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THE TRANSPORT SECTOR AND GLOBAL WARMING

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6. ELEMENTS OF A MORE SURPRISING FUTURE

This chapter acts as a counterpoise to the previous one. While Chapter 5 presented a "business as usual" scenario for 2025, this one presents a menu of marked departures from business-as-usual intended to suggest what directions of surprising change would have the largest impacts on transport CO_2 emissions. Each section proposes a particular departure from present projections, with back-of-the-envelope calculations of its effect on transport energy and CO_2 emissions. For this chapter, and the policy chapter that follows, the focus is on US transport emissions only.

This chapter is admittedly speculative, the selection of particular directions of change is arbitrary, and the distance moved in each direction is chosen subjectively. These changes are elements of a surprise scenario, not policy options. Each is intended to represent no more than a 5% to 10% chance of occurring by 2025 under present trends, but could become significantly more likely if there are surprising discontinuities in technology, markets, social attitudes, or policy. The magnitudes are chosen to be unlikely, but not inconceivable; they should stretch belief, but not quite to the breaking point.

The grounds for indulging in such speculation lie in the difficulty of thinking as far into the future as 40 years. Over such a long time, projections tend strongly to overstate the extent to which the future will be like the recent past. An admittedly arbitrary exercise of speculating about extremes may help to counteract this bias. It may also serve to broaden the range of policy options that suggest themselves for consideration.

At the end of the chapter, the effects of each surprise on US 2025 transport CO_2 emissions, relative to the reference case, are tabulated.

6.1 Major Technical Breakthroughs in Vehicle Efficiency

The list of efficient technologies presented in Section 4.3 above omitted all of the high-gain, low-probability ones. There are a number of technologies now in early development that could if successful bring much larger increases in fuel economy than projected above, even without substantial change in the size or performance of vehicles. One recent study discusses three of these technologies, any one of which could more than double fuel economy in current-sized vehicles, and projects that if pursued aggressively, any of the three could be commercial within twenty years.[117]

The three are oxygen enrichment, the adiabatic diesel with exhaust gas heat recovery, and the complete energy-storage system. Oxygen enrichment, selected as a priority technology by the Japanese government, would permit much smaller engines to produce the same power by reducing the amount of superfluous nitrogen drawn into the cylinder with combustion oxygen. Preliminary calculations suggest that an oxygen-separating engine of only .125 liters could produce 100 horsepower and drive today's family-sized sedan at 60 mpg.[118]

The adiabatic (or heat-insulated) diesel engine would run without coolant, eliminating a major source of energy loss. The engine would need a ceramic block and head and solid lubricants to withstand its high operating temperature, as well as new developments to recapture exhaust gas energy. These engines are under development in the US and, more aggressively, in Japan. Engineers at one US effort have projected that their engine would

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[117] Bleviss (1988), Table 2.8.

[118] Dow Chemical Company (1986); Automotive News, June 3, 1985.

achieve nearly 80 mpg in a 3000-pound Ford Tempo (with CVT),[119] and that the engine could be on the market in 10 years.

The complete energy storage system would combine regenerative braking, a CVT, and an energy-storage device such as a flywheel, to let the engine run at full load all the time. The CVT would transmit full-load power over the entire range of speeds, the engine would be stopped for idle and deceleration, and the brakes would recharge the storage device through the CVT for nearly full recovery of braking energy. By essentially eliminating part-load losses, braking losses, and idling losses, this system could more than double fuel economy, but research is presently only at an early prototype stage.[120]

These are only three technologies, already identified and under development, any one of which could double new car economy by 2005 to 2010. It is also possible that two or three of these could be combined for still larger gains. Since none of these is reflected in the reference case projections above, and other innovations not yet thought of could also be commercialized by 2010 to 2025, a "sufficiently surprising" technological progress scenario would have roughly a doubling of new light vehicle economies by 2010, and a tripling by 2025, relative to the values assumed in the reference case scenario. Increases in the fleet mileage would, of course, be smaller. If, in the reference case scenario, new car and light truck mileage in 2025 were tripled, the fleet efficiency would be 75 - 85 mpg,[121] and US transport energy use would drop to 13.5 to 15.1 quads and carbon emissions to 275 - 302 TG.

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[119] Bleviss (1988), p. 37.

[120] Ibid, p. 77-79.

[121] Using a factor of .835 to convert new car efficiency into fleet efficiency, as in Table 18 above.

The above technologies could be applied to trucks and buses as well as cars, but their impact may be less because of power limits on the energy-storage system, or the smaller proportional gains from reducing engine size in a larger vehicle. 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.

6.2 Consumer Acceptance of 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. Even considering only shifts in market share among today's US size classes, Cheng's analysis cited above (chapter 4) showed that size mix shifts were more significant than the assumed rate of technical progress in determining economy. Even now there are still smaller commercial models selling well in Japan and Europe[122] in the "micro-mini" class, with displacements around .5 liters and city economies from the high 40s to the high 50s. Smaller still, GM has a half-width, 1-2 passenger high-performance prototype that achieves 120 mpg,[123] suitable for high-speed commuting and requiring only narrow lanes and small parking spaces.

Such small cars will never be suitable for some needs, so their ultimate penetration will be limited. But there are many applications, notably urban commuting, where they are

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[122] Ibid, p. 98.

[123] Sobey (1988).

physically suitable but presently limited by consumer resistance. Over 40 years, with potentially large increases in congestion, fuel prices, and environmental sensitivity, consumer preferences could shift to the extent that such cars becor the norm.

The 1983 National Personal Transportation Survey found that 57% of all vehicle-miles travelled were with only one person in the car, 83% with two or less, and 91% with three or less.[124] Suppose most miles were driven in a car sized for its load -- 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. These efficiencies are all demonstrated with present technology. Then fleet efficiency, allowing up to 15% degradation on the road, would be 75-85 mpg, yielding the same value for total CO_2 in 2025 as the technical tripling of light vehicle mileage above.

A larger increase still in efficiency would be attainable with present technology if consumer's views of required power, as well as required size, changed. The major weight constraint on current micro-minis is the engine size needed for highway accelerations and speeds. A car with a top speed of 45 Mph, higher even now than the average speed of many congested urban worktrips, could be made much lighter.

While such tiny cars would obviously be unsuitable for long distances or highway travel, their increased use for urban travel would be consistent with present movement to multiple vehicles per household. The most likely constraint on lightness would be crashworthiness, particularly if light cars with modest top speeds share the road with full-sized cars and ever-larger freight trucking. The solution would likely be in separate roadways for different classes of vehicle. A road network designed for light vehicles with low

[124] OTA (1988), p. 121.

top speeds could be separated from the present network, with greatly reduced structural demands and cost, and with higher capacity through narrow lanes suitable for 45 Mph. Some safety problems would remain, principally from fixed-object collisions, but these could be mitigated by suitable roadway design.

6.3 Major Shift to New Power Sources

The reference case scenario, by the CO_2 emissions coefficient it uses for all regions, implicitly assumes that gasoline and diesel from petroleum continue to dominate transport in 2025. Indeed, this coefficient is already incorrect for Latin America in 1985 because it neglects the Brazilian ethanol program; the value should be roughly 10% lower, assuming that forests are not being cleared to plant sugar and the sugar crops are managed sustainably.[125] If any region of the world moves strongly to new fuels, the proportionality between emissions and energy will change. This section sketches three possible kinds of departure.

Suppose the US committed to an aggressive program to replace petroleum with methanol. Methanol could be produced from biomass, natural gas, or coal, with coal the most abundant source. If produced sustainably from biomass, it would have no associated greenhouse emissions; if from natural gas, emissions would be slightly lower per unit of energy than with the present system; and if from coal at a yield of 61% (DeLuchi's "higher efficiency" projection above), emissions would rise by 50%. A major program would likely

[125] Brazil has 37% of Latin America's vehicles, and diesel and fuel oil represent about half of Brazil's transport energy demand; of the other half (which would otherwise all be gasoline), ethanol supplies about 60%. While the program is not displacing standing forest, it is displacing land from food production.

employ all three sources, of which biomass would be the most constrained,[126] and coal the least. If, for example, a total of 70% of 2025 US transport energy were replaced by methanol -- 10% 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, the US could pursue a natural gas program as a bridge to a hydrogen-powered transport sector in the long run. Since this would represent a larger technical change, the degree of fuel substitution by 2025 would likely be lower than with an alcohol program, even with aggressive policy. Hydrogen, in particular, would have to await sufficient price declines in photovoltaics, or price declines and safety improvements in nuclear, that it could be produced without fossil fuels. Suppose, for example, that by 2025 20% of light vehicles (mostly the larger ones) use CNG, 10% use LNG, and hydrogen penetration is just beginning, with 10%; that commercial freight (truck, rail, and shipping), due to cost advantages and easier fuel storage in large vehicles, has moved 90% to CNG; and that the newest generation of aircraft have cryogenic fuel storage and represent 40% of air traffic (30% are 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. The performance limits of electric vehicles at present, and the slow pace of progress in batteries, make large market penetration harder to imagine for EVs than for either gas or alcohol vehicles. Major expansion of their use would be most credible for urban freight and travel in large

[126] Both Knowles (1984) and SERI (1981) estimate that biomass could supply at most one third of US transport energy. Knowles's estimate assumed that all crop and forestry wastes were converted; DeLuchi et al., p. 59-60.

metropolitan areas that have both severe air quality problems and the prospect of enough electrical generating capacity. If, for example, 10% of American light vehicle miles travelled were replaced by electric vehicles[127] 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.

