Institutional Price: $50.00

THE TRANSPORT SECTOR AND GLOBAL WARMING

Edward A. Parson

E-90-11 G-90-07

The views expressed in this paper are the author's and do not necessarily reflect those of the Energy and Environmental Policy Center, of the Science, Technology and Public Policy Program, of the Global Environmental Policy Project, or of Harvard University. Reproduction of this paper is not permitted without permission of the Energy and Environmental Policy Center. For permission, contact the Publications Department, Energy and Environmental Policy Center, John F. Kennedy School of Government, Harvard University, 79 John F. Kennedy Street, Cambridge, MA 02138.

THE TRANSPORT SECTOR AND GLOBAL WARMING

Edward A. Parson

Room G-27, Kennedy School of Government
79 JFK St
Cambridge MA 02138
(617) 495-1443

ACKNOWLEDGEMENTS

The work presented in this report was partially supported by the United States Congress Office of Technology Assessment, as part of their study of policy options pertaining to global climate change. I am indebted to my employers and colleagues at OTA for the wonderfully stimulating work environment they provided, and for their incisive and challenging criticism and comment: Rosina Bierbaum, Peter Blair, Joy Dunkerley, Bob Friedman, Henry Kelly, Stan Kolar, Jana Milford, Bob Niblock, Steve Plotkin, Rich Rapoport, Nick Sundt, and others. Others whose comments and advice contributed to the report include Bill Chandler, Bill Clark, K.G. Duleep, Phil Patterson, Maxine Savitz, Lee Schipper, and Michael Walsh. I owe a particular debt of thanks to the participants in OTA's workshop of April 6, 1989. Remaining errors are my sole reponsibility.

EXECUTIVE SUMMARY

This report examines the relationship between transport and global warming. It looks at both the technology and the economics of transport, at passenger travel and freight, and at the domestic US sector and the rest of the world. Because of data and length limitations, though, the US treatment is much more detailed than that of the rest of the world. Generally, US information is presented in some detail, and a sense of worldwide variability is conveyed through figures for aggregated world regions or representative nations, depending on availability. The discussion of surprising futures in Chapter 6, and policy options in Chapter 7, both focus exclusively on the USA.

TRANSPORT CO_2 IN CONTEXT

Transport's contribution to global warming comes principally from the carbon dioxide (CO_2) released by burning fuel. Consequently, to a close approximation, transport's contribution to global warming is proportional to transport energy consumption. The important exceptions are that chlorofluorocarbons (CFCs) are used in vehicle fabrication and for transport air conditioning, and that if other fuels replace petroleum as the principal source of transport energy, the constant of proportionality between CO_2 emissions and energy use will be changed.

In 1985, the US Transport sector consumed 20 Quadrillion BTUs of energy (Quads) and emitted 413 Teragrams (million metric tons) of carbon as CO_2. This carbon represented about 30% of total US fossil fuel carbon emissions, while the US contributed 23% of world

fossil fuel carbon emissions. Worldwide, fossil fuel combustion was about 75 - 80% of total carbon emissions (the rest came mostly from deforestation), and CO_2 represents about half of total current contributions to the greenhouse problem. Multiplying all these shares together indicates that the American transport sector contributes about 5% of total world CO_2 emissions, or about 2.5% of the total greenhouse problem.

TRANSPORT ACTIVITY AND TRENDS

In 1985, Americans travelled 3.2 trillion passenger-miles, 13,335 miles per person. 88% of this total (11,800 miles per person) was in cars and light trucks, and another 9% (1,185 miles per person) by air. This represents more total travel, more travel by car, and higher auto ownership than in any other nation. Worldwide, total travel per person ranges from 5600 miles in the OECD countries to 370 in the low-income developing countries, while car ownership ranges from one car per 1.5 people in the USA to one per 1,374 in the People's Republic of China.

Total travel, car ownership, and travel by car have all increased steadily throughout the world over the past two decades, gradually in the industrial countries and rapidly in the developing countries. In America, the growing quantity of highway travel comprises a modestly declining share of total travel, because air travel is growing even faster. Other modes have shown a slow, steady decline over the past 25 years. In all LDCs, travel and car ownership have been growing faster than income, in many nations faster than 10% per year. Freight has also been growing worldwide, but total freight per dollar of GDP -- which reflects the structure of a nation's economy -- has declined significantly in the US since 1970,

fossil fuel carbon emissions. Worldwide, fossil fuel combustion was about 75 - 80% of total carbon emissions (the rest came mostly from deforestation), and CO_2 represents about half of total current contributions to the greenhouse problem. Multiplying all these shares together indicates that the American transport sector contributes about 5% of total world CO_2 emissions, or about 2.5% of the total greenhouse problem.

TRANSPORT ACTIVITY AND TRENDS

In 1985, Americans travelled 3.2 trillion passenger-miles, 13,335 miles per person. 88% of this total (11,800 miles per person) was in cars and light trucks, and another 9% (1,185 miles per person) by air. This represents more total travel, more travel by car, and higher auto ownership than in any other nation. Worldwide, total travel per person ranges from 5600 miles in the OECD countries to 370 in the low-income developing countries, while car ownership ranges from one car per 1.5 people in the USA to one per 1,374 in the People's Republic of China.

Total travel, car ownership, and travel by car have all increased steadily throughout the world over the past two decades, gradually in the industrial countries and rapidly in the developing countries. In America, the growing quantity of highway travel comprises a modestly declining share of total travel, because air travel is growing even faster. Other modes have shown a slow, steady decline over the past 25 years. In all LDCs, travel and car ownership have been growing faster than income, in many nations faster than 10% per year. Freight has also been growing worldwide, but total freight per dollar of GDP -- which reflects the structure of a nation's economy -- has declined significantly in the US since 1970,

as the economy has increasingly moved from primary industry toward high-value, information-intensive goods and services.

Over the same period, the energy efficiency of transport has been increasing worldwide. The largest gains have been in American light vehicles, which doubled in average fuel economy (from 14 mpg to 28) between 1975 and 1985 through the combined effects of technical progress, oil price shocks, and regulation. This change represented cumulative fuel savings of 178 billion gallons from 1975 to 1987, and cumulative avoided CO_2 emissions of 451 Teragrams carbon. Efficiency gains in American light vehicles have almost ceased since 1985, though. Less dramatic but nevertheless substantial efficiency gains have been made in other modes and nations.

PROJECTING TRANSPORT TRENDS

Future trends in transport greenhouse emissions will be determined by three factors: population growth, travel per person, and greenhouse emissions per unit of travel. Travel per person, and modal shares, are determined by economic choices, many of which are constrained in the short run by existing patterns of settlement, economic activity, and available transportation infrastructure; these constraints determine both how much travel is needed and what choices of modes are available. Greenhouse emissions per unit of travel are largely determined by vehicle efficiency technology, including such market-determined factors as the average size and power of vehicles in the fleet. These factors are also constrained in the short run, due to the remaining lifetime of existing vehicles and the lead times required for introduction of substantial innovations in new vehicles.

Recent growth in the demand for travel has been driven by fast workforce growth, movement of people and jobs from older city centers into lower-density suburbs, and spreading out of worktrip patterns. The consequences have been a sharp increase in auto vehicle-miles travelled (VMT) and accompanying decline in public transit use, increasingly severe congestion on suburban road networks that were principally designed for concentrated suburb-to-Central Business District (CBD) flows, and an increase in average worktrip length (that now shows some signs of reversing as suburban jobs and residences come more into balance). Most analysts project continued VMT growth of 2% to 3% per year until the turn of the century. Finding ways of designing efficient public transit to serve diffuse travel patterns remains a major challenge, but increased concentration of activity in new suburban centers holds some promise, particularly with transit service innovations such as flexible response or smaller vehicles.

Even if revived public transit is able to damp projected VMT growth trends, cars and light trucks are likely to continue to dominate US transport. Consequently, the single most important factor determining future transport energy use and greenhouse emissions will be the rate of light vehicle efficiency gains. Today's best production models and prototypes, which surpass 50 mpg and 80 mpg respectively, both indicate that cars much more efficient than today's average are technically feasible. While several factors will make it difficult to translate efficiencies this high into production fleet performance, an examination of technologies now available suggest that substantial efficiency gains can be attained over the next 10 years even without changing size or performance.

Efficiency improvements are more readily adopted in other modes than in private vehicles, because commercial operators pay more attention to fuel's large share of life-cycle

costs. Efficiency improvements will depend on the rate of technical progress, fuel prices, and the general economic trends that determine the rate of new investment.

New transport fuels may also change the rate of greenhouse emissions per unit of travel. Fuels under development include methanol derived from natural gas or coal, ethanol derived from fermented plant feedstocks, natural gas in compressed (CNG) or liquefied (LNG) form, and hydrogen derived from electrolysis of water. Electric vehicles that run on rechargeable batteries are also being developed aggressively. When the total fuel system is considered, new fuels may increase or decrease greenhouse emissions per mile travelled. Hydrogen or electric vehicles from nonfossil electricity, or ethanol from sustainably managed biomass, will essentially eliminate greenhouse emissions. Natural gas systems (CNG or LNG) will reduce emissions by 15% to 20%, methanol from natural gas or electric vehicles from the present generating mix will leave emissions approximately unchanged, and any system based on coal -- for producing methanol or generating electricity -- will increase emissions from 25% to 100%.

BASELINE PROJECTIONS

This report uses baseline projections drawn from work done by the World Resources Institute (WRI) and Lawrence Berkeley Laboratory (LBL), as part of the recent EPA Stabilization Report. These projects developed two greenhouse scenarios for nine world regions, intended to represent equally plausible baseline futures in the absence of both significant surprises -- technical, political, social, or economic -- and concerted policy intervention. In one scenario, called "rapid change", rising incomes and high energy prices

promote fast efficiency gains, and population growth is on the low side; in the other, called "slow growth", slower income growth and low energy prices hinder new investment and technical gains, while population growth is faster.

In the OECD, these projections show modest activity increases offset by efficiency gains, giving roughly constant transport energy and CO_2 -- slightly lower in the US, slightly higher in the rest of OECD. In the USSR and eastern Europe, activity gains dominate efficiency gains, giving more than a doubling of transport energy. In the five developing regions activity gains swamp efficiency gains, giving 2025 energy levels from double to five times 1985 levels. The projections are shown below.

WORLD TRANSPORT ENERGY USE IN QUADS, 2025 (TABLE 21 IN TEXT)

Region	1985	2025 Rapid Change	2025 Slow Growth	2025 CO_2 (TG C)1
USA	20.0	17.54	19.43	355 - 393
CAN + W EUROPE	13.0	13.84	14.69	280 - 300
JAPAN + ANZ	4.4	4.74	5.31	96 - 107
CP EUROPE	7.0	17.25	18.01	350 - 365
TOTAL DEVELOPED	44.6	53.36	57.63	1080 - 1170
S + E ASIA	2.7	7.49	5.11	103 - 150
CHINA	1.0	5.12	3.15	64 - 104
AFRICA	2.1	10.06	5.81	118 - 204
LATIN AMER	4.4	13.93	9.11	185 - 282
MIDDLE EAST	1.1	3.95	3.04	62 - 80
TOTAL LDCS	11.3	40.55	26.21	530 - 821
TOTAL WORLD	56.0	93.90	83.84	1700 - 1900

Note: 1. CO_2 emissions at 20.256 grams carbon per thousand BTU.
Source: Sathaye et al (1988); Mintzer (1988).

POSSIBLE SURPRISES

Many things may happen in transport that are not represented in these baseline scenarios. As a thought experiment in how different the future might look, a list of possible surprising departures from the "business as usual" case was compiled, with back-of-the-envelope calculations of the effect each would have on 2025 US transport CO_2 emissions. Each surprise was chosen subjectively to represent no more than a 5% to 10% chance of occurring by 2025 under present trends, but not so implausible that it could not

occur under credible discontinuities in technology, markets, social attitudes, or policy -- over 40 years. These hypothetical surprises are not policy options.

Major Efficiency Breakthroughs

There are several technologies now in early development that could, if successful, bring a doubling or more of average fuel economy, even without substantial change in the size or performance of vehicles. These include, among others, oxygen enrichment, the adiabatic diesel with exhaust energy recovery (or other advanced engines), and energy-storage systems. If through these or other technical gains, new car and light truck mileage in 2025 were tripled, the fleet efficiency would be 75 - 85 mpg, and US transport energy use would drop to 13.5 to 15.1 quads and carbon emissions to 275 - 302 TG.

The above technologies could be applied to trucks and buses as well as cars, but their impact may be less. If in addition to the light vehicle gains above, heavy truck and bus mileage were to double relative to the 2025 base case, total US transport energy would drop to 11 - 12.2 quads, with carbon emissions of 225 - 250 Teragrams.

Radically Smaller Automobiles

Huge efficiency gains can be achieved if consumers will accept smaller, lighter, less powerful cars. Today's lightest production models show that 50 - 60 mpg is already achievable in a 4 to 5 passenger car, and much smaller designs are demonstrated in prototype or available overseas. While limited in applications, tiny cars are suitable for some purposes such as urban commuting. If most miles were driven in cars sized for the number of passengers travelling -- say, 40% of vehicle-miles in half-width cars getting 120 mpg, 30%

in micro-minis getting 80 mpg, 20% in subcompacts getting 50 mpg, and 10% in compacts getting 40 mpg -- then fleet efficiency would be 75-85 mpg, yielding the same value for total CO_2 in 2025 as the technical tripling of light vehicle mileage above.

New Power Sources

If any region of the world moves strongly to new fuels, the proportionality between CO_2 emissions and energy will change. If, for example, the US replaced petroleum by methanol as the principal transport energy source -- say, 70% of total transport energy replaced by methanol of which 10% came from biomass, 20% from gas, and 40% from coal -- then total transport emissions would rise by 10% relative to the petroleum reference case, to 390 - 435 Teragrams of carbon.

Alternatively, natural gas could be used as a transition to hydrogen. If, for example, 20% of light vehicles (mostly the larger ones) use CNG by 2025, 10% use LNG, and hydrogen penetration is just beginning, with 10%; if in addition commercial freight has moved 90% to CNG due to cost advantages; and if the newest generation of aircraft have cryogenic fuel storage and represent 40% of air traffic (30% burning LNG and 10% hydrogen); then relative to baseline transport CO_2 emissions, the new light vehicles would save 8%, the freight 6% and the aircraft 2%. Emissions would drop 16% in total, to 300 - 330 Teragrams of carbon.

Finally, the US could pursue an electric vehicle program. If, for example, 10% of American light vehicle miles travelled were replaced by electric vehicles and 50% of all rail travel were electrified, and if the required electric energy came 40% from the present

generating mix and 60% from new, nonfossil sources, then this would reduce US transport carbon emissions by 4.2%, to 340 - 375 Teragrams of carbon.

Urban Public Transit

While American ridership shares of public transit remain low, the experience of cities elsewhere in the world -- and the promising performance of several new light rail systems in western US cities -- suggest that it need not remain so. If for example, through planning, investment, and service innovations, America's major metropolitan areas achieved a 40% public transit share (now achieved in some Canadian cities), then total US transport energy use and carbon emissions would decline by 12.6%, to 310 - 345 Teragrams carbon.

Human-Powered Transport

While the bicycle represents a very small share of US travel (1.8% of worktrips in 1985), recent rapid growth of this share (a quadrupling since 1975) and cycling mode shares as high as 40% in several European cities both suggest that much larger contributions are possible. If in 2025, for example, 30% of trips less than 5 miles and 10% of trips from 6 to 10 miles were replaced by human power, then total urban passenger vehicle-miles would decline by about 8% and total transport energy and CO_2 by 4%, to 340 - 375 Teragrams of carbon. Still larger cycle use, 50% of trips less than 5 miles and 25% of those 6-10 miles, would reduce total transport energy and CO_2 by 8%, to 325 - 360 Teragrams.

generating mix and 60% from new, nonfossil sources, then this would reduce US transport carbon emissions by 4.2%, to 340 - 375 Teragrams of carbon.

Urban Public Transit

While American ridership shares of public transit remain low, the experience of cities elsewhere in the world -- and the promising performance of several new light rail systems in western US cities -- suggest that it need not remain so. If for example, through planning, investment, and service innovations, America's major metropolitan areas achieved a 40% public transit share (now achieved in some Canadian cities), then total US transport energy use and carbon emissions would decline by 12.6%, to 310 - 345 Teragrams carbon.

