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AUTOMOBILE FUEL EFFICIENCY: THE OPPORTUNITY AND THE WEAKNESS OF EXISTING MARKET INCENTIVES

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ABSTRACT

The average fuel consumption of light vehicles can be reduced several-fold by the use of currently available technology. This conclusion is based on a simple computer model which has been found to reproduce the fuel economies of some existing energy-efficient passenger cars. It is shown, however, that the associated life cycle cost savings for new car buyers are too small to generate sufficient market pressure to realize more than a fraction of the available fuel savings. The potentials of various public policy tools for helping to overcome this market inertia are discussed. The importance of automotive fuel efficiency improvements in facilitating a graceful transition to the post-fossil-fuel era is also briefly considered using the example of Europe.

THE IMPORTANCE OF AUTOMOTIVE FUEL ECONOMY

> *The umbilical cord of the industrialized free world runs through the Strait of Hormuz into the Arabian Gulf and the nations which surround it.*

This statement by U.S. Secretary of Defense Weinberger [1] describes his security concerns about the distribution of the world oil resources and flows shown in Fig. 1 (taken from [2]). His words can hardly be a source of comfort to any resident of the globe, considering the explosive nature of the politics of the Middle East and the expressed willingness of the U.S. to use nuclear weapons if necessary to defend Western access to the oil there.

Much of the flow through the oil "umbilical cord" feeds the light duty vehicle fleets (passenger cars and light trucks) of the industrialized democracies. These fleets consumed in 1978 the equivalent of about 40% of the summed oil imports of their nations — about 11 million barrels of oil per day (0.55×10^9 metric tonnes/year (Mg/y)). This was over 85% of all the oil consumed by light vehicles worldwide in 1978 [3–6]. (See Table 1 and Fig. 2.) A substantial reduction in the oil used to fuel light vehicles might, therefore, diminish the global significance of future crises in the Middle East.

One possible approach to the problem of limited and uncertain future supplies of oil is to produce synthetic fluid fuels from more abundant solid

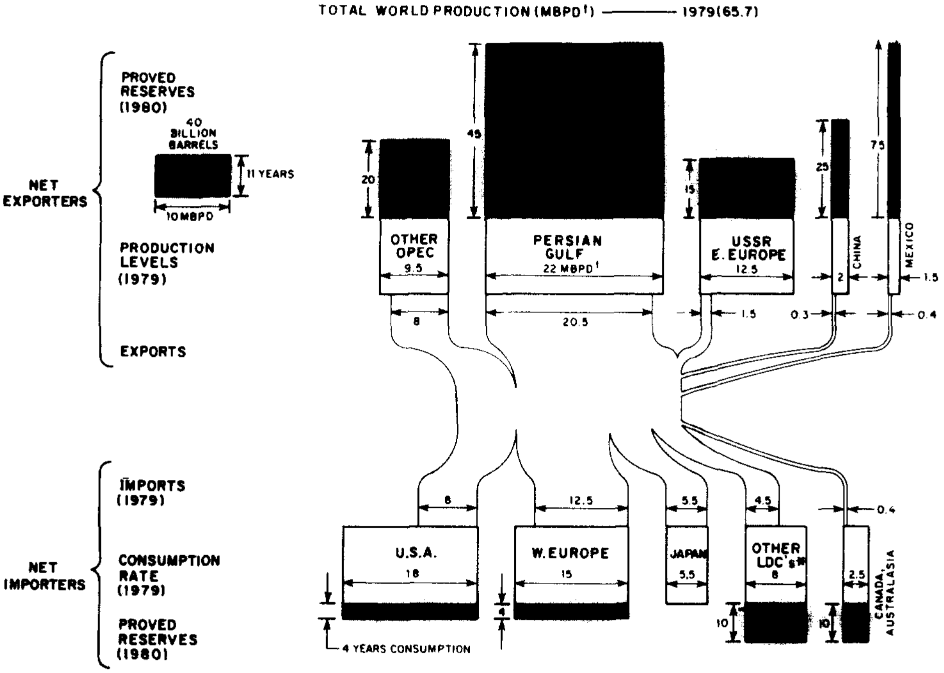

Fig. 1. World oil reserves and flows, 1979.