6.4 A Boom in Urban Public Transit.

Every author who looks at public transit concludes that Americans just don't like it. A recent OTA report put it as follows:

> The American distaste for the comparative inflexibilities and inconveniences of public transit is obvious. Between 1970 and 1980, real family income declined, the number of workers living in urban areas increased by 15 million, large new public transit investments were made in Washington, DC, Atlanta, and San Francisco, and large operating subsidies meant that cost of public transit rose only 44% while the cost of owning and operating an auto increased 250%. Nonetheless, public transit ridership fell from 8.9% to 6.4% of the journey to work, while the use of personal vehicles for the journey to work increased from 80.2% to 85.7%.[128]

It need not remain so. Not only do many cities in the rest of the industrial world have efficient, heavily-used public transit systems, but there exist examples of cities similar in many ways to American ones recapturing large numbers of motorists to public transit through service improvements.

Ottawa Canada, a metropolitan area of about 0.6 million, began a major program of

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[127] With present regional distributions, this would be similar to electrifying all vehicle travel in greater Los Angeles, Seattle, Denver, Phoenix, Houston, and greater Miami.

[128] US Congress OTA (1988), p. 120.

transit improvement in the mid-1970s (coupled with the abolition of free parking downtown for federal public servants).[129] The cornerstone of the program was construction of a 20-mile dedicated busway, separated from other traffic but with ramps feeding into arterial roads at major stations, spaced at about 1-mile intervals. The program also included premium-priced express service between outlying suburbs and major employment centers (many of which are not in the CBD), expanded connections to inter-city terminals, an increased bus fleet including double-length articulated buses, and many operating innovations (for example, an express bus service operating along a freeway with stops at each interchange, operating all day with 10-minute headways).

The program's success has been impressive. Ottawa has the highest transit mode split of any medium-sized city in North America. Transit mode splits are 23% to 45% along major suburban screenlines (up from 2% to 20% in 1971), and over 50% at the edge of the CBD. Annual ridership per person in 1986 was 160 trips, and 30% of all trips can be made door-to-door as fast (or faster) by bus as by car. The system covers a steady 60% of operating costs from revenue. The busway, as well as permitting extreme flexibility in service routing and schedules, is predicted to pay for itself by 2000 through the smaller bus fleet size that the busway's higher speed permits.

Curitiba Brazil is a prosperous and rapidly growing metropolitan area with a population of about 1.5 million.[130] Faced with rapidly growing traffic congestion in the early 1970s, the city developed a comprehensive public transport plan based on a 35-mile network of separated bus lanes along the medians of radial arterial roads. The lanes are not

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[129] This section is drawn from Ottawa-Carleton Regional Transit Commission (1986); Regional Municipality of Ottawa-Carleton (1986).

[130] This section is drawn from Poole (1983).

grade-separated at intersections, but have signal priority. The system is operated by several private companies with co-ordinating management committees to oversee such matters as inter-company reimbursement for transferring passengers. Fares are low, and the companies are profitable.

In 1970 about 40% of trips in Curitiba were made by private auto, indicative of the higher incomes here than in other Brazilian cities.[131] The remarkable success of the transport system is that between 1970 and 1980, while Curitiba's auto fleet grew by more than 10% per year, the fraction of metropolitan trips made by auto declined to 30%.

The experiences of both Ottawa and Curitiba suggest that attracting riders from cars to public transit depends on comprehensive attention to details of service convenience and quality, and that major gains can be made when, because of priority treatment on congested roads, public transit is faster and more convenient than driving.

Are these experiences relevant to American cities? Curitiba's 70% transit share may not be, but Ottawa's surely is. Suppose that through comprehensive planning, equipment upgrading, traffic priority and service innovations, America's major metropolitan areas achieved a 40% public transit share, somewhat below Ottawa's current level. Then, with reasonable assumptions for modal energy intensities,[132] these passengers' energy use would decline from 2,000 BTU per passenger-mile to 725. Total US transport energy use and

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[131] The nationwide average for metropolitan areas was 30%.

[132] Auto load factors do not change, so 1985's 4,000 BTU/PM becomes 2,000 with doubling of fleet mpg; US energy intensities for bus and train are not a good starting point, because they reflect very low load factors. Using typical European 1970s values, 1375 BTU/PM for bus and 785 for rail, modified by the modal efficiency improvements assumed in the reference case scenario, and putting 60% of the travel on bus, 40% on rail, gives a 2025 weighted average intensity of 725 BTU/PM.

carbon emissions would decline by 12.6%, to 310 - 345 Teragrams carbon.[133]

6.5 A Revival of Human-Powered Transport

The bicycle gets little serious attention in transport planning, but its prospects may be greatly underestimated. In the US, only 1.8% of all commuters commuted by bicycle in 1985, fewer than walked to work, but this number represented a quadrupling since 1975.[134] Both the dominance by bicycles of urban courier services, and Seattle's recent innovation using bicycles for downtown police patrol,[135] though, show bicycles' advantages for travel in congested central cities.

Bicycle use is higher in most other countries. In Rotterdam and several other major European cities, bicycles still carry more than 40% of all trips,[136] although their share has declined steadily since the war. In much of the developing world, they are the largest carrier of both passengers and freight. China, with more than 1,000 people per car, has one bicycle for every 4 people.

Bicycles have several important advantages for serious transport; they offer the independence and flexibility of the automobile, but are cheap and pollution-free, use no petroleum, require very little space for travel and parking, and provide exercise. Their disadvantages are just as obvious; not everybody likes exercise, particularly when

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[133] Assumes light vehicle passenger travel remains at 55% of transport energy, and that it is 90% metropolitan, as in 1985.

[134] Lowe (1988).

[135] "Bicycle Cops Drawing National Attention", AP March 15, 1988.

[136] Wilson (1984), p. 66.

well-dressed on the way to work; cycling is unpleasant in bad weather and potentially dangerous in traffic, and both bicycles and cyclists may be targets of crime.

These problems are serious, but are all at least partially amenable to technical or institutional solutions. There are advanced bicycle and tricycle designs with comfortable seats and sprung suspension,[137] whose proponents claim that ordinary unathletic adults can pedal them at 20 Mph for long periods without working up a sweat.[138] For many commuters, cycling would be a viable option if their employers provided lockers and showers; for others, if bikes could be parked securely at transit stations or carried on transit vehicles.[139] Lightweight transparent covers can extend the seasonal range of cycling, particularly with modern tricycles, as could covered or enclosed bikeways. Flow separation into special lanes or dedicated bikeways would improve safety, as would well-balanced 3-wheel designs.

A particularly interesting possibility would be the convergence of the roadway needs of a fleet of 1 to 2 person urban cars driving at 30 to 40 Mph, and a fleet of advanced pedaled vehicles carrying one person at 20 to 30 Mph. Their roadway needs could be accommodated by construction of a separate network of light roads. It could have a high congestion-free capacity because of narrow lanes; light cheap construction, because it need not support the heavy truck axle weights that determine present design standards; and could accommodate both these modes safely. For inter-city and freight transport, there could be a separate, less extensive network of heavy-duty roads.

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[137] Riess and Pivit (1988).

[138] Wilson (1984), p. 87.

[139] Bike-transit trips are a substantial fraction of worktrips in Japan, the Netherlands, and West Germany. Replogle (1983).

By 2025, with thoughtful planning and attention to design details, it is conceivable that human power could make a large contribution to US urban passenger transport. If, 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.[140] 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.

6.6 High-Speed Inter-City Rail

High-speed passenger trains hold promise for a large volume of energy-efficient transport in corridors sufficiently heavily travelled to support the capital expenditure for infrastructure. With reasonable assumptions for energy intensities, moving a passenger from inter-city auto to rail could reduce energy consumption by 80%, and from a short airline flight to rail, by 87%.[141] 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.

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[140] Using trip length distribution for worktrips from NPTS 1983, Table 7-13.

[141] Auto assumed 2,000 BTU/PM in 2025; air 4,000 in 1985, assumed halved by 2025, arbitrarily adjusted upward to 3,000 BTU to reflect that rail passengers would come off the shortest, least energy-efficient flights. Intercity rail value of 550, typical of European trains in the 1970s, scaled according to reference case assumptions for 2025 (divided by 1.4) to give 400.

6.7 Surprises in Freight

A potential technical surprise in freight would be a return to lighter-than-air transport. Now in use for a few remote resource applications such as mining and logging, this technology has the advantages of low energy consumption and no required infrastructure. In the US, significant expansion is too unlikely even to include in a surprise scenario; the structural economic trends described above are moving against such a low-speed mode and development may be blocked by safety concerns, particularly for transport over urban areas. But significant application may be plausible in developing countries, where low cost (and energy use) per ton-mile and the ability to avoid congested or inadequate infrastructure could be decisive.

Freight also holds the possibility of one serious feedback from a changing climate to the transport system, as was revealed by the hot, dry 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.[142] If water transport represented a similar fraction of transport energy in 2025 as in 1985 and 30% 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.

[142] Davis et al. (1988), Table 1.19. The ratio is quite variable from year to year.

6.8 Much Less Travel

If there were a fundamental reorganization of the American workplace by 2025 such that working at home became the norm and travelling to the office the exception, what would the maximum reduction in travel be? If the American economy still has stores, warehouses and factories staffed by people, then many jobs will have to be done at a workplace away from the home. As an extreme case, suppose that by 2025, 30% of urban passenger travel is displaced by people working at home, and moreover that 10% of intercity air travel is displaced by new forms of communication links. The effect would be roughly a 15% decline in total transport energy and CO_2, to 300-335 Teragrams carbon. The displacement of business travel by new communication technology is extremely hypothetical, though; not only is it as yet unobserved, but the effect may be to increase rather than decrease travel.[143]

6.9 Summary of Effects

Table 22 shows the effects of each of the surprises discussed above on greenhouse emissions from the US transport sector in 2025, relative to the reference case values presented in Chapter 5. These numbers of course depend on how much movement along each dimension is deemed "barely believable," and consequently merit much skepticism. Nevertheless, the wide range of effects in Table 22 suggests that the exercise is of some use. Changes in the energy intensity of highway modes dominate all other effects. Movement to

[143] OTA (1988), p. 231; de Sola Pool (1977).

public transit or reductions in travel give effects about half as large, and movement to bicycles or intercity trains about half as large again. This rough ranking is thus robust to disagreements of about a factor of two in how large a shift is "barely plausible." This ranking of effects of course neglects the cost of any of the proposed shifts. A relatively small gain may be worth pursuing if its cost is also small.