Human-Powered Transport

While the bicycle represents a very small share of US travel (1.8% of worktrips in 1985), recent rapid growth of this share (a quadrupling since 1975) and cycling mode shares as high as 40% in several European cities both suggest that much larger contributions are possible. If in 2025, for example, 30% of trips less than 5 miles and 10% of trips from 6 to 10 miles were replaced by human power, then total urban passenger vehicle-miles would decline by about 8% and total transport energy and CO_2 by 4%, to 340 - 375 Teragrams of carbon. Still larger cycle use, 50% of trips less than 5 miles and 25% of those 6-10 miles, would reduce total transport energy and CO_2 by 8%, to 325 - 360 Teragrams.

High-Speed Inter-City Rail

If high-speed trains capture half of inter-city passenger travel in light vehicles, and a quarter of air travel, total transport energy and carbon emissions would drop 4.5%, to 340-375 Teragrams carbon.

Surprises in Freight

Freight holds one possibility for a serious feedback from changing climate to transport, as was revealed during the summer of 1988. If some domestic shipping became impossible because of low water levels, the traffic would most likely be diverted to rail, whose energy intensity per ton-mile is about 50% higher. If water transport represented a similar fraction of transport energy in 2025 as in 1985 and 30% of water transport were diverted, total transport energy would increase by about 1%. A more serious feedback from climate to transport would be posed in the longer term, if projected sea level rise in the 21st century inundates ports, rail terminals, and highways.

Less Travel

As an extreme case of technical progress reducing travel demand, suppose that, by 2025, 30% of urban passenger travel is displaced by working at home, and that 10% of air travel is displaced by new forms of communication. The effect would be roughly a 15% decline in total transport energy and CO_2, to 300-335 Teragrams carbon.

The table below shows the effects of each of these surprises on US transport greenhouse emissions in 2025, relative to the reference case. While these numbers depend on the subjective decision of how much departure from the reference case is deemed "barely

believable," the wide range of estimated effects suggests a moderately robust rank-ordering (tolerant of disagreements within a factor of two) of feasible effects. Changes in the energy intensity of highway modes dominate all other effects. Movement to public transit or reductions in travel give effects about half as large, and movement to bicycles or intercity trains about a quarter as large.

EFFECT OF SURPRISES ON US 2025 TRANSPORT CO_2 (TABLE 22 IN TEXT)

Type of Surprise	% Change in CO_2	CO_2 Emissions (Teragrams C)
Reference Case	—	355 - 393
Triple Light Vehicle Eff'y	-23%	275 - 302
Plus Double Heavy Truck Eff'y	-36%	225 - 250
Major Auto Size Shift	-23%	275 - 302
Big Shift to Methanol (mixed source)	+10%	390 - 435
Big Shift to Natural Gas, Hydrogen	-16%	298 - 330
Big Shift to Electric (mixed source)	-4%	340 - 375
Public Transit Boom	-13%	310 - 345
Bicycles 1	-4%	340 - 375
Bicycles 2	-8%	325 - 360
Intercity Trains	-4%	340 - 375
Climate Diversion of Water to Rail	+1%	360 - 397
Less Travel	-15%	300 - 335

POLICY OPTIONS

In the US, transport's contribution to global warming is dominated by carbon dioxide emissions, which in a petroleum system are proportional to energy consumed. The largest share of transport energy is consumed in urban passenger travel in light vehicles. It is also in light vehicles that the market for fuel efficiency seems to operate less effectively than in

other modes. Consequently, the two largest directions of policy to combat transport's contribution to global warming should be, first, measures to increase the energy efficiency of light vehicles, and second, measures to encourage urban passengers to drive less by ride-sharing, switching to more energy-efficient modes, or reducing travel.

To promote substantially higher efficiency of light vehicles a combination of several policy initiatives will be necessary, including fuel efficiency standards, taxes on fuel and/or efficiency-based taxes and rebates on new automobiles, and government support for research and development on promising medium-run efficiency technologies such as energy storage, oxygen separation, the continuously-variable transmission, and advanced engines.

Fuel Taxes

A fuel tax would correct the discrepancy between the private and social costs of consuming petroleum, inducing consumers to consume the "right" amount of fuel, while leaving them free to choose how they adjust. Moreover, a fuel tax would create appropriate incentives for increased efficiency and travel reduction for all modes. Estimates of the social cost of a gallon of fuel, though, are high -- suggesting that if a fuel tax is to be the only component of fuel economy policy, it should be as high as two to four dollars per gallon. Such a tax would be highly regressive, and not likely politically achievable except in a period of extreme energy shortage or widely recognized environmental emergency. In conjunction with other elements of a fuel economy policy, though, a more moderate fuel tax may be necessary to ensure that market signals to auto purchasers are consistent with regulatory requirements on auto makers.

Fuel Economy Standards

The fuel economy standards for light vehicles in place since 1978 have effectively promoted increases in auto fuel economy, but have had serious flaws in implementation and have imposed strongly unequal burdens on different automakers. Renewed and better-designed standards will be a necessary component of effective fuel economy policy through the next decade, for their ability to influence the design tradeoffs that underlie new model development and introduction decisions. They must, though, be designed and implemented to minimize their burden and avoid bias in favor of particular firms, and should reflect some sensitivity to differences in makers' size mixes. This can best be achieved by a target that varies with vehicle volume, such as the proposed Volume-Average Fuel Economy (VAFE) or an explicit formula that requires modestly higher technical efficiency effort in a large car than in a small one (but less than the extreme form of the present system, in which a large car and a small one are held to the same standard). By defining a suitable equivalency between load capacity and interior room, light trucks should be held to the same level of technical effort as automobiles.

A suitable level of standards would be high enough to strongly influence research and product development decisions, but not so high as to require significant size mix shifts or disrupt the orderly development of new models or the required flow of earnings. Recent DOE analysis of cost-effective levels of fuel economy suggests that a standard around 32 or 33 mpg in 1995 would correct for high consumer discount rates with gasoline at $1.10. If market forces or taxes are expected to double the real price of gasoline by this time (to 1987 $2 or more), then a standard in the high 30s would be appropriate. The higher the price of fuel, the higher the fuel economy standard that is cost-effective for consumers; consequently,

Fuel Economy Standards

The fuel economy standards for light vehicles in place since 1978 have effectively promoted increases in auto fuel economy, but have had serious flaws in implementation and have imposed strongly unequal burdens on different automakers. Renewed and better-designed standards will be a necessary component of effective fuel economy policy through the next decade, for their ability to influence the design tradeoffs that underlie new model development and introduction decisions. They must, though, be designed and implemented to minimize their burden and avoid bias in favor of particular firms, and should reflect some sensitivity to differences in makers' size mixes. This can best be achieved by a target that varies with vehicle volume, such as the proposed Volume-Average Fuel Economy (VAFE) or an explicit formula that requires modestly higher technical efficiency effort in a large car than in a small one (but less than the extreme form of the present system, in which a large car and a small one are held to the same standard). By defining a suitable equivalency between load capacity and interior room, light trucks should be held to the same level of technical effort as automobiles.

A suitable level of standards would be high enough to strongly influence research and product development decisions, but not so high as to require significant size mix shifts or disrupt the orderly development of new models or the required flow of earnings. Recent DOE analysis of cost-effective levels of fuel economy suggests that a standard around 32 or 33 mpg in 1995 would correct for high consumer discount rates with gasoline at $1.10. If market forces or taxes are expected to double the real price of gasoline by this time (to 1987 $2 or more), then a standard in the high 30s would be appropriate. The higher the price of fuel, the higher the fuel economy standard that is cost-effective for consumers; consequently,

high standards should be considered in conjunction with fuel taxes. In the longer run, standards in the high 30s or higher could force new technology, increasing the cost-effectiveness of any particular level of standards.

Vehicle Taxes and Rebates

Taxes and rebates on vehicles can create incentives to buy more efficiency, including incentives to sacrifice some size and performance for economy -- a tradeoff that is much more risky to pursue through measures addressed to the producer. The present gas guzzler tax applies such incentives to cars achieving below 22.5 mpg. Such a program would be most effective if accompanied by rebates for highly efficient cars, and if the thresholds for both tax and rebate increased over time as average fuel economy increases. Such an expanded program of auto purchase incentives could be complementary with both fuel economy standards and taxes, but would pose serious trade difficulties as long as the high-efficiency end of the auto market is dominated by imports. A related proposal would make high-efficiency rebates the prize in a government-sponsored competition for new high-efficiency production vehicles meeting specified performance, safety, and emission constraints.

Research and Development

Large R&D efforts will be essential for further technical efficiency advances beyond the turn of the century. A substantially expanded program of co-operative research between government and the automotive industry, similar in design to the CARP program of the 1970s, may be necessary to promote the American development of such promising

medium-term technologies as the CVT and energy-storage systems. Other areas where federally supported R&D could have substantial impact include new engine design for heavy trucks, innovations to permit increased intermodal freight, and urban public transit -- especially in vehicle and service innovations to improve the competitive position against the automobile.

New Fuels Programs

An evaluation of new transport fuels in terms of greenhouse effect gives both prescriptions and proscriptions for policy. First, the substantial increase in greenhouse emissions that would come from switching much of the transport system to any fuel derived from coal should preclude any such program. In the case of fuels that, like methanol, can be derived from natural gas, biomass, or waste for net greenhouse reductions, or from coal with net greenhouse increases, policy should be designed to exclude coal-based fuels from promotional incentives granted to fuels derived from other sources.

Large movement to the new power sources that offer the largest greenhouse reductions -- natural gas, and hydrogen or electricity from nonfossil sources -- is blocked by technical problems of cost, vehicle performance and fuel storage, and threshold problems related to repair and fuel distribution systems. While it is premature to decide now which if any of these merits the most vigorous support, federal policy can help with this assessment through expanded research in such areas as boil-off control in cryogenic fuel storage, hydrogen engines, and photovoltaics, and through continuing medium-scale demonstration programs to assess actual performance. In the longer term, if and when large-scale movement to a new fuel has become clearly appropriate, government intervention will likely

be necessary to push the new fuel system to the threshold of viability. This could include a major conversion program in one or several major metropolitan areas, subsidies for the purchase of vehicles or for the conversion of fueling and service facilities, or establishment of metropolitan regions where only public transit and new-fuel vehicles are permitted.

Transportation Control Measures

To promote mode switching and ride-sharing by urban passengers, the most promising route will be further exploration of a broad class of Transportation Control Measures. Because little information is yet available on the design of comprehensive TCM systems, further experimentation and data collection on a variety of program designs is imperative. Regional experiments should include both employer and areawide programs to promote mode switching and ridesharing, major transit improvements, bicycling improvements, and zoning and planning control to make new development more suitable for non-auto modes. As extremely efficient cars become more available, they should receive preferential access to congested roads, perhaps by giving special lanes to vehicles achieving, say, 100 person-miles per gallon. In the longer run, measures to balance jobs and residences on a local scale, such as the Los Angeles plan, hold much promise.

In addition to these major policy thrusts, several other possible federal measures could contribute to reductions of transport greenhouse emissions. While these offer smaller potential reductions, they move in the right direction, may bring other benefits, and may represent important symbolic statements. They include reimposing (and enforcing) the 55-mph speed limit; requiring high-efficiency oils, radial tires, and fairings for trucks, enforced through efficiency inspections; requiring high-efficiency tires and oils on federal

vehicles; preferential use of rail and intermodal roadrailer for federal freight; subsidizing intermodal road-rail terminal installation; and charging efficiency-discriminating parking fees at federal offices and contractors.

While the potential impacts of such policies as vehicle and fuel taxes and efficiency standards are large, they require five years or more to reach full effectiveness. The most likely scenarios for greenhouse-induced climate change show slow changes occurring over several decades, so delays of five to ten years in realizing the effects of policy are not troubling. If for some now unforeseen reason it happens that large greenhouse reductions are required in only a few years, though, only severe and painful measures would be able to achieve them. Such possible emergency greenhouse policies in the transport sector would include gasoline rationing, stringent restrictions on driving and air travel, and fuel taxes of the order of $5 or more per gallon.

The following matrix summarizes the policy options considered here, sorted according to best guesses of the magnitude of the reductions from baseline emissions that each could achieve and the lead time for achieving them. The assumed baseline has activity gains roughly balanced by efficiency gains as in the reference case scenario, giving constant transport CO_2 emissions. Note that in this matrix the estimated effects presented are for each initiative alone; coordinated application of several measures -- such as combinations of fuel economy standards, fuel and vehicle taxes, TCMs, and R&D -- would be more effective and less disruptive than any single measure used to exact the entire desired reduction.

U.S. Transport Greenhouse Reduction Matrix Lead Time

Reductions in U.S. Transport Greenhouse Emissions From Baseline

Increases from Baseline

	0 - 5 Years (by 1995)	5 - 15 Years (by 2005)	15-25 Years (by 2015)
> 25% REDUCTION	•Fuel Rationing •Restrictions on driving and air travel •$1 per gallon fuel tax (or higher?)		•Large move to hydrogen or electric vehicles, nonfossil sources
10 - 25% REDUCTION	•50¢ - $1 per gallon fuel tax	•Lt. veh. fleet mid 40's MPG by 2000 •Efficiency-based veh. taxes and rebates (10%-25% of purchase price)	•Lt. veh. fleet 50's MPG by 2010 •Comprehensive urban transportation planning •Higher urban densities
5 - 10% REDUCTION	•25¢-50¢ per gallon fuel tax •Stringent employer-based TCM's	•Lt. veh. fleet in high 30's MPG by 2000 •Efficiency-based vehicle taxes and rebates (5%-10% of purchase price) •Special lanes or roads for super-high efficiency vehicles	•Lt. veh. fleet in mid 40's MPG by 2010 •Double new aircraft efficiency
0 - 5% REDUCTION	•32-33 MPG light vehicle fleet by 1995 •10¢ - 25¢ per gallon fuel tax •Enforce 55 MPH •Parking controls •Truck efficiency inspection and maintenance •Urban public transportation service innovations and improvements	•New aircraft: 50% efficiency gain •Intermodal freight: federal investment, regulators support •New heavy trucks 10 MPG by 2000	•High-speed intercity rail investment •Electric vehicles from present generating mix
BASELINE	(New light vehicle fleet 28-30 MPG by 1995)	(New light vehicle fleet 31-35 MPG by 2005)	(New light vehicle fleet 34-42 MPG by 2015)
NO CHANGE		•Move to methanol from natural gas	
0 - 5% INCREASE	•New light vehicle fleet stalls at 26 MPG through 1995		
5 - 10% INCREASE		•Methanol from mixed sources, incl. coal •Light vehicle fleet stalls below 30 MPG through 2005	
> 10% INCREASE		•Methanol from coal	•Lt. veh. fleet stalls below 30 MPG through 2015 •Electric vehicles from new coal generating stations

TABLE OF CONTENTS

ACKNOWLEDGEMENTS i

EXECUTIVE SUMMARY ii

1. INTRODUCTION 1

2. A SNAPSHOT OF THE TRANSPORT SECTOR IN THE MID-1980s 5
   2.1 Activity Level 5
   2.2 Energy Use and CO_2 Emissions 8

3. RECENT TRENDS IN TRANSPORT 11
   3.1 Trends in Activity Level 11
   3.2 Trends in Energy Intensity 16

4. ISSUES IN PROJECTION 24
   4.1 Technical and Economic Projections 24
   4.2 The Demand for Transport and its Origins 27
      4.2.1 Settlement Patterns 27
      4.2.2 Structural Economic Changes 33
      4.2.3 Personal Travel and Mode Choice 35
   4.3 Efficiency Improvements 40
      4.3.1 Light Vehicle Efficiency Improvements 40
      4.3.2 Other Passenger and Freight Modes 49
      4.3.3 New Fuels and Electric Vehicles 51

5. REFERENCE CASE SCENARIO FOR 2025 63

6. ELEMENTS OF A MORE SURPRISING FUTURE 68
   6.1 Major Technical Breakthroughs in Vehicle Efficiency 69
   6.2 Consumer Acceptance of Radically Smaller Automobiles 71
   6.3 Major Shift to New Power Sources 73
   6.4 A Boom in Urban Public Transit 75
   6.5 A Revival of Human-Powered Transport 78
   6.6 High-Speed Inter-City Rail 80
   6.7 Surprises in Freight 81
   6.8 Much Less Travel 82
   6.9 Summary of Effects 82

TABLE OF CONTENTS

ACKNOWLEDGEMENTS i

EXECUTIVE SUMMARY ii

1. INTRODUCTION 1

2. A SNAPSHOT OF THE TRANSPORT SECTOR IN THE MID-1980s 5
   - 2.1 Activity Level 5
   - 2.2 Energy Use and CO_2 Emissions 8