The global importance of Persian Gulf oil is suggested by both the relative size of its oil reserves (proportional to shaded area) and the magnitude of its exports. The principal importers were the industrialized democracies with "less developed countries" (LDC's) accounting for only about 15% of total oil imports. One million barrels per day (MBPD) = 50 million Mg/y. From [2].

fossil fuel resources. Over the past few years, there was considerable interest in this approach in the United States because of the availability of abundant coal and oil shale resources. It appears unlikely that it will be possible to exploit fully these fossil fuels, however, because of the impact on the global climate of the large increases of the level of CO_2 in the atmosphere which would result [7].

Another approach to the problem of oil consumption by passenger cars is to increase dramatically their energy efficiency. This approach is considered in this article.

THE TECHNOLOGICAL POTENTIAL

It would appear technologically relatively straightforward to reduce average passenger car fuel economy to less than one quarter of its 1978 world average value. The 1978 VW Rabbit (called the "Golf" in Europe), an average size passenger car outside of North America, when powered by a diesel engine

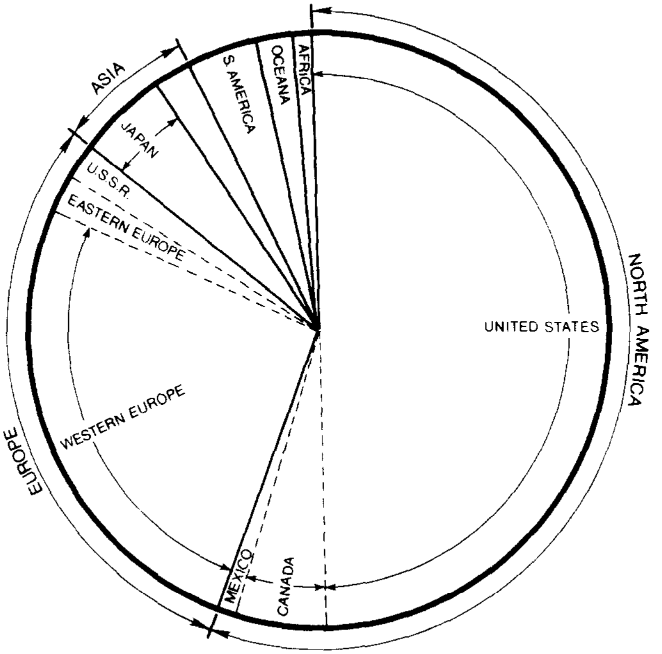

Fig. 2. World passenger car oil consumption, 1978.

The equivalent of about 40% of all the oil imported by the "industrialized democracies" (the U.S., Canada, Western Europe, Japan, Australia, and New Zealand) in 1978 was consumed by their passenger car fleets. These nations accounted for more than 85% of world passenger car oil consumption in 1978. The U.S. alone accounted for approximately 50%. From Table 1.

already uses only about 5 liters of fuel per 100 km or 40% as much fuel on a volume basis (44% on a fuel energy basis) as the world average passenger car in 1978 (see Table 1). Table 2 shows the authors' estimates that, with various technical improvements, the fuel consumption of this vehicle could be cut to 20% of the 1978 world average.

The program of energy efficiency improvements on the Rabbit shown in Table 2 and Fig. 3 includes:

(1) a reduction of both the aerodynamic drag coefficient and of the tire rolling resistance coefficient by about 30%;

(2) a shift to an open chamber diesel engine;

(3) a shift to a Van Doorne-type continuously variable transmission (CVT) controlled by a microprocessor to give optimal fuel economy and minimal engine peak power for a given acceleration performance;

(4) a reduction of the vehicle inertia weight by about 15%;

(5) a doubling of the CVT range to 10:1;

(6) the elimination of engine fuel consumption during periods when the vehicle is at rest or in unpowered deceleration.

All of these technological improvements are also applicable to light trucks.

