and replacement needs;

- Improved physical materials with new and/or improved properties for vehicles, infrastructure and other supporting components and systems;

- Molecular level computing and telecommunications that could operate transportation systems and subsystems; and

- Carbon-based 'nanotubes' as hydrogen carriers for fuel cells.

In a similar manner, advanced materials are increasingly being deployed in new transportation applications. For example, several hundred highway bridges composed of fiber-reinforced polymers have been installed in the past decade, primarily in North

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35 U.S. General Accounting Office, *Aviation and the Environment: Strategic Framework Needed to Address Challenges Posed by Aircraft Emissions*, February 2003, GAO-03-252, pp. 59-63.

36 Joosung Joseph Lee, *Historical and Future Trends in Aircraft Performance, Cost and Emissions,* Master of Science Thesis, Massachusetts Institute of Technology, September 2000, p. 138.

America and Europe. These ‘plastic’ bridges require less maintenance and last longer than conventional steel and concrete structures, and resist corrosion, frost, mold and insects. They can also be readily disassembled and reassembled if needed. In addition, strands of optical fiber are being modified to act as very efficient and cost-effective sensors in such structures as bridges, dams and pipelines.[37]

Human Factors: An important caveat to the comments above is that there may be a limit to the extent to which both operators and users of an automated system can remain comfortable with it. The role of the 'human-in-system' needs particular attention. There are a number of important questions:

- How complex can a system become before the human operator/monitor is no longer able to know when it is vulnerable to breakdown or malfunctioning?

- Will passengers be willing to entrust their safety to a fully automated transportation system, or one with no sign of a human operator?

- How can the system be designed so that it can readily adapt to people in a manner that stresses the strengths of both people and machines?

- How can the reliability of a complex software program be tested when it is even more sophisticated than any of the available testing procedures?

In addition to these topics, there are other Human Factors research topics that need to be explored. They include operator fatigue/alertness, impaired operator performance, and safety factors associated with aging operators.

Educated Workforce: The successful introduction of new technologies and related procedures into transportation must be accompanied by effective training in these new skills for both users and especially operators. In addition, current key skill shortages in such vital occupations as truck drivers, pilots, and information technology could become worse in the future and/or exacerbated by technological changes. Ironically, new training and educational technologies may also help to accomplish this goal. The primary issue here is to determine how to use new technologies to recruit, train and retain required workers at the optimum skill levels.

In addition to workforce training, however, the transportation customers must be made aware of the advantages and benefits as well as the limits of these new technologies. This knowledge will help them accept and support the changes and innovations that the transportation system will need to implement in order to continue meeting their needs.

Human Enhancement: There is another human-focused recent trend that could significantly impact the future of transportation. It can be envisioned by aggregating the

[37] *The Economist Technology Quarterly,* June 11, 2005, pp. 12-14.

plethora of advances in health sciences, genetics, biotechnology, IT and nanotechnology that all hold the promise for improving various human attributes: health, stamina, endurance, strength, speed, or intelligence. Human tissues are being grown artificially in the laboratory; various forms of therapeutic cloning are being developed; both organic and inorganic implants and replacements for portions of various bodily systems are being tested; a growing array of chemicals and pharmaceuticals are being sold not just to cure disease and correct defects, but actually to improve or enhance various human functions.

When combined, these could be collectively referred to as the ’Human Enhancement’ Movement. These capabilities raise interesting and important questions about future society, not just in transportation but also in a wide range of topics. How will our daily lives be affected by the wide-scale introduction of these enhancements into the general population? How will daily living activities like shopping, working, driving and operating machines and systems be affected? Will drivers be allowed to stay active well into their second century as long as they receive these ‘improvements’? What if only a small number of people can afford or be able to receive these enhancements? How safe will the roads be with such a wide and increasingly diverse range of skilled drivers behind the wheels?

These are heady questions that will inevitably be raised, and that society will have to try and answer, before we decide how to proceed.

Not a Likely Future Transportation System . . .

VI. <u>In Summary:</u>

The next few decades can be an exciting, dramatic time of growth and affluence, but we must start preparing for it now. Transportation demand may well explode, and must be accommodated to allow continued growth through the short-term until the longer-term solutions are in place. We will need to "manage the transition" to the future. This demand can be met only with the help of new technologies. In particular, the globe must transition to non-petroleum fuels <u>and/or</u> mitigate petroleum fuels emissions if it is to maintain an effective transportation system and a clean planet at the same time.

There are also some insidious "dangers to avoid". The first of these is <u>Inequity</u>. If growth and affluence is uneven, conflict and civil unrest will result, both within and between nations. Terrorism and/or radical politics could proliferate. Within the US, a similar social fissure could emerge if only a segment of the overall population benefits from economic growth and technological advances. The second danger is <u>Gridlock</u>. Many current transportation systems are at or near capacity, including many urban road networks and portions of the nation's air traffic control system. These problems need fixing before growth can continue smoothly - successful *transition management* will be needed. The third and in many respects most serious danger is <u>Environmental Damage</u>. What if the consequences of global warming appear sooner, and more destructively, than we think they will? What if transportation is determined to be the most significant contributor to global pollution? If transportation does not learn to clean itself up, it may be required to do so by others.

Finally, there are some important questions to ponder about the future of transportation; questions that need to be answered before we can develop and implement the improvements that will be needed. For example:

- Will we ever safely be able to drive, talk on the phone and surf the Net at the same time? Or perhaps will we learn to feel comfortable when computers are driving the vehicles in which we are sitting?
- How can the US help the developing world rapidly build a modern highway system that is safe, efficient and affordable? (Some might ask 'How can the US build one for itself?!')
- What lessons can highway traffic management learn from air traffic management? Or the reverse?
- How much tele-substitution will actually occur? Will tele-substitution truly create a reduced demand for transportation services, or will it have any noticeable impact at all?
- Above all, how safe will driving be when half of the drivers have the strength and reflexes of a Superman and the other half do not?

These and many other questions like them need more thoughtful exploration. The time to start exploring them is now.