3. RECENT TRENDS IN TRANSPORT 11
   - 3.1 Trends in Activity Level 11
   - 3.2 Trends in Energy Intensity 16

4. ISSUES IN PROJECTION 24
   - 4.1 Technical and Economic Projections 24
   - 4.2 The Demand for Transport and its Origins 27
     - 4.2.1 Settlement Patterns 27
     - 4.2.2 Structural Economic Changes 33
     - 4.2.3 Personal Travel and Mode Choice 35
   - 4.3 Efficiency Improvements 40
     - 4.3.1 Light Vehicle Efficiency Improvements 40
     - 4.3.2 Other Passenger and Freight Modes 49
     - 4.3.3 New Fuels and Electric Vehicles 51

5. REFERENCE CASE SCENARIO FOR 2025 63

6. ELEMENTS OF A MORE SURPRISING FUTURE 68
   - 6.1 Major Technical Breakthroughs in Vehicle Efficiency 69
   - 6.2 Consumer Acceptance of Radically Smaller Automobiles 71
   - 6.3 Major Shift to New Power Sources 73
   - 6.4 A Boom in Urban Public Transit 75
   - 6.5 A Revival of Human-Powered Transport 78
   - 6.6 High-Speed Inter-City Rail 80
   - 6.7 Surprises in Freight 81
   - 6.8 Much Less Travel 82
   - 6.9 Summary of Effects 82

7. POLICY OPTIONS 84
7.1 Overview 84
7.2 Fuel Taxes 85
7.3 Light Vehicle Fuel Economy Standards 87
7.4 Car Prices: Taxes, Rebates, Bonds 93
7.5 Sponsored Competitions 95
7.6 Government-Supported Research and Development 96
7.7 New Fuels Programs 97
7.8 Major Investment in Intercity Rail 99
7.9 Transportation Control Measures 100
7.10 Controlling Settlement Patterns 104

8. CONCLUSION 106

BIBLIOGRAPHY 110

LIST OF TABLES

TABLE 1: US PASSENGER TRAVEL, 1985 5

TABLE 2: US FREIGHT HAULAGE, 1985 6

TABLE 3: AUTOMOBILE FLEETS AND POPULATION, SELECTED REGIONS, 1986 8

TABLE 4: DISTRIBUTION OF US TRANSPORT ENERGY USE, 1985 .. 9

TABLE 5: TRANSPORT ENERGY USE AND CO_2 FOR NINE WORLD REGIONS, 1985 10

TABLE 6: MODE SHARES OF US PASSENGER-MILES FOR SELECTED YEARS 12

TABLE 7: US FREIGHT ACTIVITY AND MODE SHARES, SELECTED YEARS 13

TABLE 8: TRENDS IN PASSENGER TRAVEL FOR SIX SELECTED COUNTRIES 15

TABLE 9: TRENDS IN FREIGHT FOR SIX SELECTED COUNTRIES 16

TABLE 10: TRENDS IN US AUTOMOBILE FUEL ECONOMY: MPG 20

TABLE 11: URBAN FUEL EFFICIENCIES OF NEW CARS SOLD IN SELECTED COUNTRIES, 1973 AND 1985 21

TABLE 12: MODAL ENERGY INTENSITIES, SELECTED COUNTRIES AND YEARS 23

TABLE 13: PRICE AND INCOME ELASTICITIES FOR TRANSPORT ENERGY DEMAND 27

TABLE 14: EXCERPTS FROM NATIONAL PERSONAL TRANSPORTATION SURVEY 30

TABLE 15: 1980 GASOLINE USE IN CITIES BY WORLD REGION 32

TABLE 16: HIGH-ECONOMY PRODUCTION AUTOMOBILES 42

TABLE 17: HIGH-ECONOMY PROTOTYPE AUTOMOBILES 43

TABLE 18: PROJECTED FUEL ECONOMY IMPACTS OF AUTO TECHNICAL CHANGES 46

TABLE 19: GHG EMISSIONS FROM ALTERNATIVE VEHICLE FUELS 53

TABLE 20: CALCULATIONS FOR USA 2025 REFERENCE CASE SCENERIO 65

TABLE 21: WORLD TRANSPORT ENERGY USE, 2025 66

TABLE 22: EFFECT OF SURPRISES ON US 2025 TRANSPORT CO_2 EMISSIONS 83

THE TRANSPORT SECTOR AND GLOBAL WARMING

1. INTRODUCTION

This report considers the relationship between transport and global warming. It takes a broad (and broad-brush) view, looking at both the technology and the economics of transport, at passenger travel and freight, at urban and inter-city transport, and at the domestic US sector and the rest of the world.

With such breadth the treatment is bound to be schematic, at times superficial. In particular, foreign transport is treated in much less detail than American, a serious omission because foreign transport sectors are both unlike the US and unlike each other; global averages are not instructive. This choice was dictated both by limitations in international data and the need for brevity. The compromise taken is to present US information in some detail, then give a flavor for worldwide variability by presenting figures for aggregated world regions or "representative" nations, depending on availability. The report presents no original modelling, except for simple, back-of-the-envelope calculations.

The report uses a basic conceptual scheme, first articulated by Ehrlich and Holdren (1971), for thinking about the environmental impact of any human activity. In this scheme, total impact is regarded as the product of three factors: population, activity per person, and impact per unit of activity. This separation helps to distinguish the effects of technology (which determines environmental impact per unit of activity) and of consumer choice (which determines activity per person).

Transport's contribution to global warming comes principally from the carbon dioxide

(CO_2) released by burning fuel. There are other contributions -- refinery emissions and methane from tailpipes, for example -- but these are both much smaller than, and roughly proportional to, the warming contribution from CO_2.[1] Consequently, to a close approximation, studying transport's contribution to global warming is the same as studying transport energy consumption. Warming contribution, expressed as mass of carbon emitted, is calculated by multiplying energy consumption by an emission coefficient that is roughly constant for all petroleum-based transport.

There are three important exceptions to this equivalence of greenhouse emissions and energy consumption, though. First, there are chlorofluorocarbons (CFCs) used in transport, as air conditioning working fluids and in smaller quantities as foam padding and insulation, which need not vary proportionally with energy consumption. Their contribution is discussed separately, in the box at the end of the paper. Second, if other fuels replace petroleum as the principal source of transport energy, then the constant of proportionality between CO_2 emissions and energy use will change. The effect of new transport fuels for transport is discussed in Sections 4.3 and 6.3. Finally, the secondary effects of non-greenhouse tailpipe emissions such as carbon monoxide and reactive hydrocarbons may be large, for they both contribute to the formation of tropospheric ozone (a greenhouse gas) and reduce concentrations of the hydroxyl radical (OH), which scavenges many trace gases from the atmosphere.[2]

---

[1] For US highway vehicles, DeLuchi et al (1987A, p.15) estimate the following shares of contribution to greenhouse emissions: 85% CO_2 from vehicle tailpipes, 11% CO_2 from production and non-highway distribution of fuels, 3% from flaring and venting of natural gas, and 0.2% from tailpipe methane emissions.

[2] Ibid, p.4; Walsh (1988), p.5.

Transport activity is measured in passenger-miles, or ton-miles of freight.[3] Its level depends on many factors: population, the pattern of settlement, the structure of the economy, the level of incomes and transport prices, and the transport and communications technology available.

Describing activity levels is complicated by the ambiguous nature of transport. Transport is mostly an intermediate good, but partly a final good; people usually travel not for the pleasure of it, but as a necessary adjunct to doing something they want to do (and freight never travels for pleasure). Sometimes people do travel for pleasure, though, and even for essential travel they may have strong preferences regarding mode and quality. So it is not possible to say whether we would be better off with more or less transport; more travel may mean that people have more freedom to move when, where, and how they want to, or that they are being forced to endure more travelling to reach the same jobs, services, and recreation opportunities. A passenger-mile is not a passenger-mile is not a passenger-mile.

The measurement of impact per unit of activity also reflects the dual character of transportation. When you drive, your emissions of CO_2 per passenger-mile depend on the kind of fuel efficiency technology in your car, but also on how big and powerful a car you drive and how fast you drive it, on road and signal design, on how many people you carry, and on the fact that you have decided to drive rather than take the bus. If you change from driving alone to car-pooling or riding the bus, your impact per passenger-mile has gone down; but your activity has changed too, unless you care not at all about the difference between an empty car, a full car, and a bus.

---

[3] All freight in the report is measured in short tons, 2000 pounds.

Chapter 2 describes the state of transport around 1985 – activity levels, energy consumption, and greenhouse emissions. Chapter 3 discusses the trends in technology and activity levels that have led to this state. Chapter 4 discusses the major factors affecting transport energy use and greenhouse emissions, both economic and technical, and provides a conceptual foundation for projecting future emissions. Chapter 5 presents a reference case or "business-as-usual" scenario for worldwide 2025 transport energy use and greenhouse emissions, drawn from two recent projects for EPA that modelled greenhouse emissions by world region and economic sector. This scenario is intended to be a plausible state of world transport in 2025 if there are neither surprises nor serious policy intervention. Chapter 6, in contrast with this "business-as-usual" projection, speculates on what kinds of surprising changes could occur in transport by 2025, and roughly calculates their effects on CO_2 emissions relative to the reference case. These calculations are applied to an abbreviated set of model outputs, without considering how the changes would affect the full model. Chapter 7 reviews policy options that may influence transport greenhouse emissions over the period to 2025.

2. A SNAPSHOT OF THE TRANSPORT SECTOR IN THE MID-1980s

2.1 Activity Level

In 1985, Americans travelled 3.2 trillion passenger-miles by all powered modes, or 13,335 miles per person. Of this total, highway travel in cars and light trucks represented 88% (11,800 miles per person), and air travel 9% (1,185 miles per person). Table 1 shows the detailed breakdown.

TABLE 1: US PASSENGER TRAVEL, 1985

Mode	Vehicle-Miles (millions)	Passenger -Miles (millions)	Miles per Person	Share
Automobile	1,260,565	2,142,960	8,976	67.3%
Personal Light Truck	373,072	671,530	2,813	21.1%
Motorcycle	15,600	17,160	72	0.5%
Bus (Transit and Inter-City)	2,764	46,274	194	1.5%
Air	7,207	282,761	1,185	8.9%
Rail (Transit and Inter-City)	903	22,127	93	0.7%
Total		**3,182,812**	**13,332**	**100%**

Source: Davis et al (1988). School buses omitted.

The dominance of personal light vehicles -- cars and light trucks -- is reflected in the size of the vehicle fleet as well. In 1987 there were 164 million cars and light trucks

registered in the US,[4] one for every 1.48 people and slightly more than one for every licensed driver.[5] Each light vehicle was driven an average of 9,560 miles per year, with an average load of 1.7 people.[6]

Total freight haulage in the US was 2.95 trillion ton-miles in 1985, roughly 12,340 ton-miles per person or 0.65 ton-miles per dollar of GDP.[7] Table 2 below shows the contribution of each mode.

TABLE 2: US FREIGHT HAULAGE, 1985

Mode	Vehicle-Miles (millions)	Ton-Miles (millions)	Share	Tons Shipped (millions)	Average Haul length (miles)
Truck	82,867	610,000	20.7%	2,139	538
Railroad	24,920	876,984	29.7%	1,320	635
Shipping		892,970	30.2%	1,011	884
Pipeline		564,300	19.1%		
Air Freight		9,048	0.3%		
Total		2,954,640	100%		

Note: "Shipping" includes both coastal and internal.
Source: Davis et al (1988), Tables 1.17 and 3.2.

[4] MVMA (1988), adjusted to remove heavy trucks. The 1985 heavy truck fleet from Davis et al (1988) is scaled according to the ratio of total fleet sizes in 1987 and 1985, and deducted from MVMA's total car and truck fleet.

[5] Davis et al (1988), Table 2.22; MVMA (1988)

[6] MVMA (1988), p.54; Davis et al (1988).

[7] 1986 Dollars. Derived from US Commerce Dept (1987) MVMA (1988).

In the rest of the world both the amount and the mode of passenger travel vary greatly from region to region, and are strongly correlated with income. Around 1975, annual travel per person ranged from 5600 miles in the OECD countries to 1,600 in eastern Europe and 370 in the low-income developing countries.[8] Car ownership ranges from one per 1.8 people in North America to one per 1,374 in China. Table 3 shows automobile fleets in relation to population for selected countries and regions in 1986. That year, the world's motor vehicle fleet stood at 500 million -- 386 million cars and 113 million trucks and buses -- of which 40% were in North America, 35% in Europe, 15% in Asia, 5% in South America, and 2% each in Africa and Oceania.

Annual travel per vehicle tends to be lower in regions with higher vehicle ownership. In the poorest communities, the few cars available are often used as taxis or as transport for an entire community, carrying freight as well as people. This trend is complicated, though, by the skewed income distribution of most developing countries; cars held by small elites are not used as heavily. Modal split in developing countries is also complicated by highly skewed income distributions. In the poorest regions, walking and animal carts dominate transport.[9] As incomes rise, bicycles, motorcycles, light 3-wheeled powered vehicles, and public road transport emerge as dominant modes, with extensive ownership of cars only coming at very high income levels. But small wealthy elites in even the poorest countries

---

[8] Moavenzadeh and Geltner (1984), p.114. The OECD average also conceals much variation. The US value was 11,500 miles, while Canada and Australia were 25% lower, Western Europe roughly half, and Japan one-third (Ang, 1984). Values for the poorest countries are biased downward because they omit walking, cycling, and animal transport.

[9] Leach et al (1986), p.131, describe a typical village in Bangalore, India, where virtually all travel is by foot or bullock cart. Averous (1981) reports mode splits for 20 cities worldwide; in the poorest, more than 70% of all travel is on foot.

account for rapidly growing levels of both automobile ownership and air travel.[10]

TABLE 3: AUTOMOBILE FLEETS AND POPULATION, SELECTED REGIONS, 1986

Region	Cars	Population (millions)	People Per car	People per Vehicle
N. America	146,908,426	267.8	1.8	1.4
W. Europe	123,343,207	343.8	2.8	2.5
Japan	28,653,669	121.4	4.2	2.5
S. America	18,563,648	278.7	15	12
USSR	11,800,000	278.8	24	14
Africa	7,960,647	578.2	73	47
China	761,086	1,045.5	1,374	292
World Total	386,307,614	4,808.3	12	9.6

Note: "Vehicles" includes cars, buses, and trucks of all sizes.
Source: MVMA (1988).

2.2 Energy Use and CO_2 Emissions

In 1986, the US Transport sector consumed 20.76 Quads of energy, 28% of total US energy consumption. Because transport's energy demand is almost entirely petroleum,[11] transport's share of petroleum consumption is much larger, 62.8%.[12] 73% of transport energy was consumed by highway vehicles.[13] Table 4 shows an approximate allocation of transport energy use by mode and by purpose.

[10] Meyers (1988).

[11] 96.3% in 1986, with the balance from natural gas and electricity.

[12] US Energy Information Administration (1988), Tables A2 and A8.

[13] Davis et al, (1988), Table 1.11.

TABLE 4: DISTRIBUTION OF US TRANSPORT ENERGY USE, 1985
QUADRILLION BTU (PERCENT OF TOTAL TRANSPORT ENERGY)

	PASSENGER	FREIGHT	OTHER
ROAD	11.30 (53.6%)	4.11 (19.5%)	—
AIR	1.68 (8.0%)	—	—
WATER	0.23 (1.1%)	1.08 (5.1%)	—
PIPELINE	—	0.76 (3.6%)	—
RAIL	0.07 (0.4%)	0.43 (2.0%)	—
OFF-HIGHWAY (Farms, Mines, Const)	—	—	0.71 (3.4%)
MILITARY OPERATIONS	—	—	0.71 (3.4%)
TOTAL	14.00 (66.2%)	5.71 (27.1%)	1.42 (6.7%)

Note: For highway modes, heavy truck and 25% of light truck energy are allocated to freight, 75% of light trucks with autos, motorcycles, and buses are allocated to passenger. Air energy is designated all passenger.
Source: Davis et al (1988), Table 1.10.

Three recent studies for EPA have assembled data on 1985 transport energy use and CO_2 emissions for nine major world regions. These are shown in Table 5. The inter-regional differences in the ratio of transport CO_2 emissions to transport energy reflect different energy source mixes. [14]

[14] Yenny and Uy (1985), p.35.