TABLE 1

The world passenger car fleet and its oil consumption in 1978

Region	Number[a]		Average fuel efficiency[b,c]	Crude oil consumption[c,d]	
	× 10^6	(% of world total)	(liters/100 km (mpg))	(10^6 Mg)[e]	(% of world total)
North America	120	41		280	56
U.S.	104	36	17 (14)	250	50
Canada	10	3.5	17 (14)	25	5
Mexico and Central America	5	1.5	10 (24)	6	1
Europe	115	41		150	30
West	100	35	10 (24)	130	26
East (ex. U.S.S.R.)	10	3.5	10 (24)	13	2.5
U.S.S.R.	7	2.5	10 (24)	9	2
Asia	28	10		36	7
Japan	21	7.5	10 (24)	27	5
Other	7	2.5	10 (24)	9	2

South America	12	4.5		19	4
Brazil	7	2.5	10 (24)	9	2
Argentina	3	1	10 (24)	5	1
Other	3	1	10 (24)	5	1
Africa	5	2		6	1
S. Africa	2	1	10 (24)	3	0.5
Other	3	1	10 (24)	4	0.5
Oceania	7	2.5		9	2
Australia	6	2	10 (24)	8	1.6
N. Zealand	1	0.3	10 (24)	1	0.2
Other	0.2	0.1	10 (24)	0.3	0.1
World total	290	100	13 (18)	500	100

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[a] U.S. Motor Vehicles Manufacturers' Association, World Motor Vehicle Data, 1980, except for the U.S. where passenger car registrations have been taken from Automotive News, 1981 Market Data Book Issue, April 29, 1981, p. 20.

[b] U.S. estimate from DOE, The Light Duty Vehicle Model, Fourth Quarterly Report, July 2, 1981. The same value has been assumed for Canada. Elsewhere, for lack of better information, a common estimate has been adopted.

[c] It has been assumed that passenger cars are driven 16,500 km/y in the U.S. and Canada and 15,000 km/y elsewhere. For an indication of the quality of the available data, see International Road Federation, World Road Statistics, 1976—1980 (Geneva, IRF, 1981), Chapter V.

[d] It has been assumed that it requires one volume unit of crude oil to produce one volume unit of either gasoline or diesel fuel.

[e] Fifty (49.8) million metric tonnes (Mg) of crude oil per year equals one million barrels per day. Ten liters/100 km = 23.5 mpg.

TABLE 2

The potential for passenger car fuel economy improvements

Vehicle	Inertia weight[a] (kg)	Drag coefficient	Rolling resistance coefficient (Fraction of gravity)	Engine (kW)	Transmission	Composite fuel economy[b] (liters per 100 km (mpg))
World average, 1978	—	—	—	—	—	13.0 (18)[c]
1981 VW Rabbit (gasoline)	—	—	—	55 (spark ignition)	5-speed manual	7.9 (30)[d]
1981 VW Rabbit (diesel)	—	—	—	39 (prechamber diesel)	5-speed manual	5.3 (45)[d]
Computer estimates[e]						
(VW diesel Rabbit modifications)						
Base case	1080	0.42	0.012	39 (pre-chamber diesel)[f]	5-speed manual[g]	5.3 (44)
Reduce aero. drag	1080	0.30[h]	0.012	39 (pre-chamber diesel)	5-speed manual	5.0 (47)
Reduce rolling resist.	1080	0.30	0.0085[i]	39 (pre-chamber diesel)	5-speed manual	4.8 (49)
Shift to open chamber diesel	1080	0.30	0.0085	39 (open chamber diesel)[j]	5-speed manual	4.3 (55)
Shift to continuously variable transmission (CVT)	1080	0.30	0.0085	39 (open chamber diesel)	CVT (range 3.45—0.69)[k]	3.7 (64)
Reduce engine peak power[l]	1080	0.30	0.0085	29 (open chamber diesel)	CVT (3.45—0.69)	3.3 (71)
Reduce weight	910[m]	0.30	0.0085	25 (open chamber diesel)	CVT (3.45—0.69)	3.0 (79)
Expand CVT range	910	0.30	0.0085	25 (open chamber diesel)	CVT (range 3.45—0.345)[k]	2.8 (83)
Add engine-off during coast and Idle[n]	910	0.30	0.0085	25 (open chamber diesel)	CVT (3.45—0.345)	2.6 (89)

[a] Curb weight plus 300 pounds (135 kilograms).

[b] U.S. Environmental Protection Administration (EPA) Composite Driving cycle (55% urban, 45% highway).

[c] See Table 1.

[d] US EPA Test List for 1981 cars.

[e] The following assumptions are common to all cases where numbers are estimated using a computer simulation: a projected frontal area of 1.88 m^2, an effective tire radius of 0.28 m, an axle ratio of 3.89, consumption by the accessories of 0.37 kW of the engine's output power, and a 10% loss of the remaining engine output in the drive-line between the engine and the tires.