TABLE 22: EFFECT OF SURPRISES ON US 2025 TRANSPORT CO_2

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

7. POLICY OPTIONS

7.1 Overview

This chapter discusses policies that could reduce US transport greenhouse emissions by 2025. Just as transport's contributions to global warming are the consequence of a hierarchy of decisions ranging from where and how the new subdivision will be built to how to get to work today, so can policy responses be directed at several levels of decision, from the daily to the decadal. Policy can influence the public investment decisions that determine what kind and quality of transport options are available; the private investment and market decisions that determine what kind of vehicles are offered for sale; people's location decisions for developments, homes, and workplaces; vehicle purchase decisions; and travel and mode choices.

Because of the importance and complexity of transport's role in the American economy, and because of the magnitude of changes in the transport system that may eventually be required in view of the greenhouse problem, it is most unlikely that any single policy instrument will solve the problem. This chapter discusses ten broad classes of policies. The next, concluding chapter discusses approaches to coordinating transport greenhouse policies.

Passenger travel in metropolitan areas represents the largest share of US transport energy use and greenhouse emissions. Consequently, the largest reductions in transport greenhouse emissions will come from measures that reduce the energy consumed in urban passenger travel, either by increasing the efficiency of vehicles, or influencing how much

people travel and by what modes. Because personal light vehicles are the dominant mode, and will likely remain so over the period discussed, measures to increase their efficiency are liable to have the greatest effect on transport greenhouse emissions. The first five sections of this chapter discuss ways to advance fuel efficiency: fuel taxes, fuel economy standards, vehicle purchase incentives, design competitions, and government-supported research and development. Subsequent sections discuss policies to support movement to new fuels and to encourage reductions in automobile travel.

7.2 Fuel Taxes

If the policy goal is to reduce total fuel use, a tax on fuel is the only instrument needed (and the best one) in ideal economic terms. A fuel tax would correct the discrepancy between the social cost of consuming petroleum and the price the consumer sees at the pump, thereby inducing people to consume the "right" amount of fuel. But the tax's advantage is that it would achieve this while leaving consumers completely free to choose how they reduce fuel use; they can do so by walking or cycling more, using public transit more, car-pooling, buying more efficient cars, moving closer to work or otherwise arranging their lives so as to travel less -- or if they choose, by paying the price at the gas pump for not cutting back. A further advantage for a fuel tax, suitably applied, is that it would create appropriate incentives for increased efficiency and travel reduction for all modes, not just for light vehicles.

A major challenge of such a policy is determining the appropriate tax level, the social cost of consuming a gallon of fuel. In addition to the greenhouse contribution, this social

cost includes several components whose values are likely large: the depletion of US and world petroleum reserves; the increase of oil imports, with resultant contributions to the trade deficit and to vulnerability to OPEC supply disruptions; and contribution to local air pollution. Including all of these components, guesses at the full social cost run as high as three to five dollars a gallon.[144] Indeed, if a fuel tax alone is to bear the burden of achieving a large reduction in energy use, the empirical estimates available of short-run price response suggest that the required price is more than three dollars per gallon.[145]

These high figures suggest that there are important practical reasons that a fuel tax should not bear the entire burden of achieving the desired transport energy reductions. A fuel tax so large would be strongly regressive, unless compensated by transfers to low-income households. And it is unlikely to be politically achievable except in a period of extreme energy shortage or widely recognized environmental emergency.

But these reasons argue against the sufficiency of a fuel tax in greenhouse policy, not against its necessity. Indeed, the arguments in favor of a moderate, phased-in increase in fuel taxes, accompanied by some form of lump-sum rebates to low-income households, are compelling. Aside from its fiscal benefits, a fuel tax may be the most suitable way to provide the market incentives necessary to ensure the effectiveness of other fuel economy policies such as standards. Higher taxes would be best introduced by gradual increases over several years with the schedule announced at the outset, in order to give time for consumers and producers to adjust their decisions. One proposal is for a threshold tax that kicks in when

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[144] Proceedings of OTA workshop on transport and global warming, April 6, 1989.

[145] Pindyck estimates US gasoline price elasticities of 0.1 in 1 year, 0.49 in 5 years, 0.8 in 10 years, and 1.26 in 25 years. Because these estimates include data from periods of sudden large price increases and supply shortage, they may over-estimate the responsiveness to a phased-in price increase without supply disruptions.

oil drops below a certain level (perhaps $25 a barrel, inflation-adjusted), and raises the price back up to that level.[146]

7.3 Light Vehicle Fuel Economy Standards

Fuel economy standards for light vehicles have been in place since 1978. Because of this historical experience, and because of their directness, they are at the center of present discussions of how to influence light vehicle fuel economy.

Their record is still a matter of some controversy. Supporters argue that the standards were the principal cause of the doubling of average new car fuel economy that occurred between 1975 and 1985, that they accelerated introduction of technical innovations in the traditionally conservative American auto industry, and may even have fortuitously bolstered the competitive position of US makers relative to their Japanese competitors at the time of the second oil crisis in 1979-80. Opponents respond that it was the higher price of gasoline, not standards, that caused the increase in economy; that the standards drove consumers away from American automobiles to higher-efficiency imports (with perverse trade effects) and to light trucks (with perverse energy effects); that the standards caused reductions in vehicle weight and consequent increases in deaths and injuries; and that the standards discriminate against full-line makers by requiring all makers to achieve the same standard regardless of their mix of small and large models.

On balance, the argument regarding the standards' <u>effectiveness</u> goes to the supporters. The evidence does not support claims that CAFE standards were ineffective in

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[146] Chandler, Geller, and Ledbetter (1988), p. 30; Bleviss (1988), p. 222.

improving fuel economy, or that they were responsible for the growth in market shares of Asian imports and light trucks.[147] The safety argument is more serious, and is discussed below; this argument applies not just to standards but to fuel-economy increases through any means, market or regulatory. The assertion that standards penalize full-line makers relative to small-car makers is correct, and this section discusses how standards could be implemented that reduce or eliminate this inequity.

An argument that standards are a necessary component of effective fuel economy policy is based on the following line of reasoning. Changes in the technology and design of new vehicles are a way of reducing transport energy consumption at low social cost. Manufacturers have substantial discretion in the design tradeoffs that underlie model development and introduction decisions, but give insufficient regard to efficiency in these tradeoffs. In the slightly longer term, makers direct too little research effort to technological gains that increase efficiency. Finally, it is either the case that suitably high fuel prices are infeasible, or that even with high fuel prices, consumers are prevented by various market factors from effectively demanding from automakers as much efficiency as they want. The market factors may include imbalanced information, high consumer discount rates leading to an excessive focus on first costs, oligopoly, import restrictions, and the five-year delay before makers can respond to changing consumer demand with new models.

This year, with oil prices low and automakers shifting toward larger and higher-performance models (both through incremental modification of existing models and introduction of new ones),[148] this argument for standards may be even stronger than when

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[147] These arguments, pro and con, are well summarized in EEA (1988), Chapter 5.

[148] Automotive News, October 3, 1988.

standards were first legislated in 1975. If some form of fuel economy standard is considered desirable, then the crucial questions to be resolved are three: how can standards be designed and implemented to minimize their burden and avoid bias in favor of particular firms; how should standards address the question of size mix; and how high should they be?

The present implementation of fuel economy standards, CAFE standards, has posed several major problems. As originally enacted they required annual increases in economy, which conflicts with the long lead time needed to introduce a significant technical innovation, or engineer a new body or engine. When subsequent revisions sought to correct this fault by allowing credits to be carried back to prior years, incentives were created for makers to game the system by petitioning to reduce standards that they were meeting, in order to generate retroactive credits against prior years' violations. Finally, inconsistent administrative treatment of cars and light trucks has allowed technical gains in light trucks to lag substantially behind those of autos.

Any future program of economy standards can and should incorporate the administrative lessons learned from the present program to eliminate or mitigate these problems. Standards should not increase each year, but at a slower rate that reflects feasible rates of new model introduction. The first required increase should take effect at least four years from the time of announcement, in order that it address design decisions that are within the automakers' control. Treatment of automobiles and light trucks should be equivalent, both in administrative procedure and in the level of technical effort required.

Because the present standards are based on a single, sales-weighted corporate average, they do discriminate among makers. They impose a much more onerous burden on GM and Ford, who have kept a substantial fraction of large cars in their model lineup,

than on Chrysler or the foreign makers whose fleets were (or came to be) dominated by small cars.

Several alternatives forms of standard have been proposed that remove this bias. Each maker could be required to achieve specified percentage gain in fuel economy, either on a corporate average or a size-class specific basis. This system would reward the makers who have made the least technical effort so far, though, by granting them a lenient baseline. Alternatively, different standards could be set for each size class. This approach may be the most equitable, but poses two difficulties. First, it gives makers less flexibility in how to concentrate their design effort than does a single corporate average. Second, it creates the opportunity to move a model into a larger size class with more lenient standards by increasing its interior volume.

Another proposal, called Volume-Average Fuel Economy (VAFE) makes the product of economy and interior volume the regulatory standard, effectively making required fuel economy vary continuously with interior space.[149] An ideal implementation of this scheme would be completely neutral to vehicle size mix, but this may move too far in the opposite direction from the present CAFE standard. While it is clearly not appropriate to provide just as heavy regulatory pressure against a well-designed big and powerful car as against a badly-designed small one that gets the same mileage (because the big one provides a greater service, indeed a necessary one for some applications), one might still prefer that the standard require some greater design effort for large cars than for small. To achieve this, the standard could specify the efficiency target as a line that declines continuously with increasing size, but by less than efficiency would decline with increasing size if design effort

[149] McNutt and Patterson (1986).

were held constant. By defining a suitable equivalency between load capacity and interior room, this scheme could incorporate light trucks as well.