TABLE 5: TRANSPORT ENERGY USE AND CO_2 FOR NINE WORLD REGIONS, 1985

Region	Transport Energy (quads)	Share of world	Transport Share of Region's SEC Energy
USA	20.0	35.4%	35.9%
CANADA + W.EUROPE	13.0	23.0%	31.4%
JAPAN + ANZ	4.4	7.8%	36.4%
CP EUROPE	8.4	14.9%	17.8%
TOTAL DEVELOPED	45.8	81.1%	29.3%
S AND E ASIA	2.5	4.4%	24.1%
CHINA	0.9	1.6%	6.7%
AFRICA	2.0	3.5%	39.6%
LATIN AMERICA	4.1	7.3%	33.3%
MIDDLE EAST	1.0	1.8%	16.9%
TOTAL LDCs	10.5	18.6%	21.8%
TOTAL WORLD	56.5	100%	27.5%

	Transport CO_2, Tg C	Share of World	Transport Share of Region's Fossil CO_2
USA	413.1	35.9%	29.6%
CANADA + W EUROPE	265.7	23.1%	31.4%
JAP + ANZ	90.0	7.8%	29.7%
CP EUROPE	171.1	14.8%	12.0%
S AND E ASIA	49.9	4.3%	19.0%
CHINA	18.8	1.6%	4.0%
AFRICA	40.1	3.5%	25.5%
LATIN AMERICA	83.4	7.2%	36.3%
MIDDLE EAST	20.6	1.8%	14.0%
WORLD	1152.7	100%	22.0%

Sources: EPA (1989), Appendix B; ICF Inc (1989).

3. RECENT TRENDS IN TRANSPORT

3.1 Trends in Activity Level

Total travel, car ownership, and travel by car have all increased steadily throughout the world over the past two decades. In the United States, travel per person (all modes) increased from 10,400 miles in 1970 to 13,300 in 1985, an average annual increase of 1.7%. [15] Over the same period the motor vehicle fleet increased by 3.2% per year, and car ownership increased from one per 2.08 people to one per 1.48.[16]

The fraction of their total travel that Americans do in private cars and light trucks has declined since the 1960s, although it remains higher than in any other nation. The quantity of highway travel has not declined -- in fact, it rose from 10,000 miles per person in 1970 to 11,800 in 1985[17] -- but air travel grew even faster, so highway's share of the total declined modestly, from 93% to 89%. Other modes have shown a slow, steady decline over the past 25 years, with two exceptions: between 1960 and 1970, the decline of intercity rail was precipitous; and during the 1970s urban rail showed significant one-time growth with the completion of new systems in the San Francisco Bay area, Atlanta, and Washington DC. Table 6 shows the distribution of passenger-miles by mode for selected years.

These trends originate in economics, demographics, and settlement patterns. As the large post-war "baby-boom" generation and unprecedented numbers of women moved into the workforce, the number of workers increased much faster than the total population -- so

---

[15] Transportation Energy Conservation Data Book, 1977; Davis et al (1988).

[16] Davis et al (1988), Table 2.22

[17] Leach et al (1986), pg. 136; consistent with Davis et al (1988).

much faster that even in metropolitan areas whose total population declined between 1960 and 1980, the workforce increased.[18] The increasing workforce, with the accompanying increase in work travel, accounts for much of the growth in per capita car ownership and travel. Also during this period, low-density suburbs grew more rapidly than central cities. The resultant increase in average trip distance contributed to the increase in travel per person.[19] The large increase in air travel since 1960 can be attributed both to rising

TABLE 6: MODE SHARES OF US PASSENGER-MILES FOR SELECTED YEARS

Mode	1960	1970	1980	1985
Private Road:	94.8%	92.8%	89.5%	89.0%
Bus:			1.8%	1.5%
Intercity	1.4%	1.1%	1.0%	0.7%
City	NA	NA	0.8%	0.7%
Train:	1.6%	0.5%	0.8%	0.7%
Intercity	1.2%	0.3%	0.2%	0.2%
City and Commuter	0.3%	0.2%	0.6%	0.5%
Air	2.3%	5.6%	7.9%	8.9%

Notes:
1. 1960 and 1970 exclude light trucks, 1960 also excludes motorcycles. Private road passenger-miles are about 90% local, 10% intercity.
2. 1960 and 1970 city/commuting train figures exclude urban subway systems. City buses exclude electric buses. School buses excluded.

Source: Transportation Energy Data Books, various years.

[18] Pisarski (1987).

[19] Data are ambiguous on whether or not average trip length has increased. A plausible story would be increase through the 1960s, levelling off or declining since the 1970s. Pisarski (1987), Table 3.26; Klinger and Kuzmyak (1986); Lowry (1988).

personal incomes and to the declining real cost of air travel brought about by technological advance and, in the 1980s, deregulation. Events of the last few years suggest, though, that industry consolidation may bring higher real prices, moderating current growth trends.

US freight haulage per capita has grown slowly, from 9,400 ton-miles in 1970 to 11,000 in 1987,[20] while freight per dollar of GNP shows a more complex trend. After remaining nearly constant at 0.75 ton-miles per dollar for many years, it dropped in the early 1980s to about 0.6.[21] Freight mode shares have been roughly constant since the mid-1970s, while over a longer period freight has shifted gradually from rail to truck and pipeline. The shift to truck has been more pronounced in high-value industrial products; rail's decline has been partly masked by a large increase in coal shipping since 1973. Table 7 shows US freight per capita and per dollar of GNP, with mode shares, for selected years.

TABLE 7: US FREIGHT ACTIVITY AND MODE SHARES, SELECTED YEARS

	Ton-Miles per Person	Ton-Miles per $1986 GNP	Mode Shares (Per Cent) Road	Rail	Water	Pipe	Air
1965	8446	0.74	22	43	16	19	0.12
1970	9444	0.75	21	40	16	22	0.17
1980	10900	0.72	22	38	16	24	0.19
1987	11000	0.62	25	37	16	22	0.33

Source: MVMA (1988).

[20] MVMA (1988), p.57.

[21] Calculations from US Commerce Dept (1987), MVMA (1988).

Worldwide, travel per person and car ownership have increased steadily over the past two decades, gradually in the industrial countries and rapidly in the developing countries. In all LDCs, travel and car ownership grow faster than income; in many, the rates of growth surpass 10% per year.[22] Even in most countries with very low car ownership, highway modes dominate passenger travel. Only in China and to a lesser extent India does rail remain a dominant passenger mode.[23] Table 8 shows trends in total passenger travel, mode split, and automobile ownership for six countries of various income levels in selected years.

Freight per capita is also increasing in all regions, at roughly the same rate as GNP in developed countries and faster than GNP in developing countries. Freight intensity (freight per dollar of GNP) varies greatly between countries, a function of size, population density, and economic structure. It increases as an economy moves from agriculture into primary industry, then declines slowly with shifts toward secondary and tertiary manufacturing and services. Freight mode shares depend on the infrastructure available; to ship by rail, you need a rail network. But even in poor countries with extensive rail networks, rail is declining in favor of road and other modes as in the US.

---

[22] Sathaye et al (1987).

[23] Sathaye et al (1987), p.267.

TABLE 8: TRENDS IN PASSENGER TRAVEL FOR SIX SELECTED COUNTRIES

		Passenger-Miles per Person	People per Car	Mode Shares (Per Cent) Road (priv)	Road (pub)	Rail	Water	Air
UK	1971	4817	—	79	12	9	–	0.4
	1976	5183	4.0	81	11	7	–	0.5
	1981	5643	3.6	85	8	7	–	0.6
Japan	1965	1657	—	37	9	52	1	1
	1970	2700	12.0	51	12	34	1	2
	1980	3366	4.9	57	11	26	1	5
USSR	1970	1624	147	6	38	43	1	12
	1980	2976	32	19	41	27	1	13
	1985	3304	24	22	40	25	1	13
Brazil	1965	485	—	26	59	13	0	2
	1970	752	34	28	66	5	0	2
	1980	2270	15	33	62	3	0	2
China	1965	60	—	–	24	69	7	0.4
	1970	76	27,700	–	23	70	7	0.2
	1980	145	18,700	–	32	61	6	1.8
India	1965	201	—	5	44	50	–	NA
	1970	263	902	7	52	41	–	0.5
	1980	487	718	7	52	41	–	0.9

Notes:
1. The division of road transport into private and public for Japan, Brazil, China, and India is estimated based on other studies.[24]
2. Walking and cycling, large modes in China and India, are excluded.
Sources: Leach et al (1986); Yenny and Uy (1985); Tretyakova and Kostinsky (1987); MVMA, various years.

[24] For Japan, a 1968 Tokyo study on trip split has been used for 1965 and 1970 (81% private, 19% public; Moavenzadeh Table 4-14), and aggregated mode splits for Japan, Australia and New Zealand in 1979 used for 1980 (84% private; Ang, Table 6.6). For Brazil, a 1967 Sao Paolo trip survey has been used for 1965 and 1970 (30% private; Moavenzadeh Table 4-14), and a 1977 trip survey of all metropolitan areas for 1980 (Poole Table 3.2). For China, because of extremely low auto ownership, all road travel has been called public. For India, a crude estimate was derived from registration data presented in Dunkerley et al (1987). It was assumed that annual miles per bus were triple the value for autos, and that buses averaged 30 occupants versus 2 for automobiles. These assumptions yielded estimates of 89% private in 1965, 88% in 1970 and 1980.

TABLE 9: TRENDS IN FREIGHT FOR SIX SELECTED COUNTRIES

		To-Miles per person	Ton-Miles per $1986 GNP	Mode Shares (Per Cent) Road	Rail	Water	Pipeline	Air
UK	1971	1686	0.23	65	16	16	3	--
	1976	1790	0.21	67	14	14	4	--
	1981	1858	0.22	64	12	18	6	--
Japan	1965	1306	0.27	26	31	43	--	--
	1970	2317	0.28	39	18	43	--	--
	1980	2068	0.21	41	9	51	--	--
USSR	1965	7338	1.70	6	80	5	8	0.05
	1970	9510	1.68	7	76	5	12	0.06
	1980	15538	2.23	7	58	4	30	0.05
Brazil	1965	893	0.72	69	17	15	0	0.09
	1970	970	0.61	70	17	12	1	0.15
	1980	2068	0.72	70	17	10	3	0.29
China	1965	319	1.68	8	79	13	0	0.01
	1970	362	1.52	9	79	12	0	0.01
	1980	595	1.63	9	67	18	6	0.02
India	1965	242	1.02	32	68	--	--	--
	1970	241	0.91	34	66	--	--	--
	1980	252	0.94	33	63		"OTHER": 4	

Sources: Yenny and Uy (1985); Leach et al (1986); Poole (1983); Tretyakova and Kostinsky (1987).

3.2 Trends in Energy Intensity

The energy intensity of a transport mode is the amount of energy required for one passenger-mile or one ton-mile. It depends on several factors. The technical characteristics of a vehicle, with road and traffic conditions and driving habits, determine energy per vehicle-mile; the energy per passenger-mile or per ton-mile then also depends on the load factor, how many passengers or how much freight is carried. The most striking changes in

transport since 1970 have been decreases in energy intensity. The largest gains have been in American automobiles, but cars and trucks worldwide and other modes have also all made strong improvements.

In model year 1974, the tested fuel economy[25] of new domestic US cars bottomed out at 13.2 miles per gallon,[26] while the in-use economy of all cars on the road averaged 13.4 mpg.[27] In contrast, in the 1988 model year new domestic models averaged 27.0 mpg and new imports 31.0 mpg, for a new fleet average of 28.4 mpg.[28] The average economy of all cars on the road in 1986 was 18.3 mpg, increasing more slowly because many less efficient older cars remain on the road.[29] New test efficiency for light trucks also increased markedly over this time, though less than cars: from 13.7 mpg in 1975 to 21.2 in 1987.[30]

This dramatic increase in economy was achieved by several changes. Cars were reduced in weight, through a combination of new design techniques and materials substitution, market shift toward smaller size classes, and modest down-sizing of each size

---

[25] New vehicle fuel economy figures cited are unadjusted EPA combined city and highway test results. Actual in-use efficiencies are 10-20% lower, due to cold starts, wind and terrain, accessories, and differences in driving skill. Total fleet economies shown are in-use figures. Calculations of fuel and carbon emissions saved use actual, in-use fuel economies.

[26] New imports averaged 22.2 mpg, giving a total new fleet average of 14.2 mpg. MVMA (1988) compilation of EPA and DOT data.

[27] Davis et al (1988) Table 1.18, using their figure of 125,000 BTU per gallon of automotive gasoline (higher heating value), Table A-1.

[28] Heavenrich and Murrell (1988), Tables 1 and 17.

[29] MVMA (1988), pg. 54, shows compilation of DOT data. Davis et al (1988) show in-use efficiency of 18.2 mpg for 1985, the last year reported.

[30] Heavenrich and Murrell (1988), Table 2.

class.[31] The shift to front-wheel-drive transaxles both reduced drive-train losses and permitted further weight reductions. Lower weight permitted a shift toward smaller engines without loss of performance, and engine efficiency was increased by sophisticated microelectronic control of spark timing and fuel mixture. The introduction of catalytic converters gave more latitude for optimizing combustion. Drive-train efficiency was improved by increasing use of overdrive gears in both manual and automatic transmissions, and by lock-up torque converters in automatics. Finally, losses to rolling friction and air resistance were reduced by better tire design, and by decreasing drag coefficients from about .5 in the mid-1970s to .36-.38 in 1987.[32] Light truck efficiency gains also included technical improvements in all size classes, but were driven much more than cars by a market shift to small models and drivetrain configurations.[33] Small pickups, vans, and utility trucks went from 14% of the total light truck market in 1975 to 55% in 1988.[34]

The effect of these efficiency gains has been a large reduction in energy consumption. In 1987, American cars burned 35 billion gallons less gasoline than they would have at 1975 efficiencies,[35] and cumulative gasoline savings from 1975 to 1987 (undiscounted) were 178 billion gallons. In CO_2 emissions, this represents 1987 savings of 89 Teragrams of Carbon

---

[31] EPA size classes. Down-sizing refers to reducing the exterior size and weight of a model while maintaining its interior size.

[32] Energy and Environmental Analysis Inc (1988), pg. 2-9. The best present designs, such as the Taurus/Sable, have drag coefficients of .30 -.32.

[33] Westbrook and Patterson (1985), Table 5.

[34] Heavenrich and Murrell (1988), Table 2.

[35] Greene et al (1988), p. 16. Their calculation used 1987 vehicle mix and driving patterns, and 1975 mpg.

(26% of estimated 1985 transport emissions), and cumulative savings of 451 Teragrams.[36]

The movement to more efficient cars was prompted by the combined effect of three forces: the oil price shocks of 1973 and 1979, aggressive competition from foreign automakers offering high-quality efficient small cars, and congressionally mandated economy standards (CAFE standards, or Corporate Average Fuel Economy standards). The standards, enacted by the Energy Policy and Conservation Act of 1975,[37] required that each manufacturer's automobile line achieve sales-weighted average economy of 18.0 mpg in model year 1978, rising annually to 27.5 mpg in model year 1985 and thereafter.

Table 10 shows the yearly history of standards, average new car economy, and fleet efficiency. Imports were far ahead in 1974 and improved slowly, while domestic models improved rapidly and shrunk the gap. Initially both domestic and foreign makers stayed well ahead of the standards, but progress slowed after 1983, putting the fleets of General Motors and Ford in violation of the standard.[38] General Motors and Ford successfully petitioned for relaxation of the standard, which was set at 26.0 mpg for model years 1986 through 1988, and 26.5 mpg for 1989. In May 1989, the Secretary of Transportation announced that the 1990 standard will return to 27.5 mpg.

---

[36] 125,000 BTU per gallon of automotive gasoline (Davis et al (1988), Table A-1), 19.2 Tg Carbon per Exajoule (Marland, 1982).

[37] Public Law 94-163.

[38] The CAFE legislation permits makers to carry credits for years in which they exceed the standard forward or backward to reduce liability for years in which they violate the standard. Both GM and Ford had several years of accumulated CAFE credits in 1983, and with the carry-back of additional credits created by the 1986 standard relaxation, they avoided any liability for their 1983 to 1985 fleets that failed to meet the standard.

TABLE 10: TRENDS IN US AUTOMOBILE FUEL ECONOMY: MILES PER GALLON

Year	Federal Standard	New Domestic	New Import	Total New	Total Fleet
1974	none	13.2	22.2	14.2	13.4
1975	none	14.8	23.3	15.8	13.5
1976	none	16.6	25.4	17.5	13.5
1977	none	17.2	27.7	18.3	13.8
1978	18.0	18.7	27.3	19.9	14.0
1979	19.0	19.3	26.1	20.3	14.4
1980	20.0	22.6	29.6	24.3	15.5
1981	22.0	24.2	31.5	25.9	15.9
1982	24.0	25.0	31.1	26.6	16.6
1983	26.0	24.6	32.2	26.4	17.1
1984	27.0	25.6	31.8	26.9	17.8
1985	27.5	26.4	31.4	27.6	18.2
1986	26.0[1]	26.9	31.6	28.2	18.3
1987	26.0[1]	26.7	31.0	28.2	n.a
1988	26.0[1]	27.0	31.0	28.4	n.a
1989	26.5[1]				
1990	27.5				

Note: 1. Revised downward from original value of 27.5.
Source: Heavenrich and Murrell (1988); Davis et al (1988).