[f] The prechamber diesel of the VW Rabbit has been represented by the thermal efficiency map for a 4 cylinder naturally aspirated diesel engine shown in Fig. 36 of B. Wiedemann and P. Hofbauer (VW), 1978. Data Base for Light-Weight Automotive Diesel Power Plants, Society of Automotive Engineers (SAE) Paper #780634. It has been assumed that the zero power fuel demand is 0.13 mg per revolution per peak engine horsepower at 1000 *rpm*, rising linearly with rpm to twice that level at 5000 rpm.

[g] Using the gear ratios: 3.45, 1.94, 1.29, 0.97, and 0.76 (VW *Rabbit*, 1980) *and the standard* EPA shift schedule: 11/21/32/42 mph (18/34/51/67 km/h).

[h] A number of the prototypes shown at the 1981 Frankfurt auto show had aerodynamic drags in the range 0.24—0.3. Richard Feast, 1981. Cars of *tomorrow* add spice to Frankfurt Show: innovation and slippery shapes predominate, Automotive News, (Sept. 28), p. 1.

[i] Recent EPA tests found that a number of commercially available radial tires have rolling resistances of approximately 0.1 at 0.24×10^6 *pascal* (35 psi) inflation pressure, 80% of rated load and tested on a 0.85 m radius dynamometer drum. Gayle Klemer, 1981. Standards Development and Support Branch, Emission Control Technology Division, Office of Mobile Source *Air Pollution Control*, US EPA, Rolling Resistance Measurements for 106 Passenger Car Tires, (August). Dividing by the standard correction factor, $(1 + r/R)^{1/2}$ (where r, the radius of the tire, is assumed to be 0.28 m and R is *the* radius of the drum), the flat surface rolling resistances of these tires is calculated to be about 0.0085.

[j] The engine map has been scaled from the 52 kW (peak output) engine map shown in U.G. Carstens and I. Isik (Sauer), and G. Biaggini and G. Cornetti (Fiat), 1981. Sofim small high-speed diesel engines — D.I. versus I.D.I., SAE Paper #810481, Fig. 10. The same idle flow discussed in [f] has been used.

[k] An international consortium made up of the Dutch Company, Van Doorne *Transmission* BV, Borg—Warner, Fiat, and the Dutch government has produced prototype CVTs with a ratio range of 5 for automobiles, 5.9 for light trucks, and, "with the addition of a liquid cooled Borg—Warner torque con*verter on the input side*", 10 for medium trucks. Jan Norbye, 1981. Van Doorne: automatics with twist, Automotive News (Sept. 14) p. 28. In another analysis (P. Baudoin, 1979. Continuously variable transmissions for cars with high ratio coverage, SAE Paper #790041), it was found that, with the substitution of a Van Doorne 4.7 ratio coverage Transmatic for a 4 speed manual transmission, the fuel economy of a Renault 14 was increased by 28% on the EPA urban cycle and 21% at a constant 88.5 km/h (55 mph). There was an associated increase of the lowest (1000 rpm) in-gear speed from 6.9 to 9.5 km/h. (In the calculations reported here, the corresponding speed has been fixed at 7.9 km/h.)

[l] Since the CVT makes full power available at all road speeds above 40 km/h, this horsepower would allow the vehicle specified to accelerate from 0—80 km/h (0—50 mph) and 64—96 km/h (40—60 mph) in less than 13 and 11 seconds respectively, assuming that the accessories draw 0.37 kW (0.5 horsepower) throughout the acceleration period.

[m] The VW Research Vehicle 2000 has been described as being "between the compact and *subcompact class*" (the Rabbit is in the subcompact class) and having a weight of 786 kg (1730 lb), corresponding to an inertia weight of 920 kg (2030 lb). Ulrich Seiffert, Peter Walzer and Hermann Oetting (VW), 1980. *Improvements* in automotive fuel economy, Proceedings of the First International Automotive Fuel Economy Research Conference, U.S. DOT, p. 95.

[n] It is assumed that 0.37 kW (0.5 hp) is drawn from storage by the accessories when the engine is not delivering power to the wheels during the driving cycle. The storage is replenished at a constant rate during the engine-on period. *It is assumed that the* "round trip" efficiency of the energy storage system is 70%, i.e., that the engine has to produce $(1.4)^{-1}$ kWh of energy for every kWh drawn from storage.