On the question of how high standards should be, it is important not to be carried away by the performance of the best commercial models or prototypes. For fuel economy to rise, it is not sufficient that makers introduce high-efficiency models; consumers must buy them, and the industry must receive enough revenue to support the required research and investment. A standard so high as to require substantial mix shifting would be liable to violate these conditions. A suitable level of standards would be high enough strongly to influence research and product development decisions, but not so high as to force major mix shifts, or disrupt the orderly development of new models or the required flow of earnings.

Recent DOE work on cost-effective introduction of fuel economy technology gives instructive advice regarding a suitable level of standards. They projected that in 1995 with unchanged real gasoline prices ($1.10 in 1987 dollars), a fleet economy of 32 mpg would be cost-effective for a car's first owner (4-year ownership), 35 mpg would be cost-effective over the car's 10-year life, and 38 mpg would be the maximum technically achievable without mix shifting.[150] The 38-mpg car would be cost-effective at $2.10 per gallon or more. The corresponding maximum-technology figure for 2000 was 40 - 55 mpg, depending on the assumed penetration of diesels or other new engines.[151]

These figures suggest a suitable range for fuel economy standards, depending on the intent of the standards. If the goal of the standards is simply to correct for high consumer

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[150] presentation of Carmen DiFiglio, OTA workshop on transport and global warming, April 6, 1989. These figures were disputed by the representatives of Ford and General Motors, who asserted that economy gains achievable from the technologies listed were smaller, and their costs were larger. The same analysis done for OTA with slightly different assumptions gave a cost-effective figure of 33 mpg in 1995. (OTA 1989).

[151] 40 mpg with no penetration, 55 mpg with 100% penetration.

discount rates with gasoline at $1.10, then a standard around 32 or 33 mpg in 1995 would be appropriate. If market forces or taxes are expected to double the real price of gasoline by this time, or if the standard is intended in part to substitute for fuel taxes that reflect the full social cost of gasoline, then a standard in the high 30s would be appropriate. If a standard is used to substitute for fuel taxes in this way, though, the analysis indicates that consumers will bear a cost at car purchase that is not compensated by fuel savings. Such a discrepancy between market signals to consumers and regulatory signals to manufacturers would be liable to be disruptive. The higher the price of gasoline, though, 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.

Are efficient cars necessarily more dangerous? Other things being equal, a larger and heavier car is both safer and less fuel-efficient.[152] Any factor that shifts the vehicle fleet toward smaller and lighter cars -- with other factors held constant -- will increase fatalities. This argument applies not just to standards, but to any market or regulatory effect that pushes toward lighter cars.

The issue is complicated, though, by variation in safety records of different models, and by the role of safety technology. Good design and safety features can mitigate the effects of decreasing vehicle weight, as the steady decline in fatalities per mile travelled

[152] Crandall and Graham (1989).

since the mid-1970s illustrates.[153] The possibility of designing extremely safe lightweight cars was also demonstrated by DOT's Research Safety Vehicle Program.[154] Nevertheless, to achieve the large efficiency gains of a substantial move to smaller and lighter cars, maintaining or improving occupant safety will be a major engineering challenge.

7.4 Car Prices: Taxes, Rebates, Bonds

Policies that affect vehicle prices are the most direct way to influence consumers' purchase decisions. A program of taxes and rebates can create incentives to buy more efficient cars, 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.

There is such a program in place already: the gas guzzler tax, which applies increasing taxes to cars whose economy is below a threshold. The tax starts at $500 for cars below 22.5 mpg, increasing to $3850 for those below 12.5 mpg. The tax was originally intended to be coupled with a rebate for extremely efficient cars, but the rebate was never enacted.

The program would have the most effect on purchase decisions if rebates for highly efficient cars were enacted and if the thresholds for both tax and rebate increased over time as average fuel economy increases. For instance, thresholds could be placed at the upper and lower quartile limits of the new vehicle fleet, with the size of the tax and the rebate

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[153] Between 1975 and 1988 new car fuel economy doubled and average weight declined by 1000 lbs, but deaths dropped from 3.6 per hundred million vehicle miles to 2.4. This decline represents a combination of technical advance, increased seat belt use, and drunk driving crackdowns, but its magnitude suggests that vehicle weight is not yet a binding constraint on safety improvements.

[154] DOT (1980); DOT (1981b).

increasing for more extreme models as at present. If the thresholds do not increase over time, then, if the policy is successful, the tax revenues will decline and the subsidy requirements increase over time. Consequently, the details of such a program would have to consider its fiscal impact.

Such an expanded program of auto purchase incentives could be complementary with both fuel economy standards and taxes. By sending consistent signals to both the buyer and the seller of an automobile, they would reduce the likelihood that high fuel economy standards would cause large drops in vehicle sales or shifts between makers. By effectively rolling part of the life-cycle cost into the first cost, they could correct for the reduced effectiveness of fuel taxes due to consumers' high discount rates. A related proposal would accomplish the same objective by requiring the consumer to purchase a bond at the time of car purchase, whose value is larger for less efficient cars.[155]

A serious difficulty with any such program of efficiency-specific auto purchase incentives, though, would be its trade impact. While the targets of the present gas-guzzler tax are almost all European imports, under present market conditions the targets of a broader-based fuel efficiency tax would include many domestic models while the beneficiaries of the high-efficiency rebates would mostly be imports. The net effect of such a program would likely be to subsidize imported cars at the expense of domestically produced ones, while a program that sought to exclude imports from the benefits would likely represent a violation of principles of fair trade.

Fleet efficiency could also be influenced at the end of a vehicle's life rather than the beginning, by encouraging the early scrappage of low-efficiency cars. Bonuses could be paid

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[155] Williams, OTA correspondence, Nov 24, 1987. The bond could be redeemed either at a fixed maturity date -- say 2 to 4 years after purchase -- or when the car is resold or scrapped.

for low-mpg cars in running condition sold for scrap. This would require careful administrative design, though, for it presents obvious opportunities for abuse.

7.5 Sponsored Competitions

There have been several proposals to use government-sponsored competitions to induce manufacturers to develop high-efficiency cars, including a bill introduced in 1982.[156] Such competitions pose a number of problems, though. By targeting design effort rather than major product introduction decisions, they could actually take research resources away from the development of efficient production models. Moreover, it is unlikely that the government could pay enough in prize money to induce major manufacturers to participate.[157]

A promising variant has been suggested by Ross,[158] in a measure that injects competitive elements into a high-efficiency rebate program. He suggests that the government identify a few classes of vehicles most in need of economy improvement, and offer a competitive reward in the form of large (eg $500) consumer rebates on a large (eg 200,000 units) production run of a new vehicle achieving the best fuel economy (above a specified threshold), subject to performance, safety, and emission constraints. To avoid discontinuities, a smaller rebate would be offered on the next 200,000 units of the same vehicle, and on the first 200,000 of the best entrant from another manufacturer.

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[156] The Shamansky bill would have sponsored a competition to produce an 80-mpg gasoline car or a 100-mpg diesel car meeting minimum performance, safety, and emissions criteria. To win, the car would have to be put into limited production.

[157] Bleviss (1988), p. 241.

[158] (1988a), p. 42

The merits of this proposal should be weighed against those of a straightforward rebate program for high-economy vehicles. This form seeks to elicit a spirit of competition among manufacturers for the distinction of developing the best new vehicle in a class, spurring them to greater efforts than a simple rebate would. But from the manufacturer's viewpoint, it replaces a certain benefit with a risky one, and so would likely discourage some (who are more risk-averse, or who think their probability of winning low) from participating. For makers who decide thus, the program gives no added incentive to pursue efficiency in new models. The relative merits of the programs will depend on which is likely to have a greater effect on fleet efficiency: moderate gains on all models, or major gains on a few.

7.6 Government-Supported Research and Development

A recent study of the state of fuel efficiency research and development in the auto industry found that American automakers lag far behind their Japanese, and to a lesser extent their European, counterparts -- especially in moving research results to the market.[159] A program to support more aggressive research and development in the American auto industry was introduced in the late 1970s (the CARP program), but foundered in the prevailing atmosphere of mistrust between the industry and government.

Large R&D efforts, including continued and expanded co-operative research programs between government and the automotive industry, will be essential for further technical efficiency advances beyond the turn of the century. A small program of joint industry-government funded research has continued in the Department of Energy, working

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

on major new engine designs -- ceramic gas turbines and ceramic (adiabatic) diesels -- and electric vehicles. Participants now estimate that these engines could be commercial in automobiles within 10 - 15 years.[160] A substantially larger program of co-operative research, similar in design to the CARP program, may be necessary to promote the American development of other promising medium-term technologies, such as the CVT and energy-storage systems.

Light vehicle fuel economy is the area where significant technical advances would have the biggest effect on total transport greenhouse emissions, but there may be other areas where federally supported R&D would also have substantial impact. If such efforts are pursued, the focus should be on larger discrete innovations, offering potentially major but risky payoffs in the medium future -- the kind of innovations less likely to attract enough research effort from the private sector alone. Promising areas may 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.

7.7 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

[160] Presentation of M. Savitz, OTA workshop, April 6, 1989.

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.

While other fuels could reduce greenhouse emissions, large movement to new transport fuels is blocked by two categories of obstacles: technical problems of cost, vehicle performance and fuel storage; and threshold problems related to fuel distribution and repair systems. The new power sources that offer the largest reductions in greenhouse emissions -- natural gas, and hydrogen or electricity from nonfossil sources -- are both the furthest from large-scale technical viability, and the most difficult to move to from a gasoline system.