The slowing of progress in fuel economy stands in sharp contrast to projections made in the early 1980s that fleet efficiencies would be well over 30 mpg by 1985.[39] Indeed, it was not failure to achieve anticipated technical progress that stalled the gains, but market trends. Following several years of decline of real oil prices, both automakers and consumers slowed their movement away from larger and more powerful cars. Indeed, while the average interior volume of new cars declined sharply following both oil crises, it rebounded after 1982 and has since remained almost equal to its level in 1978 and 1979.[40] Makers have also

[39] eg, OTA (1982), p.126. Their lowest estimate, with slow technical progress and no size shift, was 30 mpg in 1985. Their highest was 37 mpg.

[40] Heavenrich and Murrell (1988), Table 4.

chosen to realize some of the gains available from technical innovations (such as turbochargers) in the form of increased performance rather than increased economy.[41] Strong market growth in light trucks has also reduced total light vehicle fuel economy.[42] Though light truck economy has improved since 1975, it has fallen progressively further behind auto economy.

Cars sold elsewhere in the developed world were more efficient than US cars in the early 1970s; since then, they have advanced less but are still ahead. Much of the remaining advantage, though, is due to size differences. US cars are now slightly more efficient than European ones of the same weight, but less efficient than Japanese.[43] Table 11 shows average car efficiencies for several countries in 1973 and 1985.

TABLE 11: URBAN FUEL EFFICIENCIES OF NEW CARS SOLD IN SELECTED COUNTRIES, 1973 AND 1985

Country	1973 MPG	1985 MPG	Change: 1973-1985
United States	13	24	+85%
United Kingdom	21	31	+48%
West Germany	23	31	+35%
Japan	23	30	+30%

Source: IEA (1987).

Other transport modes have also shown efficiency gains worldwide since the early

[41] For example, average acceleration declined through the 1970s to 14.4 seconds (0 - 60 mph), but has since increased to 12.6 seconds in 1988. Heavenrich and Murrell (1988).

[42] Light trucks represented 30% of all light vehicles sold in 1988, Heavenrich and Murrell (1988).

[43] IEA (1987).

1970s. In the US, commercial air efficiency per passenger-mile doubled between 1970 and 1985, due to a combination of more efficient aircraft and higher load factors. Truck freight efficiency improved by 20% over the same period, while rail and water modes remained roughly constant.[44] The energy intensity of US buses actually increased, due to lower load factors.

Modal energy intensities vary significantly between countries due to differences in equipment, road surface and condition, and load factor. The largest differences due to equipment technology are in rail in China and India, where many steam locomotives still in use consume energy at more than four times the rate per mile of a diesel engine. Table 12 shows modal energy intensity trends for the US, the UK, and the USSR, and selected other countries.

[44] Davis et al (1988), Table 1.19.

TABLE 12: MODAL ENERGY INTENSITIES, SELECTED COUNTRIES AND YEARS

		Passenger: BTU/pass-mile				Freight: BTU/ton-mile		
		Auto	Bus	Rail	Air	Truck	Rail	Water
USA	1970	4,281	1,760	--	10,35	16,463[1]	655	545
	1980	4,511	1,990	3,176	5,837	13,534[1]	592	358
	1985	4,040	2,273	2,800	4,376	13.187[1]	488	446
UK	1970	2,669	1,144	2,333	--	4,432	1,257	
	1975	2,730	1,037	2,363	--	4,267	1,201	
	1979	2,898	1,052	2,379	--	4,294	980	
USSR	1970	3,785	650	--	4,844	5,516	720	
	1980	2,655	630	--	4,693	4,065	600	
	1985	2,388	630	--	4,514	3,340[2]	590	
Sweden	1975	3,403	1,098	549	5,764	1,093	348	745
Brazil	1975	4,476	330	1,100	10,150	1,890	547	
China	1980	1,678	778	4,270	6,490	704	967	

Notes: 1. BTUs per Vehicle-Mile.
2. 1982.

Sources: Moavenzadeh (1984) Table 6.3; Cheng (1987); Yenny and Uy (1985); Tretyakova and Kostinsky (1987); Ang (1983); Davis et al (1988); Mintzer (1988); Leach et al (1986).

4. ISSUES IN PROJECTION

4.1 Technical and Economic Projections

Before we turn to projections of future transport energy use and contribution to global warming, this chapter examines the ingredients that go into any such projections. It discusses each of the major factors that will determine the future contribution of transport to global warming, with the goal of providing some understanding of what projections are based on, and how credible they are.

There are two issues that pervade the discussion of projections in the sections that follow. The first is that future transport greenhouse emissions will be the outcome of a hierarchy of decisions, each of which is constrained by others that have preceded it. At the broadest level, the population of a country, its pattern of settlement, and the structure of its economy all define certain minimum transport needs, both for passengers and freight. These factors change only slowly, and in the meantime they limit the amount of adjustment that is possible in transport activity levels, energy use, and greenhouse emissions.

Within the broad bounds imposed by settlement and economic structure, the transport system is shaped by investment decisions in equipment and infrastructure -- whether and where to build highways, railroads and airports, and how many and what kind of vehicles to buy. These investment decisions in turn constrain the range of mode choices that are available for any particular transport decision downstream.

Finally, in the short run, individuals choose when and how much to travel, and by which of the available modes. The aggregation of these individual decisions ultimately

determines transport energy and greenhouse emissions, but these decisions represent only the final link in a series of choices. Given a person's place of residence and work, the locations of stores, services, and recreation, and the location and quality of roads and public transit, there is little discretion left in the quantity and mode of his transport choices.

The second issue that pervades the discussion of projections is that transport decisions are shaped by the interaction of technology, which determines what choices are available, and of economic factors, incomes and relative prices. While technology and economics interact in a complex dynamic manner to shape outcomes, the two most common approaches to energy projections each examine one factor separately.

The end-use approach stresses technology. It projects technical trends in energy efficiency of each mode, based on recent trends or particular innovations now under development. For example, projections of car mileage can be made by examining advanced production models, prototypes and research underway, and estimating the market penetration of each innovation and its effect on economy. The strength of this approach is that it explicitly reflects physical constraints on efficiency as they exist at each time. Its weakness is that it neglects both the marketing problem of the automakers and the response of consumers. Makers must evaluate innovations for their effect on cost, performance, safety and comfort as well as economy, also thinking about how their competitors are likely to respond. End-use analysts normally address these issues by restricting their projections to innovations that are cost-effective and invisible to the consumer (or nearly so).

The econometric approach starts from the opposite end. It assumes that changes in transport energy are driven by consumer and producer responses to prices and incomes. Technical innovation is considered a producer response to long-run market conditions, so

no particular innovation need be considered explicitly. The approach uses statistical analysis of historical data to estimate short-run and long-run elasticities,[45] which reflect the entire hierarchy of choices that shape transport energy demand. A short-run price elasticity estimate reflects all the short-run ways that people have responded in the past to gasoline price changes, such as car-pooling or taking public transit, combining trips, or travelling less. A longer-run estimate reflects the increased range of adjustment choices available to the economy over a longer time, such as buying more efficient cars, moving closer to work, building transit systems, or zoning for higher densities. The weaknesses of the econometric approach are that the data often do not permit stable elasticity estimates, and that it is impossible to model the impact of major technological advances or changes in consumer tastes.

With a petroleum-based transport system greenhouse emissions are proportional to energy demand, so we would estimate future greenhouse emissions using energy demand elasticities. Moving to new transport energy sources uncouples the current relation between energy and greenhouse emissions, and so can not be addressed through this approach.

Elasticity estimates span a moderate range because of data difficulties, inter-country differences, and differences in the models fitted. Most studies share two broad conclusions, though. The response to either a price or an income change is greater in the long than in the short run. And developing country demands respond less to price changes and more to income changes than do industrial country demands,[46] although these differences are more

---

[45] An elasticity is a dimensionless quantity that measures the ratio of two proportional changes. For example, the price elasticity of demand for gasoline is the percent change in gasoline demand induced by a 1% change in price.

[46] Dunkerley and Hoch (1985).

pronounced in the long than in the short run. Table 13 presents ranges of published price and income elasticity estimates for transport energy demand.

TABLE 13: PRICE AND INCOME ELASTICITIES FOR TRANSPORT ENERGY DEMAND

Price Elasticities	**Short-run**	**Long-run**
Industrial Countries	-0.15 - -0.5	-0.8 - -1.1
Developing Countries	-0.06 - -0.12	-0.15 - -0.5
Income Elasticities		
Industrial Countries	+0.13 - +0.57	+0.3 - +1.25
Developing Countries	+0.1 - +0.56	+1.0 - +1.9

Sources: Estimates presented in Moavenzadeh and Geltner (1984) Table 5.11; Noll (1982), Appendix 1; Dunkerley and Hoch (1985).

4.2 The Demand for Transport and its Origins

4.2.1 Settlement Patterns

Transport is a derived demand. Very little travel is done for its intrinsic pleasure; people travel in order to get to somewhere they want to be. Consequently, the total demand for transport is always strongly shaped by where people live in relation to their workplaces, stores, services, and places of recreation. In the aggregate, the location possibilities that are open to people are shaped by the density and the mix of settlements.

The US is moving from a period of fast population and workforce growth with a young population into one of slower growth with an older population; from a period of rapid

suburban and non-metropolitan growth that even saw absolute declines in some central cities, to one of continued suburban (but probably not non-metropolitan) growth and resumed central city growth; and from a period of steadily declining residential densities to one of sharp conflict over whether densities should be higher or lower.[47]

Since the 1970s, jobs have been moving to the suburbs, following with some delay the movement of people that began in the 1950s. The emerging suburban pattern is neither one of strong, distinct new centers as many planners advocated, nor one of undifferentiated sprawl; rather, it has been a superposition of the two, which has been called "sprawl with lumps."[48]

This pattern has several implications for travel. First, because it makes it possible for people to live closer to their jobs than when everyone lives in the suburbs and works downtown, average worktrip length should decrease. This potential was evident in the 1980 Census, which showed that suburb-to-suburb commutes, which were the shortest of all metropolitan worktrips except central-to-central, had become the most common commute.[49] As Table 14 shows, average worktrip length declined from 1969 to 1983, although inconsistencies in these data may call this trend into question.[50]

Second, shorter worktrip distances should encourage some increase in walking and cycling. Table 14 shows that the fraction of worktrips that are shorter than 5 miles is over

---

[47] Pisarski (1988); Spencer (1988); Lowry (1988).

[48] Pisarski (1988); Lowry (1988) p. 24-27 cites Peter Gordon's unpublished studies of Los Angeles, which show that even the region's 17 largest employment centers together contain less than 20% of the region's jobs.

[49] Pisarski, Table 3.26.

[50] Respondents were asked both about their usual worktrip and their actual worktrip on a specific day. While actual worktrip length showed the decline presented in Table 14, usual worktrip length was roughly constant. Lowry contends that this reflects increased chaining, because actual trips were defined as a single leg.

50% and growing, and that walking and cycling represent a modest but growing fraction of trips of this length.[51]

Third, as workplaces spread around suburbia at low densities the pattern of work travel becomes ever more diffuse, making efficient public transit more difficult and imposing increasingly severe congestion on suburban road networks that were principally designed for concentrated suburb-to-CBD flows. Conventional mass transit can only provide frequent service at competitive cost with at least 3,000 riders per peak hour,[52] and suburban housing densities can only generate that many riders if workplaces are concentrated in a dense, distant CBD. Table 14 shows the consequence of this and other factors, the declining share of public transit in work travel.

---

[51] Strictly speaking, this mode category is called "other," and includes "walking, cycling, school bus, airplane, other;" but because a student's trip to school is not counted as a worktrip, and because the survey only includes respondents 16 years old or over, this category for short distances is considered essentially all walking and cycling.

[52] Meyer and Gomez-Ibanez (1981), p. 52.

TABLE 14: EXCERPTS FROM NATIONAL PERSONAL TRANSPORTATION SURVEY

A: Average Trip Length by Purpose of Trip (miles)

	1969	1977	1983
To and From Work	9.4	9.1	8.5
Shopping	4.4	5.0	5.3
Doctor/Dentist	8.4	10.3	9.7
Social and Recreational	13.1	10.3	10.5
All Trips	8.9	8.4	7.9

B: Home-to-Work Trips by Length and Mode

	1969		1977		1983	
	0-5 mi	All Trips	0-5 mi	All Trips	0-5 mi	All Trips
Priv. Veh.						
Driver			66.4%	71.4%	72.8%	75.2%
Passenger			16.9%	18.3%	11.1%	12.2%
Public Trans			4.5%	5.2%	3.2%	4.6%
Walk or Bike			12.2%	5.1%	12.9%	8.0%
All Modes	52.5%	100%	53.2%	100%	54.1%	100%

Source: Klinger and Kuzmyak (1986).

Although the emerging pattern presents the opportunity for conveniently clustered workplace and service centers, with moderate transport needs (and hence little congestion) and a high-quality environment, it has not worked out that way. Instead, the present US metropolitan settlement pattern presents three kinds of spatial mismatch between jobs and people. The first is the traditional mismatch of the "bedroom suburb," with most jobs in the central city and most residences in the suburbs. Although this mismatch is declining with continuing job movement to the suburbs, it still exists; the suburbs remain the largest origin and the central city the largest destination of worktrips. The second is a smaller-scale

mismatch within the suburbs, with some communities containing mostly housing and others having far more jobs than there are workers nearby. The third is a mismatch between the skill levels of new suburban jobs and the income needed to live in the suburbs. This creates a growing labor shortage for suburban employers and a long reverse commute for low-income people in the central city taking suburban jobs. All these mismatches create inflated transport needs, which are further inflated by lack of planning. Even dense suburban centers of jobs and shopping are often developed so as to discourage foot travel for short distances, so local auto traffic vies with through traffic on the congested roadways.[53]

The most important issue for future US settlement patterns will be density. A continuing decline in household size (and possibly household income), reduced rate of household formation, and continuing difficulty for first-time home buyers due to high suburban land prices will all likely create forces in the housing market for higher residential densities. Further pressure will be created if people react to increasing congestion by trying to live closer to their jobs. But local political forces will likely continue to resist higher densities, expressing the opposition of current suburban homeowners to perceived degradation of their spacious lifestyle and reduction of their property values.[54]

A recent study examining cross-sectional data on per capita gasoline use in cities concluded that urban density and public transit provision accounted for most of the variation in fuel use among US cities, and that low-density cities like Houston and Phoenix could save 20% to 30% of their fuel use through modest increases in density and transit

---

[53] Cervero (1986), p.50-53.

[54] Downs (1988).

improvements.[55] The differences between cities in the US and elsewhere are even more striking, as shown in Table 15. The second column adjusts fuel use elsewhere to remove the effects of income, fuel price, and auto efficiency. The authors argue that the remaining variation reflects the effects of urban form and public transit.

TABLE 15: 1980 GASOLINE USE IN CITIES BY WORLD REGION

	Actual Gasoline Use (Gallons per capita)	Adjusted Gasoline Use (Gallons per capita)
US CITIES	446	446
AUSTRALIAN CITIES	227	333
TORONTO	265	199
EUROPEAN CITIES	101	237
ASIAN CITIES	42	94
NON-US AVERAGE	131	237

Source: Newman and Kenworthy (1989).
Note: Adjustment applies long-run elasticities to equalize to US income, fuel price, and average car mpg.

If density goes up, transport needs go down and the bleak prospect for public transit may be improved. Transit service becomes more viable as either origins or destinations become more concentrated, so some argue that the existing "sprawl with lumps" pattern is already near a threshold of viability.[56] Modest increases in either the size of suburban workplace nodes or the concentration of suburban residences could make the difference,

[55] Newman and Kenworthy (1989).

[56] Pisarski (1988).

particularly with transit innovations such as flexible response or smaller vehicles. Many cities worldwide are experimenting with such systems now, in an attempt to tap the suburban market.

Japanese and European cities are denser and more compact than American cities, but they show the same tendency to expand and become less dense as incomes rise.[57] Their form supports much higher levels of public transit, and of foot and cycle trips, than in North America; this pattern will likely remain true through the early part of the next century. In the developing world, cities are growing rapidly through both internal population growth and migration from the country. While the rapid growth of poor urban dwellers creates an enormous need for public transit, its very pace makes planning exceedingly difficult, and scarce capital is often spent on more prestigious auto-based projects to serve the few wealthy enough to own cars. The result is extremely overcrowded public transit, with many people depending on foot and bicycles.