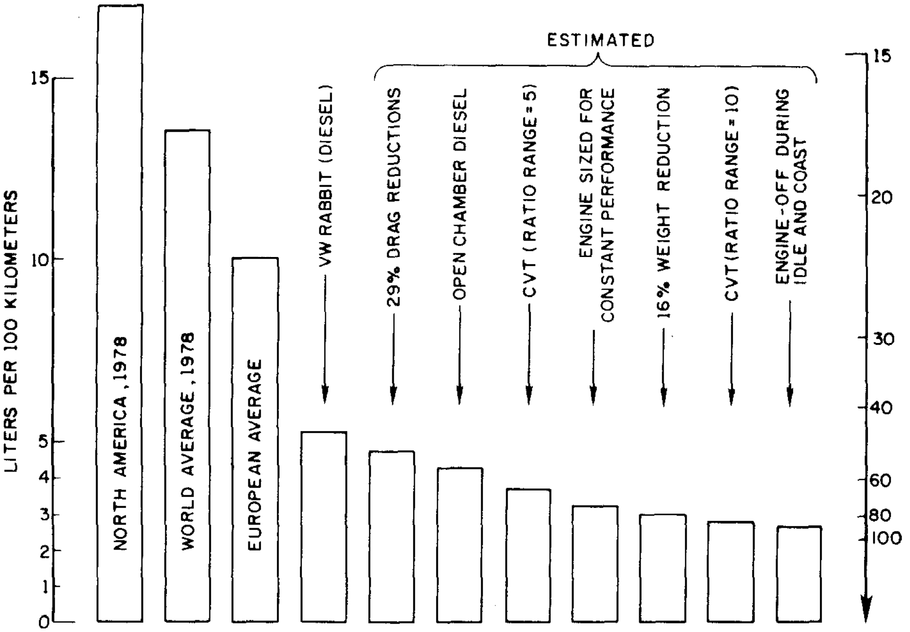


Fig. 3. The potential for reduced passenger car fuel consumption (EPA composite cycle).

Estimates of the practical potential for fuel economy improvement of a vehicle the size of the VW diesel Rabbit suggest that it would be feasible to decrease the average fuel consumption of the world passenger fleet per km to one fifth of its 1978 value. The program of proposed improvements includes: aerodynamic drag and weight reductions, a more efficient (open chamber) passenger car diesel engine, automatic shut off of the engine when power is not required at the wheels, and the use of a continuously variable transmission (CVT). Fuel efficiency is measured using the U.S. Environmental Protection Agency's (EPA) "composite" (55% urban, 45% highway) driving cycle. From Table 2.

Fig. 4 shows the dramatic reduction in U.S. light vehicle fuel consumption which would result if the average fuel consumption of new U.S. light vehicles (including light trucks) were reduced to the range of 4—6 liters/100 km by 1995 (assuming constant total annual vehicle—km) [8].

If such dramatic improvements are possible, the question arises as to whether they will be introduced into the new vehicle fleet reasonably promptly. If not, how much and what kind of government intervention would be appropriate and/or necessary to stimulate fuel economy improvements that might not otherwise occur?

THE "INVISIBLE HAND" OF THE MARKET

In the United States the government has rediscovered the "invisible hand" of the market by which manufacturers are directed to produce goods with the characteristics that consumers desire. Indeed, U.S. auto manufacturers recently experienced a very strong push from the market's invisible hand