Federal policy can help with both these obstacles. First, much more information is needed to determine what the best long-run fuel source for transport will be. Expanded research programs in such areas as boil-off control in cryogenic fuel storage, hydrogen engines, and photovoltaics are needed to see more clearly what direction we should be going, and to expand the range of options available. This should proceed in parallel with continuing medium-scale demonstration programs with a variety of fuels to assess actual performance.

In the longer term, it may become evident that a large-scale movement to one of these other energy sources from petroleum is clearly desirable. At that point, threshold issues represent the principal obstruction. A new fuel technology must be introduced at a large enough scale that motorists can find fuel, service, and substitute vehicles. Government intervention will likely be necessary to push a new fuel system to this threshold of viability. This could take the form of a major initiative to convert most of the fleet in one or several major metropolitan areas over to a new fuel source. It could include subsidies for the

purchase of vehicles or for the conversion of fuelling and service facilities, or establishment of regions in a city where only public transit and new-fuel vehicles are permitted. If the new energy source is electric vehicles or some other technology with limited range, subsidized neighborhood leasing businesses or co-operatives could provide the required flexibility of range, by leasing a fleet of electric vehicles for regular use and having a smaller number of conventional vehicles available for longer trips.

7.8 Major Investment in Intercity Rail

Large increases in rail ridership are feasible over a number of heavily-travelled intercity corridors. High-speed trains can make trips up to about 300 miles at speeds competitive with air travel, particularly as congestion of airports and highways increases. Diverting intercity passengers from either auto (at 1 or 2 people per car) or air onto rail reduces net energy consumption and greenhouse emissions, assuming reasonably high rail load factors. Because intercity passenger travel is a rather small share of total transport energy use, though, the total reductions available by diversion to rail are modest; the surprise scenario in Section 6.7 above showed only a 4% reduction.

The obstacle to more rail travel is lack of infrastructure. Amtrak does not have exclusive use of high-speed track except in the Washington-New York corridor. Particularly to bring fast service to new markets, the requisite track improvement would require large federal expenditures. This may be justified for other reasons, and would move greenhouse emissions in the right direction. But the high cost relative to the maximum reductions achievable suggests that this should not be a priority component of a greenhouse reduction

policy.

7.9 Transportation Control Measures

Several American cities are now experimenting with policy measures intended to reduce travel in private automobiles. There are a large number of such measures, that can reduce energy use and greenhouse emissions even within existing settlement and employment patterns, collectively called Transportation Control Measures or TCMs.

The metropolitan areas using TCMs are motivated by congestion or air quality problems. Different measures are intended to move travel to uncongested times of day, to encourage ride-sharing or mode switching, and to reduce travel. Most of these measures will reduce energy use and CO_2 emissions as well; displacing travel and mode switching do so directly, and rescheduling travel to reduce congestion saves the fuel that would have been burnt idling in congested traffic.[161]

The promise of TCMs is that they address urban passenger miles travelled directly, the largest source of transport greenhouse emissions. They also illustrate the possibility of combining several initiatives coherently to achieve larger reductions than separate measures can. The art is in a very early stage, though. While many cities have experimented with one or two measures, the range of possibilities and the complexity of interactions between different measures means that any major TCM initiative must proceed by trial and error.

A recent study summarized US experience with twelve major categories of

[161] This quantity is substantial. Renner (1988), p. 47, estimates that Americans wasted 3 billion gallons of gasoline in congestion in 1984, 4% of total national consumption.

TCMs.[162] It reported that, far from having a systematic body of information on the total craft of designing TCMs, several promising categories lacked any quantitative data on their effects. The consequence is that estimated impacts are very soft (and because analysts seek conservatism, tend to be biased downward). More recently, the Southern California Association of Governments has developed a comprehensive plan for achieving air quality goals by 2010, including an ambitious program of TCMs with corresponding projections of VMT reductions.[163]

The major categories of TCMs are as follows:

-Area-wide Ride-sharing (promotion and matching services): achieved area-wide reductions of 0.1-3.6% in VMT (average 0.3%), in 32 programs now in place.

-Employer-based Transportation Management: Comprehensive programs are run at the workplace to get people out of solo cars and into any alternative -- carpools, vanpools, bike, or transit. The programs combine high parking charges for solo drivers with transit or vanpool subsidies and expedited transactions -- e.g., bus passes, van leasing and insurance are all on sale at work. Such programs have achieved movements of 30-80% of all workers into non-solo modes at large workplaces, with reductions of VMT from 10 to 50%. Feasible area-wide VMT reduction depends on the concentration of workplaces, but is estimated around 1%. The Los Angeles plan proposes mandatory programs at all workplaces over 100 employees, combined with municipal parking restrictions, street closures, HOV lanes, and transit improvements, and projects a combined impact of 6% mode shift and 4.6% VMT reduction by 2010.

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[162] Cambridge Systematics Ltd. (1986).

[163] Southern California Association of Governments (1988).

-**High-Occupancy Vehicle (HOV) Lanes:** Restricting lanes on freeways or arterials to cars with 3 or 4 occupants or buses can reduce congestion and give time incentives for ride-sharing. The 14 examples operating in the US as of 1985 showed reductions of 5-10% in peak corridor VMT.

-**Bicycling Promotion:** The Cambridge Systematics study found that comprehensive programs including bike lanes or paths, secure locking facilities and showers, and public education and promotion, can reduce area-wide VMT by .05 to .1%. The data are very weak, though, and American experience with bicycling promotion programs is very limited. Crucial factors for larger penetration would be separation of traffic flow, mean work trip distances (they suggest that bicycles can capture a large fraction of trips less than 4 miles), terrain, and weather.

-**Auto Use Management** (restricted zones, or restricted times): Most experience to date is with restricted zones, pedestrian or transit malls established to foster a pleasant, car-free urban environment. These mostly re-route travel, so greenhouse emissions remain unchanged, or perhaps increase due to increased route circuity and cruising for parking. Auto-restricted times may achieve large VMT reductions, but may also represent severe mobility restriction. Cambridge Systematics estimates potential area-wide 7-10% VMT reductions.

-**Parking Management:** This includes parking taxes or development surcharges, restricting street parking, and mandated high parking charges at workplaces (usually with special rates for carpools). American data are very weak, but the experience of Ottawa suggests that the impact can be large, especially if coordinated with improvement of alternatives to driving.

-**Park-and-Ride:** There are two approaches. Remote park-and-ride tries to reduce VMT by intercepting drivers near to their origins, but the remote lots pose theft problems; peripheral park-and-ride seeks principally to reduce CBD congestion and has little effect on total VMT. Cambridge Systematics estimates potential 2-4% VMT reduction within specific corridors.

-**Transit Improvements:** Even large investments in rail systems have achieved at most 3-5% reduction in area-wide VMT. Short-range improvements including bus service expansion, operational changes, and fare changes have been much more successful. Cambridge Systematics cites experience in nine cities showing increases in transit ridership from 8% to 50% and reductions in VMT from 0.1% to 0.5%. Eugene increased ridership by 271%, suggesting that there is much room for creative transit service improvement. Ottawa's experience suggests the same.

-**Travel Substitution** (telecommunications, work-at-home, and flexible hours): Views are still mixed on the potential for telecommunications and work-at-home to reduce travel. The Los Angeles plan takes an ambitious stance, and projects 20% reduction in worktrips due to telecommuting and 10% due to alternative work schedules, for a net decrease in area-wide VMT of 6.8%. Cambridge Systematics estimates total impact of flexible schedules as only 0.1-1.0% area-wide VMT reduction.

-**Traffic Flow Improvements** (sophisticated signals, ramp metering, intersection improvement): These measures are principally intended to reduce congestion, but secondarily reduce energy and greenhouse emissions, because less fuel is burnt idling in stopped traffic, and average speeds increase. Fuel economy increases with speed up to 35-40 Mph, then declines. Reductions in fuel consumption up to 6% have occurred on particular

routes, but area-wide impacts have not been measured in American cities. If faster traffic induces people to drive more, such measures can increase fuel consumption, though. A recent study in Perth Australia found just this perverse effect.[164]

In aggregate, transportation control measures hold large promise for reducing VMT, but much more experimentation and data are needed before their potential impact can be assessed. Perhaps their most promising aspect is that they militate for the creation of regional-level bodies with planning authority, which can take a broader view of metropolitan transport needs than can any single municipality.

7.10 Controlling Settlement Patterns

Long-run reductions in emissions can be achieved by changing patterns of settlement to reduce the need for travel. This can be accomplished through higher densities, or through mixing uses so that residences, jobs, and services are roughly balanced at a local scale. When more destinations are close to home, more trips can be made by foot or bicycle; when densities are higher, public transit can serve more trips effectively.

In the US, except possibly for some high-growth areas in the south and west, efforts to change the shape of settlement in major cities is bound to have limited impact. Because we are entering a period of slower population growth, the shape of cities will not be changing as drastically as they did in the 1950s and 1960s. In a period of slow population growth, change in urban shape proceeds only marginally faster than the replacement of the standing building stock, which takes 50 to 100 years.

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[164] Newman and Kenworthy (1988).

Nevertheless, some changes are feasible, particularly in the balancing of homes and workplaces in the suburbs. The Los Angeles air quality plan, for example, includes measures to balance jobs and housing through a combination of market and regulatory measures. It projects that 12% of jobs and 6% of housing in the region will be affected by the measures, and reductions of 8% in VMT will be achieved.[165]

Modest changes in density are also possible in the US, through changed zoning and infilling. The difficulty will be that urban residents uniformly and strenuously resist increasing densities. Paradoxically, traffic congestion is often cited as one of the reasons to oppose higher density development, although with fixed travel needs congestion is higher in lower-density areas.