4.2.2 Structural Economic Changes

The recent decline in American freight per dollar of GNP reflects structural shifts in the American economy, as well as technological change and the effects of deregulation. The decline is consistent with movement from primary industry toward high-value, information-intensive goods and services. As the output of the economy becomes less dense in mass and more dense in value, two effects follow; there are fewer tons of material to ship,

[57] Meyer and Gomez-Ibanez (1981), p.15. Recent data, though, show a slowing of the historical trend in both the US (Macauley 1985) and Europe (v.d.Berg et al 1982; Klaassen et al 1981), and the beginnings of reversal among the young (Dynarski 1986).

and more value in fast, flexible shipping. The first effect contributes to the overall decline in freight per GNP; the second contributes to the growing dominance of trucking, and to the growing position within trucking of specialty carriers, small parcel services, and couriers.[58] The same factors have driven the growth of air freight.

Four structural trends account for the decline in demand for basic materials in the US economy: substitution of materials, more efficient use of materials, saturation of markets, and shifting consumer tastes toward more knowledge-intensive, less material-intensive goods.[59] These are likely to continue, leading to a continuing gradual decline in the freight intensity of the American economy. Continued movement of producers to low-density suburbs, often far from rail spurs, and increased used of sophisticated logistics and inventory management, such as just-in-time delivery systems, will provide a continuing advantage to modes that can offer fast, flexible service -- either trucking or novel inter-modal combinations.

An uncertain factor in future freight demand and structure will be recycling. As total material demands become smaller, a larger fraction can be met by recycled materials. This changes the basic path of material travel through the economy from a once-through trip from mine to plant to consumer to disposal, to a circular one (with leakages) from plant to consumer to reclamation center and back to plant. The effect on total freight requirements could be an increase or a decrease.

The factors pushing the US to reduced freight intensity are duplicated throughout the industrial world. Worldwide, these reductions will likely be partly offset by continuing

---

[58] Roberts (1988).

[59] Larson, Ross, and Williams (1986).

industrialization of LDCs, which will produce increasing shares of the world's primary goods. Evidence of this trend can be found in time trends of freight intensities. Between 1960 and 1980, the freight intensity (ton-miles per dollar of GNP) of Korea increased by more than 40%, and that of Brazil by more than 25%.[60] The offset will not likely be total, though; the forces supporting substitution of materials and increased efficiency of use operate in the developing countries as well as the industrial ones.

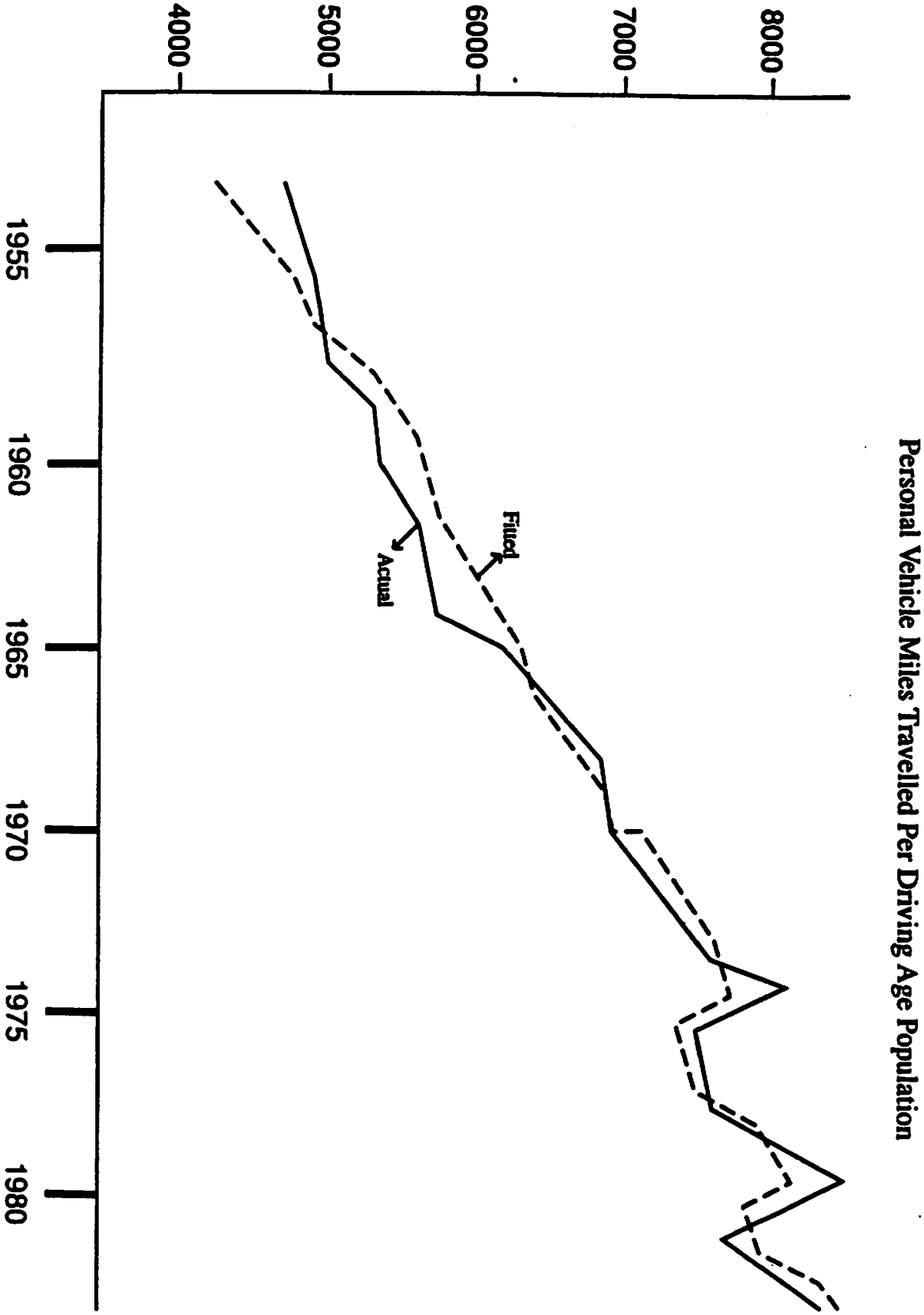
4.2.3 Personal Travel and Mode Choice

An econometric approach to studying personal vehicle travel explains total travel as a function of price and income, as in Figure 1 below. Annual vehicle miles travelled (VMT) per adult is shown as a function of real per capita income and real gasoline price per mile (price per gallon divided by average fleet mpg), and the fitted relation shows an income elasticity of .96 and a price elasticity of about -.2. The striking agreement between observed and estimated VMT values over as long an interval as 1955 to 1983 should make one cautious about claiming that the relationship will change in the future. If the relationship does not change, then only declines in real income or large increases in real cost per mile -- which with rising fleet economy means even larger increases in fuel price per gallon -- will reduce vehicle miles travelled per adult.

Despite the compelling fit of this curve, though, there are strong reasons to expect that the factors driving travel growth thus far will not continue. The increase in miles travelled per person has been driven by two factors -- the postwar generation bulge, and the

[60] Yenny and Uy (1983), Table 2.2

FIGURE 1. US VMT PER CAPITA, OBSERVED AND FITTED
SOURCE: Werbos (1985)



entry of women into the workforce -- that have largely run their course. Ross argues that increases in total VMT since 1969 (a total rate of increase of 3.5% per year) have been principally driven by increases in the number of adults and the fraction of adults employed with driving licenses, with only 1.1% increase per year in average miles driven per driver. It is unlikely that employed men 25-54 will increase their driving any more, for they already average 18,000 miles per year. By projecting that both sexes in 2000 will have the same age-specific employment, licensing, and driving patterns as men in 1983, he estimates a 2.4% per year increase in total VMT from now to 2000.[61]

More driving by older people may lead to higher VMT than this estimate. As today's adults age, they will make up not just an unprecedentedly large cohort of elderly, but a healthier one with much more lifelong experience driving than today's elderly; consequently, it may not be appropriate to apply the lower VMT per person of today's elderly to them.

Looking at miles per vehicle rather than miles per driver would also lead to higher projections of VMT. Annual distance travelled per vehicle has changed very little for more than 40 years,[62] while ownership has increased dramatically. Auto ownership may increase further. It has already surpassed one per household, one per worker, and one per licensed driver, three limits all once considered inviolable.[63] If these trends continue, VMT will grow strongly.

---

[61] 1988b, p. 10.

[62] MVMA (1988), pg.54 shows miles per car between 9,000 and 10,000 since 1940; distance per truck has increased from about 10,000 to about 13,000 over the same time.

[63] In 1986, the US had 1.83 vehicles per household, 1.80 vehicles per worker, and 1.02 vehicles per licensed driver.

But these trends cannot both continue. With further increases beyond one vehicle per driver,[64] use of each vehicle must decline. Automakers are anticipating this trend with increased marketing of specialized and recreational vehicles. An added vehicle in a household would likely bring some increase in total miles driven, even with no driver presently vehicle-less in the household. But with ever fewer drivers to go around, it is most unlikely that total miles driven will increase proportionally with the number of cars. Increased vehicle ownership will likely cause decreases in average VMT, and thus only modest increases in total VMT.

Rising personal income has contributed to increased travel by the most energy-intensive modes, private auto and air. Lower-energy modes, including urban public transit and intercity rail, have competed poorly with the luxury modes. As incomes continue to rise, the difficulty of the other modes will likely increase; but their position may also be enhanced by increasing congestion of urban roads and highways. In principle it is clear that the cost of travel has time as well as money components, and that current and projected levels of congestion may cause the time cost to dominate. If planning or special traffic measures make it easier for public transit to get through the congestion than cars, this shift in the relative time cost of modes may move many people to transit. The experience of cities where public transit offers travel times and service comparable to automobiles supports this view, as discussed in Section 6.4.

More people spending part or all of their worktime at home or working flexible hours may reduce work travel significantly. This is a dangerous prediction, though; for more than 10 years it has been foretold in vain. Indeed, both the censuses and the Nationwide Personal

[64] Currently 18.4 million US households have more vehicles than drivers; Ross (1988b), Fig 5.2.

Transportation Surveys showed progressive declines in home workers, from 4.5% of the workforce in 1969 to 3.5% in 1983,[65] although this may represent a large decline in farming masking a turnaround in metropolitan work-at-homes. One recent study showed 24 million people working at home, 9.5 million for themselves and 16.5 million for others.[66] And several factors -- growing pressure from parents with primary child care responsibility in the workforce, increasing sophistication of computer networking systems, and the small but growing body of institutional experience such as neighborhood work centers -- all suggest that work-at-home is likely to grow.

In the East Bloc and the developing world, travel is presently constrained by low automobile ownership. Auto ownership is growing rapidly, though, due to rising incomes in developing countries and policy changes increasing auto production in the Soviet Union and China. China produced only 12,000 automobiles in 1987, [67] but plans 700,000 a year by the year 2000.[68] Other countries planning major production increases include Brazil, Mexico, Indonesia, Malaysia, India, Thailand, and Taiwan. Auto growth in some countries may be constrained by the capital required for building highways and infrastructure, and consequently by congestion. [69] Continuing large income disparities in LDCs will limit car ownership, but the limit may be very high. One recent analysis projects a near doubling in

---

[65] Klinger and Kuzmyak (1986), Table 7.6.

[66] Link Resources Inc (1988).

[67] Production of trucks and buses was much higher -- 385,000. MVMA (1988), p.30.

[68] Truck production is planned at 1.3 million, for 2 million vehicles per year in total. Automotive News.

[69] Owen (1987), Ch.6.

cars per person by 2025 in every developing region, even under slow-growth assumptions, and much faster growth in other cases.[70]

4.3 Efficiency Improvements

4.3.1 Light Vehicle Efficiency Improvements

Highway modes, particularly personal travel in cars and light trucks, dominate the transport sector -- in the US, and increasingly, worldwide. This dominance seems so strongly linked to rising incomes that measures to encourage people to drive less or switch modes, while still promising, have achieved little success so far. For these two reasons, the single most important factor determining future energy use and greenhouse emissions from the transport sector will be the rate of efficiency gains in cars and light trucks.

This rate in turn will depend on two questions: how fast will technical progress enable efficiency gains in vehicles that are like today's in size, performance, and cost; and how fast will changing consumer attitudes or producer market strategies enable efficiency gains that require changes in size, performance, and cost? For any efficiency level to be attained, it must both be technically feasible, and be producible at a price consumers are willing to pay in a model they want to buy.

The importance of market strategy is illustrated by US and Japanese makers' recent model decisions. Chrysler, which moved strongly to smaller models and all but abandoned its full-size line, remained well ahead of the unrevised CAFE standards;[71] GM and Ford,

---

[70] Sathaye et al (1988), Table 4.

[71] Chrysler reached 27.2 mpg by 1982, and 27.8 in 1988.

which positioned themselves as "full-line" makers and retained full-size models whose sales have recently rebounded, fell behind the standard and won its relaxation through petition. Japanese makers, limited by voluntary quotas on the number of cars they could import, have moved aggressively to larger, more luxurious models with higher unit profits.[72] The newly-released 1989 models suggest that both domestic and foreign makers think the time now right to market bigger, more powerful cars with only modest regard for fuel economy.[73]

Some insight into both the technical and the market trends that will shape future efficiency can be gained by looking at today's most efficient models and prototypes. Table 16 shows some of the most efficient models currently on the market, while Table 17 shows a selection of efficient models currently in prototype.

---

[72] From 1979 to 1988, the average Asian import increased in interior room from 85 to 97 cu. ft., increased in weight by almost 200 lbs, and reduced its 0 - 60 mph time from 14.6 to 13.5 secs. Heavenrich and Murrell (1988), Table 16.

[73] Automotive News (October 3, 1988).

TABLE 16: HIGH-ECONOMY PRODUCTION AUTOMOBILES

Car	Fuel	MPG City	MPG Hwy	Max Power (HP)	Curb Weight	Capacity (persons)
Geo Metro (Sprint)	gasoline	59	75	48	1500	4
Honda Civic CRX	gasoline	38	52	92	1966	2
Honda Civic CRX HF	gasoline	56	71	62	1716	2
Ford Escort	diesel	45	63	52	2081	5
GM Chevette	diesel	44	59	51	2300	4-5
Nissan Sentra	diesel	50	64	55	1872	4-5
Peugeot 205	gasoline	46	55	50	1600	5
Fiat Uno ES	gasoline	49	65	NA	1595	4
Toyota Starlet	gasoline	61	NA	76	1500	4

Source: unadjusted EPA test data, compiled from Bleviss (1988), p. 96 and EPA (1989b).

In part, these advanced commercial models achieve their superior fuel economy by being small, so they exaggerate the efficiencies attainable with the present size mix in the American market. But they are neither all tiny or sluggish; several can carry 5 passengers, and the Honda CRX is a sports model that competes with the Toyota MR2 and the now-discontinued Pontiac Fiero, while achieving substantially higher fuel economy.

These models also include technical innovations, mostly incremental improvements of present technology. The CRX achieves its high economy through weight reductions from plastic body panels and an aluminum engine block, and a partial lean-burn engine. The GM/Suzuki Geo Metro, presently the most efficient car in the US market, also uses a lightweight aluminum engine block.

That these models are marketed indicates both that the technology they incorporate has proceeded to a point of commercial reliability, and that there exists a market for cars of this size, price, and performance. It is not currently possible, of course, to fill every

market need with a car getting 50 or 60 mpg; none of these models will carry 6 adults or pull a heavy trailer. But these functions represent a very small fraction of all trips,[74] and with more multi-car households the markets for small, even 2-person cars will be large.

TABLE 17: HIGH-ECONOMY PROTOTYPE AUTOMOBILES

Car	Fuel	MPG City	MPG Hwy	Max HP	Curb Weight	Capacity (Persons)	Drag Coef
GM TPC	gasoline	61	74	38	1040	2	.31
VW E80	diesel	74	99	51	1540	4	.35
Volvo LCP 2000	diesel	63	81	52/88	1555	2-4	.25-.28
Renault VESTA2	gasoline	78	107	27	1047	2-4	.186
Peugeot VERA+	diesel	55	87	50	1740	4-5	.22
Toyota AXV	diesel	89	110	56	1430	4-5	.26

Source: Bleviss (1988), Table 3.2; Williams (1987) Table 1; Goldemberg et al. (1987) Fig 4.