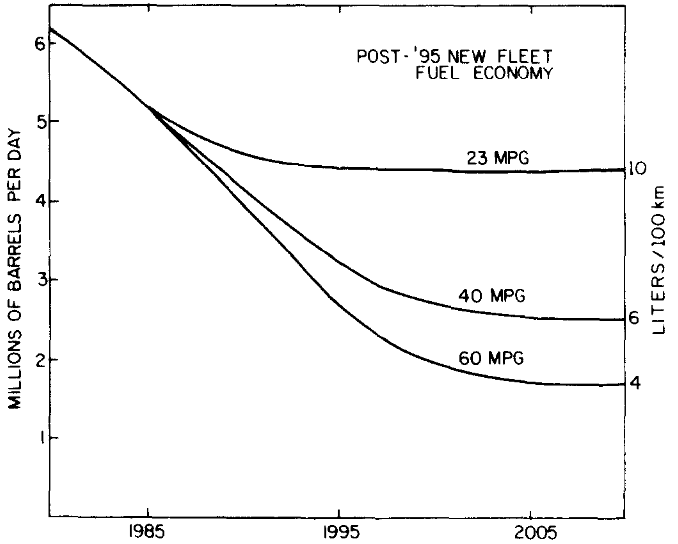


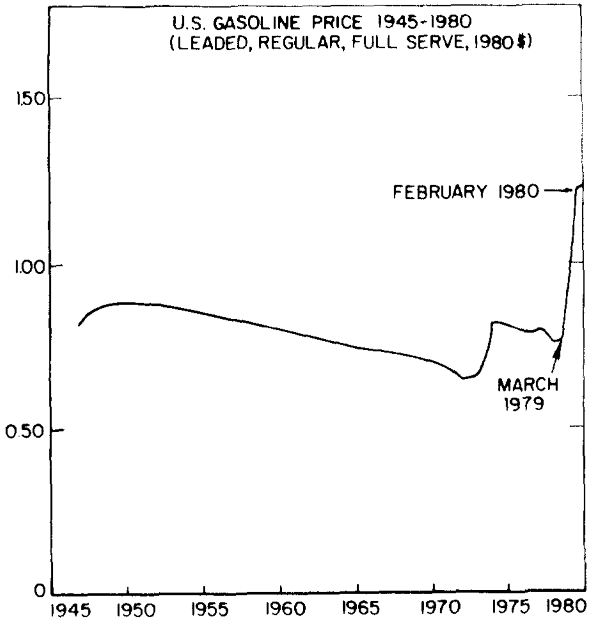
Fig. 4. Alternative Futures for U.S. Light Vehicle Fuel Consumption.

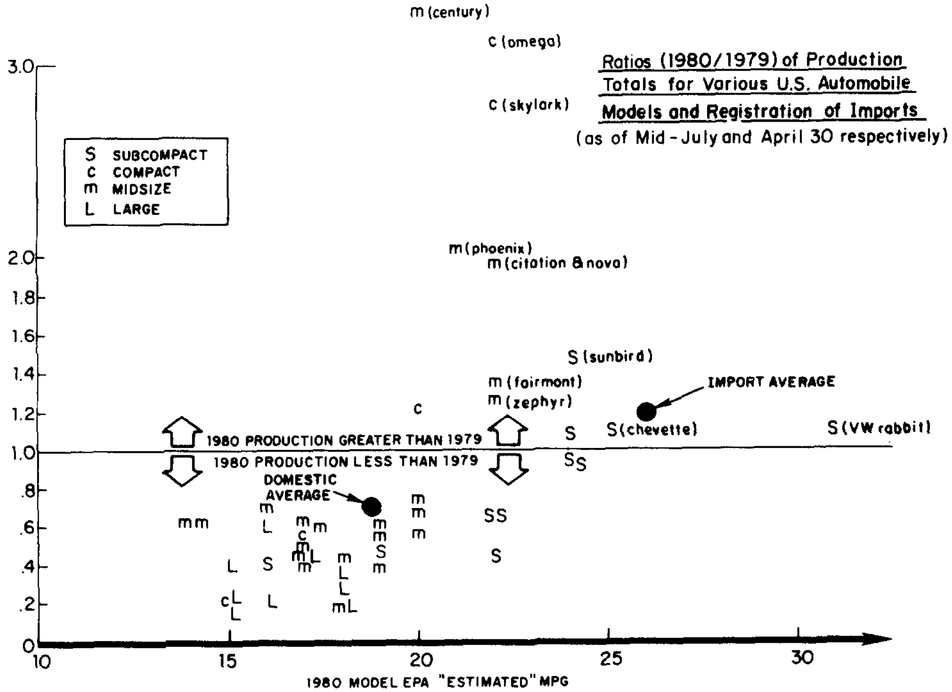
The fuel consumption of a U.S. fleet of 150 million light vehicle fleet is projected for three alternative assumptions about post-1985 efficiency improvements: no reductions below an average 1985 new fleet average fuel consumption of 10 liters/100 km; or continued reductions to levels of 6 or 4 liters/100 km for the 1995 *new* verhicle fleet. Exponential attrition of the number of vehicles of a given age group is assumed with an expected average lifetime of 10 years. On average, each vehicle is assumed to be driven 16,000 km per year with the number of km driven per vehicle decreasing by 640 km per year of vehicle age. From [8].

after the sudden increase in the price of gasoline which occurred in the U.S. during 1979 and early 1980. (See Fig. 5 [8].) As a result, between model year 1979 (which ended in August 1979) and the first seven months of model year 1981 (which began in October 1980), the average U.S. Environmental Protection Agency (EPA) composite fuel economy of cars being sold in the U.S. increased by 22% [9]. Fig. 6 shows the changed popularity of individual models as a function of their "estimated" (EPA urban) fuel economies [10].