Traffic congestion is already prompting some remarkably stringent suburban restrictions on development -- sometimes only commercial and industrial development, sometimes new residential development as well. The measures used include zoning, building fees or infrastructure impact fees, tie-ins to increase the effective cost of new commercial development, or, in the most extreme cases, banning all new building.[166] These measures will have little effect on congestion unless coordinated over entire metropolitan areas, and may even increase congestion if they reduce opportunities for people to live near work. The kind of settlement controls needed to reduce congestion and emissions (greenhouse and other) are of precisely the opposite kind to those now proposed. The pattern that reduces travel demand is one that mixes residences and workplaces, and mixes income groups, at rather higher densities.

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[165] Appendix 4-G, p. 130-131.

[166] Downs (1988).

8. CONCLUSION

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. Higher fuel economy standards -- with improved implementation and appropriate size-dependence -- could ensure that product design and marketing decisions give enough weight to efficiency. A program of efficiency-based taxes and rebates on cars could make market incentives consistent with the standards imposed on manufacturers. A moderate gasoline tax could remedy the anti-conservation effects of temporarily low oil prices; it should at least be high enough to counteract the tendency to increased driving induced by a more efficient vehicle fleet. And finally, a joint government-industry research and development program could promote development and commercialization of high-promise, medium-run technologies such as energy storage, oxygen separation, the continuously-variable transmission, and advanced engines.

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 ride-sharing, 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.

Another policy area for the longer term is strong movement to new fuels. It is premature to decide now which of the several alternatives merits the most vigorous support, so aggressive research and demonstration programs should proceed with alcohol, natural gas, electric vehicles, and hydrogen. When more knowledge has been gained, there will be a role for government policy in moving the transport system toward a new fuel at sufficient scale.

In addition to these two major policy directions, there are several other possible measures that would contribute to reductions of transport greenhouse emissions. While each of these would offer smaller potential reductions than either of the directions above, they do move in the right direction, may bring other benefits, and may represent important symbolic statements of government leadership on reducing fuel use and greenhouse emissions. They include reimposing (and enforcing) the 55-mph speed limit; requiring high-efficiency tires (radials) and oils, and fairings, for trucks, enforced through efficiency inspections; requiring high-efficiency tires and oils on all federal vehicles; preferential use of rail and intermodal roadrailer for all 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 may 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 could include gasoline rationing, stringent restrictions on driving and air travel, and fuel taxes of the order of $5 per gallon.

It may seem curious that the policy prescriptions for the "new" greenhouse problem are all familiar as proposed solutions to the "old" energy problem. This familiarity reflects the rough equivalence in transport of greenhouse emissions and energy consumption. The two issues are not completely congruent; consideration of greenhouse emissions argues against some policies that were once promoted as solutions to petroleum shortage, such as deriving synthetic fuels from coal. But the answers of increasing modal energy efficiency, principally through more efficient cars, switching to less energy-intensive modes, and finding substitutes for travel, all address both the energy problem and the greenhouse problem.

This congruence with the energy issue makes the prospect of achieving substantial reduction in greenhouse emissions more hopeful, for two reasons. First, it means that new policies do not have to be developed from scratch, and that the lessons of past efforts in energy conservation are all relevant. Second, it diminishes the importance of uncertainty

about the impact of global warming; as more issues point to the same set of policies, uncertainty about each of them matters less in deciding what direction to go.

BIBLIOGRAPHY

Alic, J.A., L.L. Jenney, T. E. Bull (1983), "Future Automobile Fuel Economy: Technology and the Marketplace", SAE Technical Papers Series 830983.

Ang, B.W. (1983), "Modelling World Energy Demand for Transport", Discussion Paper EDP 28, Energy Research Group, Dept. of Physics, Cambridge University, Cambridge, 25 August 1983.

Ang, B. W. and S. T. Oh (1988), "Transport and Traffic Management Schemes and Energy Saving in Singapore", Energy.

AP, April 12 1988: "Hydrogen Coolant Offered as Antidote to Freon".

Automotive News, June 3, 1985, "Getting the Most from the Engine".

Automotive News October 3, 1988; "Domestic Drivetrain Trends: Fasten Your Seat Belt, Virginia – Because Performance is Back", p.E67.

Automotive News February 6, 1989: "DuPont Non-CFC Refrigerant May Solve Auto-Air Problem", p.3.

Averous, Christian (1981), "Air Pollution and Transport Management", UNEP/WHO Interregional Workshop on Air Pollution from Motor Vehicles, Moscow 5-9 October 1981, Background Papers Vol 2.

BMW AG (1987), "Alternative Drive Concepts", Press Release Dec 1987.

v.d. Berg, L.R. et al (1982), Urban Europe: A Study of Growth and Decline, Pergamon Press, Oxford UK.

Bleviss, Deborah Lynn (1988), The New Oil Crisis and Fuel Economy Technologies, Quorum Books, New York.

Brown, L. R., C. Flavin, and C. Norman (1979), Running on Empty: The Future of the Automobile in an Oil-Short World, Norton, New York.

Cambridge Systematics Inc (1986), Improved Air Quality in Maricopa and Pima Counties, report to US EPA Region IX, November 1986.

Cervero, Robert (1984), "Urban Passenger Transportation", Chapter 4 of Transportation, unpublished sectoral background study to OTA Economic Transition, October 1984.

Cervero, Robert (1986), Suburban Gridlock. Center for Urban Policy Research of Rutgers University, New Brunswick NJ.

Chandler, William U., Howard S. Geller, Marc R. Ledbetter (1988), Energy Efficiency: A New Agenda. American Council for an Energy-Efficient Economy, Washington DC.

Cheng, Hsing C., Kenneth M. Novak, Meyer Steinberg (1987), "Energy Demand and Efficiency for the Soviet Union and China", Brookhaven National Laboratory, Process Science Division, July 20, 1987.

Cheng, Hsing C. (1988), "Potential Reductions in US CO_2 Emissions in 1995 and 2010 by Technology Improvements in Electricity Generation and Transportation Sectors." Brookhaven National Laboratory, Process Sciences Division, April 1988.

Committee on Nuclear and Alternative Energy Sources (CONAES, 1979), Demand and Conservation Panel, Alternative Energy Demand Futures to 2010, National Academy of Sciences, Washington DC.

Crandall, Robert W., H.K. Gruenspecht, T.E. Keeler, and L.B. Lave (1986), Regulating the Automobile, Brookings Studies in the Regulation of Economic Activity, Washington DC.

Crandall, Robert W., and John D. Graham (1989), "The Effect of Fuel Economy Standards on Automobile Safety," forthcoming in The Journal of Law and Economics, 1989.

Daniels, George H. and Mark H. Rose, eds. (1982), Energy and Transport: Historical Perspectives on Public Policy Issues, Sage, Beverly Hills.

Darmstadter, Joel, J. Dunkerley, and Alterman (1977), How Industrial Societies Use Energy, Resources for the Future, Johns Hopkins Press, Baltimore.

Davis, Stacy C., Deborah B. Shonka, and Patricia S. Hu (1988), Automated Transportation Energy Data Book, Oak Ridge National Laboratory, May 31, 1988.

DeLuchi, Mark A., Robert A. Johnston, Daniel Sperling (1987A), Transportation Fuels and the Greenhouse Effect. Universitywide Energy Research Group, University of California, UER-180, December, 1987.

DeLuchi, Mark A. Daniel Sperling, Robert A. Johnston (1987B), A Comparative Analysis of Future Transportation Fuels, Research Report UCB-ITS-RR-87-13, Institute of Transportation Studies, University of California at Berkeley.

Dow Chemical Company (1986), Generon Air Separation Systems Press Kit.

Downs, Anthony (1985), "Impacts of Rising Traffic Congestion on the Location of Activitis Within Metropolitan Areas", Brookings.

Downs, Anthony (1985b), "Impacts of Rising Traffic Congestion on the Location of Activities Within Metropolitan Areas", unpublished manuscript, April 1985.

Downs, Anthony (1988), "The Real Problem with Suburban Anti-Growth Policies", Brookings Review Spring 1988, pp. 23-29.

Dunkerley, Joy, Ramsay, Gordon, and Cecelski (1981), Energy Strategies for Developing Nations, Resources for the Future, Johns Hopkins Press, Baltimore.

Dunkerley, Joy, and Irving Hoch (1985), "Transport Energy: Determinants and Policy", Resources for the Future, Washington DC, Sept 1985.

Dunkerley, Joy, Irving Hoch, Charu Gadhok and Kapil Thukral (1987), "Energy and Transport: The Indian Experience", Pacific and Asian Journal of Energy 1987.

Dynarski, M. (1986), "Household Formation and Suburbanization", Journal of Urban Economics 19: 71-87.

Edmonds, J.A. and J. Reilly (1985), Global Energy: Assessing the Future, Oxford University Press, New York.

Edmonds, J.A., W. B. Ashton, H. C. Cheng, M. Steinberg (1988), An Analysis of US CO_2 Emissions Reduction Potential in the Period to 2010, draft report to US Department of Energy, September 1988.

Ehrlich, Paul R. and J.P. Holdren (1971), Science 171, 1212.

EPRI Journal, March 1988, "Electric Vehicle Testing at TVA".

Energy and Environmental Analysis, Inc. (1988), Developments in the Fuel Economy of Light-Duty Highway Vehicles, draft final report for OTA Energy and Materials Program, June 1988.

Fawcett, S.L. and J.C. Swain (1982), "The Pertran Project: A Summary of the Status and Plans for Development", Battelle Memorial Institute, Columbus OH, June 1982.

Florian, Michael, ed. (1985), The Practice of Transportation Planning, International Centre for Transportation Studies , Elsevier Science Proceedings Series.

Garrison, William, "Transportation Technology", Background study for Transportation, unpublished sectoral study for OTA Economic Tranasition.

Glazer, Sarah (1988), "Gridlock in Suburbia", Congressional Quarterly's Editorial Research Reports, June 3.

Goldemberg, Jose et al (1984), "Country Study – Brazil: A Study on End-Use Energy Strategy", Global Workshop on End-Use Oriented Energy Strategy, Sao Paulo, June 1984.