The prototypes in Table 17 give insight into more advanced technologies that are near commercial readiness, and that manufacturers expect to find viable market niches. Like the best production models, these prototypes achieve their economy through a combination of advanced technology and smallness. They all rely extensively on new materials to reduce weight -- plastic body panels, fiber-composite structural parts, aluminum or magnesium drive-train parts -- and on flush glass, redesign of mirrors, grille, and headlights, and reduced exterior trim to reduce aerodynamic drag. The Volkswagen, Volvo, Peugeot, and Toyota use direct-injection diesel engines, while the Renault and GM use 3-cylinder gasoline engines.

[74] Klinger and Kuzmyak (1986) p.2-29, show that 83% of 1983 VMT were driven with only 1 or 2 people, up from 79% in 1977.

The 88-horsepower version of the Volvo has a heat-insulated diesel engine with multifuel capability. Flywheel energy storage systems to allow engine-off at idle and coast are used on the Volkswagen and the Renault. Only the Toyota uses a continuously variable transmission.

These prototypes range in size from the compact class down. Two American design efforts are using more advanced technology to seek similar efficiencies in larger, more powerful cars. The Cummins/NASA Lewis car is a 4-cylinder direct-injection spark-assisted adiabatic diesel with multifuel capability, that achieves an astounding 81 mpg given its heavy weight (3000 lbs in a 1984 Ford Tempo body). The Pertran project is lighter -- 1200 pounds -- and uses a supercharged pre-chamber diesel with continuously variable transmission and flywheel for energy storage in braking. It achieves roughly 100 mpg. Both cars hold 5 to 6 people.[75]

High prototype mileage figures must be viewed with a grain of salt, though, for several reasons. First, when a prototype built by hand and tuned for maximum efficiency achieves 100 mpg, that does not necessarily mean that an equivalent production model, with all the variability of mechanized production, can do the same. Second, tooling for a production model involves significant additional design problems, and the success of a prototype does not guarantee that these can be solved at acceptable cost; indeed, cost estimates are normally highly uncertain until production design is finished. And finally, the role of a prototype in the design process is to demonstrate feasibility of a concept by taking one design element to an extreme, sacrificing other elements that enter the design tradeoff in a production model. For many prototypes, this very process makes it unlikely that

[75] Fawcett and Swain (1982); Sekar et al (1984).

consumers would buy an identical model were it available. The question that a successful high-efficiency prototype poses is how to integrate the efficiency insights it offers into a design that can sell. This general reservation aside, though, informal reports on some of the prototypes shown here suggest that they may be very attractive production models.[76]

Because it takes roughly 5 years for testing and proof-of-concept of significant new technologies and another 5 to incorporate them into a commercial model, efficiency-advancing technologies now in the labs or in prototype largely define the menu available for new cars to the year 2000.[77] To estimate their effect, a popular but contentious method is to use lab results and computer simulations to estimate gains from each technology separately, then add them up using judgmental estimates of market penetration and positive or negative interactions between technologies. Table 18 summarizes two recent projections, expressed as percentage economy improvements relative to an average present model, with no changes in size or performance.

This projection technique poses several problems. First, economy is determined by complex interactions among many technical factors; it is not possible to separate precisely the effect of each change, so total gains may be bigger or smaller than the sums in Table 18. As simulation modelling of engine and car designs advances, this problem will decline. Second, while projections are most precise for those design changes that are most incremental and least lumpy, such as weight and drag reduction, the largest gains would come from major, lumpy, discontinuous changes -- changes whose impact everyone agrees

---

[76] Mellde (1985); Bleviss (1988), p.111-113 reports from conversations with Volvo engineers that the LCP 2000 was designed with size, performance, safety, and emissions criteria to ensure marketability, and that they expect production runs of 20,000 units per year at the cost of today's average subcompact.

[77] EEA (1988), p.3-1.

TABLE 18: PROJECTED FUEL ECONOMY IMPACTS OF AUTO TECHNICAL CHANGES

Source of Change		EEA Study (2005) % mpg improvement	Cheng Study (2010) % mpg improvement
Platform:			
	Weight Reduction	11 - 14.3 (2450 - 2600 lbs)	10 - 20 (2150 - 2535 lbs)
	Aerodynamics	7.1 - 8.8 (C_d < .25)	2 - 3 (C_d = .35)
	Rolling Resistance and Lubricants	3 - 4	2 - 3
	Accessories	1.5 - 2	2 - 3
Engine:			
	Spark Ignition	13 - 15.6 (includes 2-stroke)	5.3 - 6.5
	Prechamber Diesel	—	1.5
	Direct Diesel	—	6.2 - 11.6
Transmission:			
	Conventional	4 - 6	2.75
	CVT	0.9 - 1.5	3.4 - 5.9
	Engine On-Off	—	0.3 - 0.7
Overall New Car Test MPG		44.3 - 48.1	35 - 41
Fleet On-Road MPG		37 - 40[3]	29.6 - 34.2

Notes:
1. EEA's gains are estimated relative to a typical 1987 car weighing 3070 lbs and achieving 28.0 mpg; Cheng's gains relative to a typical 1985 car weighing 2900 lbs. and achieving 27.0 mpg.
2. Gains shown here weight each author's estimated technical effect by his estimated market penetration.
3. EEA does not present fleet on-road mileages. This figure is calculated assuming the same ratio between new and fleet figures as in Cheng.

Sources: derived from Energy and Environmental Analysis (1988); Cheng (1988)

would be large if they succeed, but whose success is risky. Some technologies would bring sudden large gains in efficiency, while there are none that would bring sudden, large losses. To the extent that prudent forecasts such as those in Table 18 leave out the long shots, their estimates of future efficiencies are biased downward. Because of design lead times, this factor becomes most significant after 2010.

Finally, the automakers know better than anyone else what gains will be achievable, how soon and at what cost, and they have every incentive to keep their knowledge secret -- both to protect commercial secrets from their competitors, and to reduce the risk of governments telling them what kind of cars to build. This difficulty is particularly acute because most technical advances can be exploited in several ways in the design process. An advance that improves combustion efficiency, reduces internal losses, or reduces rolling or air resistance can be used to reduce fuel consumption, to increase performance, or to add luxury features (i.e., weight). A technical efficiency gain need not bring a design efficiency gain unless the designer chooses to take some of its benefits in the form of economy. For example, recent improvements in engine design have markedly increased the horsepower to weight ratio, but the gains have mostly been taken as higher power rather than as lower weight.

Some promising routes to higher efficiency may be blocked by strict emissions standards. Diesel engines have had difficulty so far meeting particulate standards, although Mercedes and VW have now developed emission control systems that enable their diesels to meet the US standard of 0.2 grams per mile.[78] Two-stroke engines tend to have high emissions of both nitrogen oxide and hydrocarbons, and may have particular difficulty

[78] Bleviss (1988), p. 120.

meeting the proposed 0.4 grams per mile NOx standard.[79] Advanced engines such as gas turbines, whose high efficiency in part reflects high operating temperatures, may as a consequence also have high NOx emissions.

Achieving efficiency gains in new cars sold requires not just technical feasibility, but competitive cost and acceptable size, performance, and safety. Changes that improve fuel efficiency but raise a car's price may raise or lower life-cycle costs; studies in the late 1970s found that economy gains were only cost-effective up to 35-40 mpg,[80] while more recent work has claimed that lifecycle costs are minimized at 55 mpg and remain low up to about 90 mpg, even with cheap gasoline.[81] The essential disagreement -- how much higher the first cost of efficient cars would be -- remains. The answer depends on how the efficiency gains are achieved, and how good a job the engineers do. Disagreement over whether consumers will accept smaller, less powerful cars also remains. A particularly disturbing possibility is that because of research and market decisions made by the major US makers, the goals of maintaining the competitive position of the domestic makers and making large efficiency gains in new cars may be in conflict.

Given a value of new-car efficiency, the fleet efficiency depends on fleet growth, the rate of turnover of old cars for new, and deterioration of economy over a car's life. Disparity between new car and fleet economy will be large if growth is slow. The durability of cars has been increasing over the last decade, to the point where the median age of American

---

[79] Proceeding of OTA Workshop on Automotive Fuel Efficiency, Sept 13, 1988; Walsh (1988).

[80] CONAES (1979).

[81] Von Hippel and Levi (1983); Williams (1987).

cars on the road is 7 years.[82] If this trend continues, it will lengthen the period required to translate new vehicle efficiency gains into fleet gains.

Outside the US, market conditions generally favor smaller, more efficient vehicles; cities are more crowded, incomes are lower, and gasoline prices are higher. While recent gains have been faster in the US, Japanese and European makers are presently leading in efficiency research, advanced prototypes, and efficient models ready to market.[83] Absent large increases in oil prices or major policy changes, foreign efficiencies are likely to remain ahead. In developing countries, this effect may be partly counteracted by the used car market. Cars are driven longer in poorer countries, and older cars are sold from wealthy countries to poor ones. Both these effects slow the rate at which new-car gains affect the fleet.

4.3.2 Other Passenger and Freight Modes

Efficiency improvements are more readily adopted in other modes than in private vehicles, for two reasons: vehicles are usually operated commercially, so operators pay more attention to life-cycle costs; and vehicles are operated more intensively, so fuel is a larger fraction of total costs. The broad trend worldwide is that traffic is gradually shifting to more energy-intensive modes, but that the efficiency of each mode is increasing.

For example, in all countries passengers are shifting from other modes to more energy-intensive air, but air efficiencies are advancing with progressive movement to turbine

---

[82] MVMA (1988), p.26.

[83] Bleviss (1988), Ch.5.

engines, to high-bypass engines, and to advanced wings, as well as through better routing leading to increased load factors. The next generation of airliners, now due to be marketed in 1993, use new propfan engines, supercritical wings with turbulent/laminar control, and surface drag reduction techniques to give projected savings in energy per seat-mile of one-third relative to the best flying today.[84]

Freight is progressively moving from rail to more energy-intensive truck, but the efficiency of trucking is increasing through larger loads, double trailers, engine and aerodynamic improvements, and better logistics management to increase load factors and reduce empty backhauls. New inter-modal technologies such as double-stacked containers on flat cars or trailers that double as railroad cars may reverse the decline of rail, though. Such innovations could bring about a freight system that combines the flexibility of trucking with the energy efficiency and line-haul cost advantage of rail.

Other innovations promise substantial increases in energy efficiency of marine shipping. Recent experience with computer-guided wingsails for thrust assistance on ocean vessels has shown fuel savings of 10 to 20 per cent, as well as reducing tug costs by providing auxiliary thrust during docking.[85]

The simpler market conditions of commercial modes make it somewhat easier to predict their progress than that of private autos. In general, innovations like those described here will be incorporated when they are cost-effective. The crucial uncertainties are then the rate of technical progress, fuel prices (although the operator's fuel cost does not include

---

[84] Popular Science article, Marc Ross.

[85] New Scientist 19 June 1986, p.42, ASE February 1988, p. 50.

the externalities of greenhouse emissions or other forms of air pollution), and general economic trends that determine the rate of investment in new transport equipment.

4.3.3 New Fuels and Electric Vehicles

The future transport sector may include not just more efficient vehicles, but vehicles powered by other fuels than gasoline and diesel. New transport fuels under development include methanol or synthetic liquid fuel derived from natural gas or coal, ethanol derived from fermented plant feedstocks, natural gas in compressed (CNG) or liquefied (LNG) form, and hydrogen derived from electrolysis of water. Electric vehicles that run on rechargeable batteries are also being developed aggressively. These efforts are principally directed to extending petroleum reserves and reducing local air pollution, but they will also have large effects, for good or ill, on greenhouse emissions. Some new fuels will produce substantially higher emissions than the gasoline they replace, while others are virtually greenhouse emission-free.

To assess the greenhouse effects of new fuels, you must look beyond the tailpipe. In the present petroleum-based system, emissions of CO_2 from vehicles represent about 85 per cent of total transport-associated greenhouse emissions; the other 15 per cent comes from the production, refining, and transmission of the fuel, and venting and flaring of natural gas found with the petroleum. Changes in vehicle efficiency or travel patterns alone, without changes in the sources of transport fuel, will keep this relationship unchanged; if CO_2 from vehicles declined by 25 per cent, greenhouse emissions from the transport system would decline by 25 per cent. But new fuels will change the relationship, because their sources and

manufacture will be different. Consequently, it is necessary to add up total greenhouse emissions from extraction, production, distribution, and use of new fuels to assess their net impact on emissions.

DeLuchi et al (1988) performed these calculations, and their results are summarized in Table 19. The Total column shows total Carbon-equivalent greenhouse emissions from the present volume of highway traffic if all vehicles changed to the alternative fuel. They found that the total emissions impact of new fuels varied greatly, and that some fuels with significantly lower tailpipe CO_2 emissions had such large emissions upstream at the conversion or synthesis stage that total system emissions were unchanged or increased. This section briefly discusses the prospects for each proposed new fuel.

TABLE 19: GHG EMISSIONS FROM ALTERNATIVE VEHICLE FUELS

Fuel and Feedstock	Total (CO_2-equivalent emissions, Tg C/yr)	% Change from present
Electric-nonfossil generating	0	-100%
Hydrogen from nonfossil elec	0	-100%
Sustainably managed biomass	0	-100%
CNG	295	-19%
Electric-new gas generating	—	-18%
LNG	310	-15%
Methanol from natural gas	353	-3%
Electric - present generating mix	—	-1%
Present System: Gasoline and Diesel	364	—
Electric - new coal generating	—	+26%
Methanol from coal (30% higher eff'y)	553	+52%
Methanol from coal (baseline eff'y)	720	+98%

Notes:
1. Includes differences in thermal efficiency among fuels and weight increases from fuel storage system.
2. For electric vehicles, percentage changes shown are for applications where EVs are at least three times as efficient as ICE vehicles. Total effects are not estimated, because of limits on penetration.

Source: derived from DeLuchi et al (1987a), Table 4.

Methanol

Due to both technical and cost factors, methanol is the new fuel of choice among US policy-makers and automakers. It has less energy content per gallon than gasoline, so requires a larger fuel tank to attain an acceptable range, but its good antiknock properties permit higher compression ratios, bringing improved thermal efficiency. It corrodes some metals (zinc, lead, aluminum, and magnesium), and embrittles certain rubbers and plastics,

so some material substitution in fuel systems is necessary. Methanol reduces the formation of reactive hydrocarbons in exhaust, and may reduce NOx formation because of lower combustion temperatures, thus contributing to reduced ozone formation. Emissions of formaldehyde (a carcinogen) are increased, though, and require catalytic conversion.

Methanol's great advantage is the availability of internally controlled dual-fuel systems that vary spark timing and fuel mix in response to changes in the mix of methanol and gasoline in the fuel line, permitting use of any mixture of methanol and gasoline.[86] This technology may permit a large-scale switch to methanol because methanol-burning cars can be sold in advance of a nationwide fuel distribution system. Without such flexibility, the "chicken-and-egg" problems of changing the enormous transport system over to a new fuel may block the development of any new system.

Methanol can be produced from organic sources, but the cheapest source at present is natural gas. Coal will likely be economical too in 10-15 years, although all three sources are more costly than gasoline from today's cheap oil.[87] Production from natural gas gives a yield of about 85-90%,[88] while yields from coal are lower and more speculative. DeLuchi et al. estimate yields of 47% to 61%.[89] Total greenhouse emissions depend strongly on the feedstock and the conversion efficiency. While methanol from natural gas would slightly reduce total greenhouse emissions, coal-based methanol could increase them by 50% to 100%, depending on conversion efficiency.

---

[86] Each US maker has demonstrated a different dual-fuel system. Automotive News, September 10, 1988.

[87] US DOE (1988), p. B-4; Mills and Ecklund (1987).

[88] i.e. this much carbon in the gas is converted to methanol; the rest is emitted as CO_2. DeLuchi et al (1987a), p. 23, CRS (1988), p. 2.

[89] p. 22.

Ethanol

Ethanol shares most of the technical advantages and disadvantages of methanol: it has less energy per gallon than gasoline, but better antiknock properties; it reduces CO, NOx, and reactive hydrocarbon emissions, but increases aldehydes; and it attacks some engine components, but less than methanol does, permitting the use of blends up to 20 per cent without engine modification. Indeed, about 6% of 1986 US liquid fuel demand was supplied by "gasohol," a 10% blend of corn-based ethanol in gasoline.

Ethanol can be produced from the hydration of ethylene, or through fermentation and distillation of a sugar-rich agricultural feedstock, such as corn, molasses, or sugar cane. The United States produced 825 million gallons in 1986, mostly from corn, making it the world's second-largest producer after Brazil.[90] The US industry survives through subsidies, though, for production costs are higher than the cost of methanol from natural gas, and three to four times higher than today's cheap petroleum.[91]

Brazil supports the world's largest ethanol program, fermenting it from sugar cane.[92] Although ethanol has been blended into gasoline since the 1930s to absorb excess sugar production, the present concerted program to replace gasoline with ethanol began in 1975. The program combined heavy taxes on gasoline, capital subsidies for fermentation plant construction (which were removed in 1984), subsidies for ethanol-powered vehicles, and a

---

[90] DOE, p. B-1.