How far will the invisible hand push automobile fuel economy? Fig. 7 shows what the incentive for fuel economy improvements would be *if there were no cost associated with increasing fuel efficiency of a vehicle.* Here a pre-tax purchase price of $7,000 has been assumed and has been divided by a total vehicle lifetime distance traveled of 150,000 km to obtain a corresponding depreciation cost of 4.7 U.S. cents per km traveled to which an additional 7.5 cents/km has been added for the non-fuel related operating costs of repairs, parts and maintenance; garaging, parking and tolls; insurance; and registration, titling and sales taxes [11].

The contribution of fuel costs to total operating costs is shown in Fig. 7 for three gasoline prices: (1) the average May 1981 U.S. price of 35 cents/liter of leaded regular gasoline; (2) twice this price (a typical European price in


U.S. GASOLINE PRICE 1945-1980
(LEADED, REGULAR, FULL SERVE, 1980$)


Ratios (1980/1979) of Production Totals for Various U.S. Automobile Models and Registration of Imports
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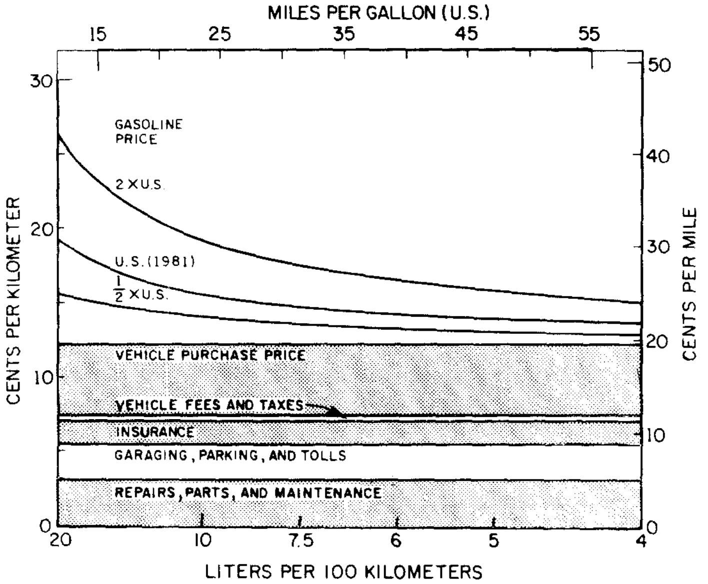

Fig. 7. Cost savings if fuel economy improvements were free.

Shown here is the estimated total cost of driving as a function of average fuel efficiency, given three fuel prices (the 1981 U.S. level, twice this level and half this level). Even though it has been assumed that the purchase price of the car is independent of its fuel economy, it will be seen that the marginal savings due to marginal fuel consumption reductions are quite small below about 10 liters/100 km, given 1981 U.S. fuel prices or 6 liters/100 km, given fuel prices twice as high (i.e. in the West European range).

March 1981 [12]); and (3) one half the U.S. price. The last price reflects the effective weight that U.S. car purchasers might put upon gasoline savings if they required any investment cost in improved fuel economy to be paid back in fuel savings within the four years duration of a typical U.S. automobile loan — a period during which the average U.S. passenger car has typically accumulated only one half of its lifetime mileage. (If Europeans were to reduce

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Fig. 5. Post-World War II history of U.S. gasoline prices.

The prices have been adjusted to constant 1980 dollars using the implicit price deflators for the US Gross National Product. Note the large price increase between early 1979 and 1980. One U.S. gallon equals 3.79 liters. From [8] and [10].

Fig. 6. Increased demand for energy-efficient passenger cars in the U.S. between 1979 and 1980.