Goldemberg, Jose, T.B.Johansson, A.K.N. Reddy, and R.K. Williams (1987), Energy for a Sustainable World, Wiley-Easton, New Delhi.

Greene, David L. (1986), "Efficiency-Related Changes in Automobile and Light Truck Markets, 1978-1986", SAE 861423.

Greene, David L., Barry McNutt, Daniel Sperling (1988), "Transportation Energy to the Year 2020", draft report, US Department of Energy.

Hagler, Bailly, and Co., Road Transportation Energy Conservation: Needs and Options in Developing Countries. HBC 86-178, prepared for Office of Energy, Bureau of S&T, US AID, September 1986.

Hammitt, James K. et al (1986), Product Uses and Market Trends for Potential Ozone-Depleting Substances, 1985-2000, Rand Corporation R-3386-EPA, May 1986.

Heavenrich, Robert M. and J. Dillard Murrell (1988), "Light-Duty Automotive Technology and Fuel Economy Trends Through 1988", US EPA Office of Mobile Sources, EPA/AA/CTAB-88-07, June 1988.

ICF Inc. (1989), background tables to EPA Stabilization Report.

International Energy Agency (1987), Fuel Efficiency of Passenger Cars, OECD Paris.

Jansen, Gijsbertus RM, Nijkamp, and Ruijgrok, eds. (1985), Transportation and Mobility in an Era of Transition, Vol. 13 of Studies in Regional Science and Urban Economics, North-Holland, Amsterdam/New York.

Khazzoom, J. Daniel (1988), "Quantifying of the Environmental Impact of a Gasoline Tax", unpublished manuscript, July 1988.

Kim, Kwang-Sik and J.B. Schneider, "Defining Relationships Between Urban Form and Travel Energy", pp. 43-50.

Kitamura, Tyuichi (1988), "Lifestyle and Travel Demand", presented to TRB Conference on Long-Range Trends and Requirements for the Nation's highways and Public Transit Systems, Washington DC, June 22-24,1988.

Klaassen, L.J., J.A. Boudrez and J. Volmuller (1981), Transport and Reurbanization, Gower, Aldershot UK.

Klinger, Dieter and J. Richard Kuzmyak (1986), Personal Travel in the US, 1983-1984 Nationwide Personal Transportation Study, US Department of Transportation, Washington DC, August 1986.

Larson, Eric D., Marc H. Ross, and Robert H. Williams (1986), "Beyond the Era of Materials", Scientific American 254:6, 34-41.

Leach, Gerald, Lorenz Jarass, Gustav Obermair, Lutz Hoffmann (1986), Energy and Growth: A Comparison of 13 Industrial and Developing Countries. Butterworth Scientific, London.

Link Resources Inc (1988), National Work at Home Survey.

Lizardo de Arauno, Joao, and Andre Ghirardi, "Substitution of Petroleum Products in Brasil: Urgent Issues", International Energy Studies Group, Lawrence Berkeley Laboratory LBL-21227.

Lovins, Amory and Hunter (1987), "The Avoidable Energy Crisis", Atlantic December 1987, p.22.

Lowe, Marcia D. (1988), "Pedaling into the Future", Worldwatch July/August 1988, 10-16.

Lowry, Ira S. (1988), "Planning for Urban Sprawl", presented to TRB Conference on Long-Range Trends and Requirements for the Nation's highways and Public Transit Systems, Washington DC, June 22-24, 1988.

Macauley, M.K. (1985), "Estimation and Recent Behavior of Urban Population and Employment Density Gradients", Journal of Urban Economics 18: 251-260.

McNutt, Barry and Philip Patterson (1986), "CAFE Standards -- Is a Change of Form Needed?", SAE 861424.

Marland, G. (1982), "The Impact of Synthetic Fuels on Carbon Dioxide Emissions", in W.C.Clark ed, Carbon Dioxide Review 1982, Oxford University Press, New York, pp.406-410.

Mellde, Rollfe (1985), "Volvo LCP 2000 Light Component Project", SAE 850570, presented at SAE Congress Feb 25 - Mar 1, 1985.

Meyer, John and J.A. Gomez-Ibanez (1981), Autos, Transit, and Cities, Harvard University Press, Cambridge MA.

Meyers, S. (1988), Transportation in the LDCs: A Major Area of Growth in World Oil Demand, LBL-24198, March 1988.

Millar, Marianne, Anant Vyas, and Christopher Saricks, "Long-term Outlook for Transportation Energy Demand", Transportation Research Record 1049, 57-69.

Mills, G. Alex, and E. Eugene Ecklund (1987), "Alcohols as Components of Transportation Fuels". Annual Review of Energy 12.

Mintzer, Irving (1988), Projecting Future Energy Demand in Industrialized Countries, draft of World Resources Institute report for EPA, October 1988.

Moavenzadeh, Fred, and David Geltner (1984), Transportation, Energy, and Economic Development: A Dilemma in the Developing World. Energy Research Vol 5, Elsevier, Amsterdam.

Motor Vehicle Manufacturer's Association (MVMA), Facts and Figures, various years, Detroit.

MVMA (1987), Testimony by Dr. Fred W. Bowditch, May 14 1987.

Mooz, W.E. et al (1982), "Technical Options for Reducing Chlorofluorocarbon Emissions", Rand Corporation Report R-2879-EPA.

National Council on Public Works Improvement (1987), Report on Mass Transit, The Urban Institute, Washington DC.

Nijkamp, P., and S. Reichman, eds (1987), Transportation Planning in a Changing World, European Science Foundation, Gower Publishing, Aldershot UK.

New Scientist (1986), "Sail-Assisted Freighters", June 19, p.42

New York City Department of Environmental Protection (1988), "Energy and Environment Background Paper", American Public Transit Association, Transit 2000 Task Force.

New York Times Oct 16, 1988, "Electronic Cottages Take Root", p.10

Newman, Peter W.G. and J.R. Kenworthy (1988), "The Transport Energy Tradeoff: Fuel-Efficient Traffic or Fuel-Efficient Cities", Transportation Research 22A:3, 163-174.

Newman, Peter W.G. and J.R.Kenworthy (1989), "Gasoline Consumption and Cities: A Comparison of US Cities with a Global Survey", Journal of the American Planning Association 55, Winter 1989, 24-37.

Noll, Scott A. (1982), "Transportation Energy Conservation in Developing Countries", Discussion Paper D-73K, Resources for the Future, Washington DC.

Oak Ridge National Laboratory (1989), Energy Technology R&D: What Could Make a Difference?, Draft Report.

OECD (1988), Transport and the Environment, Paris.

OECD Ad Hoc Group on Transport and the Environment, city case studies; Hong Kong, London, Los Angeles, New York, Paris, Singapore, Athens, Munich,

Ottawa-Carleton Regional Transit Commission (1986), Strategic Plan and Financial Forecast.

Owen, Wilfred (1987), Transportation and World Development, Johns Hopkins University Press, Baltimore.

Owens, Susan (1986), Energy, Planning, and Urban Form, Pion Limited, London.

Patterson, Philip D. (1987), "Analysis of Future Transportation Petroleum Demand and Efficiency Improvements", presented at IEA Energy Demand Analysis Symposium, Paris, Oct 1987.

Pisarski, Alan E. (1987), Commuting in America, Eno Foundation for Transportation, Westport CT, 1987.

Pisarski, Alan E. (1988), "The External Environment for Public Transit to the Year 2000: A Speculative Assessment", background paper for APTA Transit 2000 Task Force, January 1988.

Poole, Alan (1983), "Energy and Transport in Brazil", report to US Agency for International Development, January 1983.

Poole, J.E. (1988), ICI General Chemicals Group, "Alternatives to CFC-12 in Mobile Air Conditioning", presentation to Substitutes and Alternatives to CFCs and Halons Trade Fair, Washington DC, January 1988.

Portland Oregon Energy Office: pack of material on "Bike Central", a parking/repair/storage/shower/retail facility for bike commuters to the CBD.

Purcell, Gary (1988), "Commercializaton of Electric Vans", EPRI Journal Jan/Feb, p.52.

Ramanathan, V., et al (1987), "Climate-Chemical Interactions and Effects of Changing Atmospheric Trace Gases", Reviews of Geophysics 25:1441-1482.

Reddy, Amulya K.M., "An End-Use Methodology for Development-Oriented Energy Planning in Developing Cluntries with India as a Case Study", Princeton CEES Report # 181, February 1983.

Regional Municipality of Ottawa-Carleton, Transportation Department, System Status Report, December 1986.

Reitz, John R. (1985), "Potential for Energy Savings in Old and New Auto Engines", Chapter 19 of Energy Sources: Conservation and Renewables, Hafmeister et al, eds, American Institute of Physics Conference Series, Vol 135.

Renner, Michael (1988), Rethinking the Role of the Automobile, Worldwatch Paper 84, Worldwatch Institute, Washington.

Reno, Arlee T. (1988), "Personal Mobility in the United States", presentation at TRB Conference on Transport in 2020, June 22-24.

Replogle, Michael A. (1983), Bicycles and Public Transportation: New Links to Suburban Transit Markets, Bicycle Federation, Washington DC.

Riess, Falk and Rainer Pivit (1988), "Design Criteria for an Energy-Saving lightweight Vehicle for Commuting", Human Power 7:1, Spring.

Roberts, Paul O. (1988), "The Outlook for Commercial Freight Transportation", presentation to TRB Conference on Transportation in 2020, June 1988.

Ross, Howard R. (1986), "Highway Electrification and Automation R&D Program", Institute of Transportation Studies, Berkeley.

Ross, Marc (1988a), Light-Duty Vehicles and Petroleum Use in the United States, OTA Draft Report, July 15 1988.

Ross, Marc (1988b) "Energy and Transportation in the United States", Annual Review of Energy 14.