[91] DOE, p. A-2.

[92] This section draws extensively on Lizardo de Araujo and Ghirardi, "Substitution of Petroleum Products in Brasil: Urgent Issues", Lawrence Berkeley Laboratory LBL-21227.

government guarantee that the price of ethanol at the pump would not exceed 65% of the price of gasoline.[93]

As a way of replacing gasoline, the program has been astoundingly successful. Ethanol powered cars, first produced in 1979, captured 90% of the market in 1986; one third of the total auto fleet (about 2.5 million vehicles) now runs on hydrated ethanol.[94] Ethanol production was 3 billion gallons in 1986, and gasoline consumption is projected to drop to negligible levels within 10 to 15 years, as older gasoline-fuelled cars are scrapped.

The program's problems have been two: cost and land-use. Estimates of the equivalent oil cost of ethanol production range from $40 to $65 a barrel in southeast Brazil, and are as high as $100 in the more remote northeast. The original revenue source for the retail subsidy was the gasoline tax, but as ethanol has captured an increasing share of the fuel market from gasoline, the source of funds has shrunk as the need has grown. So much arable land has been turned to sugar cane production that food crops have been displaced, especially in the northeast region where malnutrition is already endemic. Improvements of 50% in yield per acre and 30% to 40% in production cost are projected by the turn of the century, though, which would mitigate both these problems.

Ethanol produced renewably from organic feedstocks does not contribute to greenhouse emissions.[95] The Brazilian experience shows, though, that the scope of an ethanol program is limited by competition for agricultural land with food production. One

---

[93] Ethanol has 65% the energy content per gallon of gasoline, so this policy equalizes price per BTU, but ethanol's efficiency advantage from higher compression ratios makes it effectively 20% cheaper.

[94] Hydrated ethanol is 96% ethanol, 4% water. The rest of the fleet runs on a 20% ethanol, 80% gasoline blend.

[95] Strictly speaking, this is only true if two conditions are satisfied: if the energy inputs to ethanol production also come from the renewable feedstock -- for example, the farm implements used to grow the corn, and the distillation process, must be powered by ethanol; and if the energy crop does not replace a standing forest.

estimate for the US shows that a corn-based ethanol program providing 10% of the nation's automotive fuel demand would require 40% of the corn harvest.[96] This limit would only become tighter if future climate change reduced soil moisture and crop output in the grain belt.

Natural Gas

Natural gas can be used in present engines with only minor modification. Performance is somewhat degraded in a dual-fuel vehicle, but need not be in a dedicated vehicle optimized for gas. Relative to gasoline, natural gas has theoretically lower CO and reactive organics emissions, although experience to date has been mixed; NOx emissions may be higher.

Gas's major difficulties lie in the transport and storage of fuel; more extensive changes in infrastructure would be needed than to accommodate new liquid fuels such as alcohols. Natural gas is most likely to be used in vehicles either compressed to high pressure (CNG) or cooled until it liquefies (LNG).[97]

CNG is stored on-board in a pressure cylinder at pressures of 2400-3000 psi. Conversion to dual-fuel operation entails significant cost, weight increase, and loss of storage

---

[96] Renner (1988), p. 22.

[97] LNG is not the same as liquified petroleum gas (LPG), commonly called propane, which presently powers about 350,000 vehicles in the US and provides 0.3% of transport fuel demand. LPG consists of mostly 3 and 4-carbon atom chains that liquefy at temperatures ranging from -44 to +31 F and can be kept liquid at room temperture by storing at a pressure of 200 psi. Consequently it is easier to store than natural gas, which requires higher pressure or lower temperature for efficient storage. LPG is available only in small quantities as a by-product of both petroleum and natural gas, though, so its contribution to total transport energy will remain small.

space,[98] which make CNG use difficult in small vehicles. In larger vehicles, though, especially in high-mileage uses such as taxis and fleets, fuel savings can pay back the conversion cost. There are currently about 700,000 CNG vehicles operating commercially worldwide.[99]

Natural gas cooled to -259 F liquefies and can be carried much more compactly and at lower pressure than CNG. Because the cryogenic storage cylinder to keep it at this temperature is both smaller and lighter than the CNG pressure tank, LNG is a more promising storage medium for small vehicles. There are only a few small-scale demonstration projects operating now and no commercial vehicles. The principal difficulty to be overcome is that the tanks do not insulate perfectly and so the fuel slowly boils off when a vehicle sits unused for several days. Depending on how the boiled-off gases are managed, this can represent a safety hazard. It is not yet clear whether boil-off will be a serious hindrance to safety or consumer acceptability of LNG vehicles.

In either form, natural gas vehicles generate less greenhouse emissions than the present system. DeLuchi et al estimated that a CNG system gives a 15% reduction, and LNG a 19% reduction in greenhouse emissions relative to gasoline and diesel. Their analysis assumed a system leakage rate of 3%; because of methane's high greenhouse effect per molecule, significantly higher leakage rates could eliminate the greenhouse advantage of natural gas relative to gasoline and diesel.[100]

---

[98] The pressure tank, fuel line, and switching equipment cost $1500-2000 per vehicle, add 300-400 pounds of weight, and take 95-190 gallons of space. DeLuchi et al. (1987b), Ch. 5.

[99] DOE Table D-1; 30,000 in US, 15,000 in Canada, 130,000 in NZ, 300,000 in Italy, 200,000 in Australia.

[100] Present pipeline systems leak about 2%. Preliminary calculations (Victor, 1989) indicate that a total system loss rate of 4% would eliminate the greenhouse advantage of CNG.

Hydrogen

Hydrogen is a possible transport fuel for the next century. It is an energy medium, not an energy source, for it must be produced by using electricity to electrolyze water. Hydrogen's viability thus depends on the availability of a non-fossil electrical source, photovoltaic or nuclear, which would make the transport energy system essentially emission-free from beginning to end. With present photovoltaic and electrolysis technology, though, the cost of hydrogen is very high.

There is little knowledge accumulated yet on the performance of hydrogen engines, although no fundamental obstacles are evident.[101] BMW has a prototype program in progress.[102] As with gas, the major technical problem is fuel storage, which requires either pressure of 10,000 psi or liquefying the fuel at -261 F and 29 psi. Boil-off is a more severe problem with liquid hydrogen than with LNG.

Hydrogen's contribution to greenhouse emissions would depend on the energy source used to produce it. If solar, hydro, or nuclear electricity are used, there are no greenhouse emissions; if new coal plants, then greenhouse emissions will increase by about 25%; and if hydrogen is produced directly from coal, emissions will more than double.

The attractions of non-fossil hydrogen are obvious. In addition to eliminating greenhouse emissions, it eliminates tailpipe CO and reactive organic emissions and reduces dependence on petroleum. The technical problems of producing hydrogen cheaply, storing it at sufficient density, and managing boil-off are severe, though, and will not be solved

---

[101] DeLuchi et al (1987b), Ch. 6.

[102] BMW AG (1987).

without a major research effort. DeLuchi et al, who are advocates of hydrogen, estimate that an aggressive research program could bring a viable hydrogen transport system in 20 years.[103]

Electric Vehicles

Another prospect for radical change in the transport power source is the electric vehicle. An electric vehicle replaces the engine with onboard electric motors and the fuel system with batteries that are recharged at night. Electric vehicles have the advantages of high efficiency, quiet operation, and zero emissions in operation, but their development so far has been limited by technical obstacles in battery performance.

To make a vehicle roughly comparable to today's in size, weight, and performance, batteries must achieve high levels of both energy storage density, which determines range between recharges, and power density, which determines acceleration and top speed. Typical electric vehicles in use today have ranges of 50 miles, top speeds of 30 to 60 mph, and take 8 or 9 seconds to accelerate to 20 mph.[104]

These performance limits are slowly yielding to further research. An example of the best present technology is the Peugeot 205 Electrique, which runs on nickel-iron batteries. It has a 62-mile range, a 62-mph top speed, a maximum power of 22.8 HP permitting acceptable acceleration for urban traffic, and weighs only 20% more than the conventional

---

[103] ibid, p. 195.

[104] ibid, p. 35.

model 205. Battery lifetime, another constraint with early designs, is estimated at 125,000 miles or 1500 recharges.[105]

It is possible that electric vehicles with limited performance relative to today's cars may still be feasible substitutes for some urban travel needs. For example, one study found that a 50-mile range would satisfy the needs of the secondary driver in a multi-car household 95% of the time, and that a 100-mile range would meet the needs of a single-driver household 95% of the time.[106] Drivers may want a car that meets their needs the other 5% of the time too, though, so EVs may only be acceptable to multi-car households.

Even with limited performance, though, electric vehicles may be acceptable for commercial use. Because life-cycle costs are low, because the safety problems of a low-acceleration vehicle are fewer with professional drivers, and because it is easier to put bulky battery packs in a larger vehicle, much development effort has focused on electric vans. Three models are now running in demonstration programs or nearing commercial status.[107] The General Motors (UK) Griffon has a 53 mile-per-hour top speed and a 60-mile range, and has logged 6 million miles in fleet use worldwide. Operating costs per mile have been about 40% lower than similar-sized conventional vans. General Motors (US) will begin marketing its G-Van (a Vandura body) in 1989, which offers performance equal to the Griffon's with 25% higher payload capacity. The Chrysler TEVan, an electric version of the Voyager/Caravan minivan, will undergo prototype testing in spring and summer of

---

[105] Bleviss (1988), p. 328

[106] Cervero (1984), p.11

[107] Purcell (1988).

1989, with commercial production planned to start in late 1991. A nickel-iron battery gives the TEVan a range of 120 miles and a top speed of 65 mph.[108]

Today's electric vehicles are clearly only competitive in limited applications, with high mileage and low performance needs. Larger markets may come with new battery technologies that increase range and performance,[109] and AC power trains that equal today's DC motor performance at half the weight and cost. Other technical prospects include hybrid vehicles combining a primary electric drive with a secondary gasoline motor to increase range to 200-300 miles,[110] and electrified roadways that permit battery recharging while driving.[111]

As with hydrogen, the effect of electric vehicles on greenhouse emissions and the feasibility of significant market penetration depend on regional electric generating capacity. Charging electric vehicles with electricity generated by solar, hydro, or nuclear would eliminate associated greenhouse emissions, while using the current generating mix would leave emissions unchanged and charging from new coal stations would increase emissions by about 25%.[112] EVs may consequently be limited to the number that can be powered by surplus renewable or gas generating capacity. In modest numbers, EVs would enable utilities to flatten their load curve, for most recharging would be done at night when capacity is idle.

---

[108] EPRI Electric Vehicles report: Product 4659.

[109] Two forms now under development, lithium-sulfide and sodium-sulfur, are particularly promising. They offer two to three times the range of current lead-acid batteries, and substantially higher acceleration and top speed.

[110] Purcell (1988), p. 55.

[111] A prototype bus system using one mile of electrified roadway is now undergoing testing in Santa Barbara. Ross, H.R. (1986).

[112] DeLuchi et al (1987a), Table 4.

5. REFERENCE CASE SCENARIO FOR 2025

This chapter and the next try to make sense of the host of complex trends and issues in the transport sector, in order to present a simple picture of how the sector could look in the year 2025. This chapter presents a reference case, or "business-as-usual" picture of transport in 2025; the next chapter contrasts this with more surprising futures on each of several dimensions. The scenario presented here is drawn from work in progress at the World Resources Institute (WRI) and Lawrence Berkeley Laboratory (LBL), as part of an EPA project to project future greenhouse emissions.[113] These two projects represent the most comprehensive attempts to date to develop consistent scenario-based greenhouse projections for all regions of the world. The intent of the reference case scenario is to be representative of what will likely happen in the absence of either significant surprises -- technical, political, social, or economic -- or concerted policy intervention to alter transport trends.

The WRI and LBL projections were based on two scenarios, one named "rapid change" and the other "slow growth." In the rapid change scenario, rising incomes and high real energy prices promote faster advancement of technical efficiencies, and population growth is on the low side; in the slow growth scenario income growth and energy price increases are both slower, hindering new investment and technical change, while population growth is faster. These are intended to be equally plausible reference cases. Table 20 presents the US projections for 2025, including some detail on the calculations for highway transport, then as now the largest component of transport energy use. Table 21 presents

[113] Mintzer (1988); Sathaye et al (1988); EPA (1989a) draft, currently being reviewed.

total transport energy for all nine world regions, and corresponding levels of CO_2 emissions.[114]

In broad outline, these projections show that in the OECD, modest increases in activity level are likely to be offset by efficiency improvements in all modes, leading to total transport energy use and CO_2 emissions in the early 21st century near today's levels -- slightly lower in the US, slightly higher in the rest of OECD. In the USSR and Eastern Europe, rising activity levels will dominate efficiency gains, yielding more than a doubling of transport energy under both reference case scenarios. In all four of these developed regions, the balance of activity growth and technical progress is such that energy use is higher under slow growth assumptions than under rapid change.

[114] Using the emission coefficient of 20.256 grams carbon per thousand BTU for liquid fuels, after Marland (1982).

TABLE 20: CALCULATIONS FOR USA 2025 REFERENCE CASE SCENARIOS

HIGHWAY MODES

Year	Vehicles per 1000 pop.	Total Vehicles (millions)	Miles per Vehicle	Tot VMT (billions)	Avg MPG	Energy (quads)
1. CARS AND LIGHT TRUCKS						
1985	550	131.3	9900	1299.9	16.7	9.73
2025 RAPID CHANGE	650	188.2	9700	1825.9	34	6.71
2025 SLOW GROWTH	600	178.1	9900	1762.7	30	7.34
2. HEAVY TRUCKS AND BUSES						
1985	170	40.6	11700	474.9	9.1	6.52
2025 RAPID CHANGE	190	55.0	15800	869.4	18	6.04
2025 SLOW GROWTH	180	53.4	14100	753.2	13	7.24

3. US SUMMARY

	TOTAL HIGHWAY ENERGY (QUADS)	TOTAL TRANSPORT ENERGY (QUADS)
1985	16.25	20
2025 RAPID CHANGE	12.75	17.54
2025 SLOW GROWTH	14.59	19.43

Source: Mintzer (1988).

In the five developing regions projected energy growth is much higher than in the industrial countries, with 2025 levels ranging from double to five times the 1985 levels. Moreover, the balance of activity growth and technical progress in these regions is such that energy consumption grows faster under rapid change than under slow growth assumptions.

TABLE 21: WORLD TRANSPORT ENERGY USE IN QUADS, 2025

Region	2025 / 2025 1985	Rapid Change	Slow Growth	2025 CO_2 (TG C)1
USA	20.0	17.54	19.43	355 - 393
CAN + W EUROPE	13.0	13.84	14.69	280 - 300
JAPAN + ANZ	4.4	4.74	5.31	96 - 107
CP EUROPE	7.0	17.25	18.01	350 - 365
TOTAL DEVELOPED	44.6	53.36	57.63	1080 - 1170
S + E ASIA	2.7	7.49	5.11	103 - 150
CHINA	1.0	5.12	3.15	64 - 104
AFRICA	2.1	10.06	5.81	118 - 204
LAT AMER	4.4	13.93	9.11	185 - 282
MIDDLE EAST	1.1	3.95	3.04	62 - 80
TOTAL LDCS	11.3	40.55	26.21	530 - 821
TOTAL WORLD	56.0	93.90	83.84	1700 - 1900

Note: 1. CO_2 emissions at 20.256 grams carbon per thousand BTU.

Source: Sathaye et al. (1988); Mintzer (1988).

These projections are consistent with other attempts to project US transport energy and CO_2 into the next century. For example, Cheng projected the likely rate of cost-effective efficiency gains in US highway transport, and so estimated total highway fuel consumption in 2010.[115] His estimated auto fleet mileage for 2010 was 29.6 - 34.2 mpg with no size shift, and 34.9 - 40.6 mpg with a major size shift, giving total highway energy use of 12.2 to 15.4

[115] (1988), p. 9.

quads. These values are consistent with those in Table 20. The Department of Energy office of Conservation projects US total transport energy use in 2010 of 16.2 quads, about 10% lower than the rapid change value in Table 20.[116] This good agreement with other US projections, as well as the plausible values for fleet efficiency, suggest that these reference case scenarios fit their role as surprise-free projections.

[116] Edmonds et al (1988), p. 34.