Sathaye, Jayant and Stephen Meyers (1985), "Energy Use in Cities of the Developing Countries", Annual Review of Energy 10, 1985, pp.109-133.

Sathaye, Jayant, Andre Ghirardi, Lee Schipper (1987), "Energy Demand in Developing Countries: A Sectoral Analysis of Recent Trends", Annual Review of Energy 12, 1987, pp.253-81.

Sathaye, J., B. Atkinson, and S. Meyers (1988a), Alternative Fuels Assessment: The International Experience, LBL-24736, March 1988.

Sathaye, Jayant A., Lee Schipper, Andrea Ketoff, Sharad Lele (1988b), An End-Use Approach to Development of Long-Term Energy Demand Scenarios for Developing Countries, International Energy Studies Group, Lawrence Berkeley Laboratory, September 1988.

Sekar, R.R., R. Kamo, and J. C. Wood (1984), "Advance Adiabatic Diesel Engine for Passenger Cars", SAE 840434, presented at SAE Congress, Feb 27-Mar 2, 1984.

Sobey, Albert J. (1988), "Technology and the Future of Transportation: An Industrial View", presentation to TRB Conference on transport in 2020, June 24, 1988.

de Sola Pool, Ithiel, ed (1977), The Social Impact of the Telephone, MIT Press, Cambridge MA.

South Coast Air Quality Management District (1987), The Path to Clean Air: Attainment Strategies, December 1987.

Southern California Association of Governments, Air Quality Management Plan, 1988 Revision, Appendix IV-G, "Transportation, Land Use, and Energy Conservation Measures", May 1988.

Spencer, Gregory (1988), "Demographic Factors and Future Demand for Public Transit", background paper for APTA Transit 2000 Task Force, January 1988.

Stamets, Leigh and G. Occhiuzzo (1985), California Transportation Energy Demand, 1984-2004, report of California Energy Commission.

Statt, Terry G., "The Use of CFCs in Refrigeration, Insulation, and Mobile AC in the US", US DOE.

Thomson, J. Michael, Great Cities and Their Traffic, Victor Gollancz Ltd, London 1977.

Tretyakova, Albina and Barry Kostinsky (1987), USSR: Motor Fuel Use and Conservation in Transportation and Agriculture, 1970 to 1984., US Bureau of the Census, Center for International Research, Staff Paper 32, December 1987.

Tirpak, Dennis A., Daniel A. Lashof, and Bill Pepper, "Responses to Global Climate Change: Stabilizing the Atmosphere". Work Plan for EPA Report to Congress. Draft, Oct 1987.

Tobey, Laurence E., "Costs, Benefits, and the Future of Amtrak," Transportation Law Journal V.15, 1987.

Transportation Research Board of US NRC (1985), "Energy Analysis and Alternative Fuels and Vehicles", Transportation Research Record 1049, Washington DC.

UPI, April 4 1988: "New Coolant said Safe for Ozone".

US Congress, Congressional Budget Office, "Fuel Economy Standards for New Passenger Cars After 1985", Washington DC, December 1980.

US Congress, Congressional Research Service, "Auto Fuel Economy Standards: Roll Back or Status Quo", Robert Bamberger, June 4, 1987.

US Congress, Congressional Research Service, "Carbon Dioxide Emissions from Methanol as a Vehicle Fuel", CRS Report for Congress 88-14 S, January 14, 1988.

US Congress OTA (1979), Changes in the Future Use and Characteristics of the Automobile Transportation System, February 1979. (Summary and Findings) OTA-T-83.

US Congress OTA (1980), Impact of Advanced Group Rapid Transit Technology, January 1980. OTA-T-106

US Congress OTA (1982a), Increased Automobile Fuel Efficiency and Synthetic Fuels: Alternatives for Reducing Oil Imports, September 1982.

US Congress OTA (1982b), Synthetic Fuels for Transportation, Background Paper #1: The Future and Potential for Electric and Hybrid Vehicles, March 1982, OTA-BP-E-13.

US Congress OTA (1982c), Working papers for 1982 report, Oil Replacement: Biomass Liquid Fuels; Natural Gas and LP Gas; Electricity;

US Congress OTA (1983), US Passenger Rail Technologies, Science, Transportaiton, and Innovation Program, December 1983. OTA-STI-222.

US Congress OTA (1984), US Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability, Sept 1984. OTA-E-243.

US Congress OTA (1988), Technology and the American Economic Transition, May 1988, OTA-TET-283.

US Congress OTA (1988b), "An Analysis of the Montreal Protocol on Substances that Deplete the Ozone Layer", Staff Paper, Oceans and Environment Program.

US Congress OTA (1988c), "Conservation and Renewable Energy R&D", Testimony of Peter D. Blair.

US Congress OTA (1989), "Increased Efficiency Potential for the US Fleet of Highway Passenger Vehicles", Testimony of Steven E. Plotkin, Subcommittee on Oversight and Investigations, Committee on Energy and Commerce, US House of Representatives, April 10, 1989.

United States Department of Commerce (1987), The US National Income and Product Accounts: Revised Estimates, July 1987.

United States Department of Energy (1988a), Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the US Transportation Sector, Progress Report One: Context and Analytic Framework, January 1988.

US Department of Energy, Energy Information Administration (1988b), Annual Energy Outlook 1987, DOE/EIA-1383(87), March 28, 1988.

US Department of Energy, Oak Ridge National Laboratory, Transportation Energy Conservation Data Book, various years.

US Department of Transportation (1980), "The Safe Fuel-Efficient Car: A Report on its Feasibility and Marketability", HS 805-644

US Department of Transportation (1981a), Office of Environment and Safety, The Costs and Effectiveness of Transportation Control Measures in Achieving Air Quality Goals, August 1981.

US Department of Transportation (1981b), Small-Car Safety for the 1980s, HS 805-729, March 1981.

US Environmental Protection Agency (1988), Addenda to the Regulatory Impact Analysis document, Protection of Stratospheric Ozone.

US Environmental Protection Agency (1989a), EPA Stabilization Report, draft.

US Environmental Protection Agency (1989b), 1989 Fuel Economy Guide.

USSR Statistical Yearbook, 1985.

UUsitalo, Liisa (1986), Environmental Impacts of Consumption Patterns, St Martin's Press, New York.

Victor, D. G. (1989), "Rethinking Greenhouse Reduction Strategies: A Case Against Natural Gas Vehicles", draft manuscript, MIT Energy Lab.

THE GLOBAL ENVIRONMENTAL POLICY PROJECT

The Global Environmental Policy Project (GEPP) began in 1989 as a joint effort of the Kennedy School of Government's Energy and Environmental Policy Center (EEPC) and its Science, Technology and Public Policy Program (STPP), and the Harvard Business School Negotiations Project. The Global Environmental Policy Project focuses on four subjects:

- Options for Negotiations

  In recent history, regional agreements have emerged bringing together countries who share a common resource. There are lessons to be learned from the formulation and implementation of these environmental negotiations. The Project explores various global negotiations issues, including technology transfer from developed to developing countries, funding mechanisms to cover the cost of reforestation, and CO_2 emissions and reductions.

- Analytic Tools

  The analytical tools that we use to evaluate environmental impact and mitigation options were developed to combat problems with local impact and short time frames. These tools are not adequate for the examination of issues, such as global climate change, which are characterized by long-time horizons, tremendous factors of uncertainty, and a broad spectrum of perceptions among nations. The Project is developing a range of analytical techniques for the evaluation of policy options to provide governments with decision rules to assist in their selection among these options.

- Social Learning

  GEPP researchers are looking at how nations have responded to issues of global environmental change over the past forty years. What lessons can we draw from these experiences? Are societies improving their responses to issues of environmental change? What impedes more rapid progress? Given that different countries react differently, what can we learn from these different responses and how can we use these lessons in developing future programs and policies?

- Training

  Global environmental issues will require nations to look at energy, environment, security and economic policy in a more integrated fashion. Furthermore, they will force countries to absorb more scientific and technical information than they can currently evaluate. Many nations do not have the internal capability independently to assess information being generated on global environmental problems.

  The Project is attempting to develop an executive program to teach senior government officials how to assess and manage global and regional environmental problems.

Von Hippel, Frank and Barbara Levi (1983), "Automobile Fuel Efficiency: the Opportunity and the Weakness of Existing Market Mechanismns", Resources and Conservation, pp. 103-124.

Walsh, Michael P. (1988), "Motor Vehicles and Climate Modification: An Assessment", report for US Congress OTA, November 1988.

Webber, Melvin M. (1976), The BART Experience: What Have We Learned?, Institute of Urban and Regional Development and Institute of Transportaiton Studies, University of California Berkeley, October 1976.

Werbos, Paul J. (1986), "Documentation of the Transportation Energy Demand Model as Used in the Annual Energy Outlook 1985", US Department of Energy DOE/EIA-M013, April 1986.

Whitford, Robert K. (1984), "Fuel-Efficient Autos: Progress and Prognosis", Annual Review of Energy 9.

Williams, Robert H. and Eric D. Larson (1987), "Materials, Affluence, and Industrial Energy Use", Annual Review of Energy 12, p. 99-144.

Williams, Robert, (1987) letter of Nov. 24, 1987 to Steve Plotkin, OTA, Efficiency improvements in automotive fuel consumption.

Wilson, David Gordon (1984), "Moving People and Goods Before the Year 2000", Technology Review May/June, p.61.

Wilson, David G. (1986), "A Short History of Human-Powered Vehicles", American Scientist 74, July-Aug p.350-357.

Yang Hongnian (1988), "Energy and Transport in China", Proceedings of the Chinese-American Symposium on Energy Markets and the Future of Energy Demand, Nanjing, June 22-24 1988.

Yenny, Jacques and Lily V Uy (1985), Transport in China, World Bank Staff Working Paper Number 723, Washington DC, 1985.

Ying Chenxiao, "China Departure," Automotive News.