Shown here are the ratios of 1980 to early 1979 production rates for various new U.S. cars plotted to show their "estimated" (EPA urban driving cycle) fuel economy. It appears that, as a result of the gasoline price increase during the intervening period (see Fig. 5), consumer demand decreased for almost all cars with estimated fuel economies less than about 23 miles per gallon (i.e. fuel consumption greater than about 10 liters/100 km) From [10].

the weight of their gasoline purchases by one half in their purchase decisions, then they would act as if they were facing U.S. prices.)

It will be seen, given the assumptions made in deriving at Fig. 7, that reducing the average fuel consumption of U.S. passenger cars by half from 17 to 8.5 (or of European passenger cars from 10 to 5) liters/100 km would reduce the cost of driving by about 20%. These are substantial but not overwhelming incentives. They will be weakened further when account is taken of the fact that in "the real world" fuel economy improvements are not free.

THE COST OF FUEL ECONOMY IMPROVEMENTS

There are a number of real and potential costs associated with automotive fuel economy improvement, both economic and "external". Among these costs are:

(1) the capital costs to the auto manufacturers of the necessary retooling;

(2) the higher production costs of some technologies (e.g. diesel engines) relative to the technologies which they replace;

(3) reduced performance if reductions to the peak power-to-weight ratio are used as part of a fuel economy improvement strategy (unless the average power available at the wheels is maintained with other improvements such as the introduction of a continuously variable transmission);

(4) reduced safety, if weight reductions are made to obtain improved fuel economy without compensating safety-related design improvements;

(5) increased emissions of pollutants associated with the introduction of some highly fuel efficient engines such as diesels.

Retooling costs

The cost of retooling for fuel economy improvements is very difficult to judge. In part it depends upon the rate at which design changes are introduced, since there are many reasons to retool aging facilities and, when new tooling is being ordered, design changes do not necessarily add greatly to cost. It is obvious, however, that the rate of retooling undertaken by the U.S. automobile manufacturers, in order to improve the fuel economy of their products rapidly during the later 1970's and early 1980's, resulted in unusually large capital investments. In 1980 the U.S. Department of Transportation estimated that U.S. automobile manufacturers would invest $56 thousand million (1980 $) between 1980 and 1986 in converting an annual production capacity of 16 million light vehicles from rear wheel to front wheel drive designs and smaller engines [13]. This comes to $3,500 per vehicle production capacity or (assuming an average capacity utilization of 75%) about $5,000 in 1981 dollars per vehicle produced annually.

In order to recapture this investment over a 6-year period with a 10% real annual rate of return, the manufacturers would have to raise the average prices of their vehicles by up to $1250 [14]. If the associated average fuel savings were about 4 liters/100 km [corresponding to a reduction in average fuel consumption from 13 to 9 liters/100 km (an increase in average fuel economy from 18 to 27 mpg)], the increase in the average purchase price would equal 50% of the resulting savings in gasoline costs to the vehicle owners (at current U.S. gasoline prices) over the expected vehicle lifetimes [15].

Increased production costs

Table 3 gives estimates of the increase in new car prices which would be associated with the various technological changes analyzed in Table 2 after the retooling costs of the automobile companies had been paid off.

Although these estimates are in some cases very uncertain, the essential policy relevant observation is not. It can be seen in Fig. 8 that the downward slope of the cost curve with increasing fuel economy is *very* shallow below a fuel consumption of 10 liters/100 km at current U.S. gasoline prices (below

TABLE 3

Purchase price increases assumed for various fuel efficiency improvements

(1981 $ per passenger car)

Technology change	
Gasoline to prechamber diesel engine	525[a]
Tire rolling resistance reductions	0[b]
Reduction in coefficient of aerodynamic drag to 0.3	100[c]
Prechamber to open chamber diesel	0[d]
Five speed manual to continuously variable transmission (CVT): 5—1 Range	400[e]
Weight reduction (upper bound estimate)	400[f]
Extended range of CVT: 10:1	100[c]
Engine-off during idle and coast	200[c]

[a] Based on the differential between the U.S. list prices of the VW gasoline and diesel powered Rabbits. Automotive News June 8, 1981, p. 2.

[b] Based on the absence of correlation between radial tire rolling resistance and price (Table 2, note [i]).

[c] Authors' guess.

[d] TRW Energy Systems Planning Division, 1979. Data base on automobile energy conservation technology (Draft).

[e] Borg—Warner expects the initial cost of the new CVT to be comparable with present automatics and that the price will come down with production (Automotive Industries, March 1980, p. 37). The automatic transmission-equipped 1981 US VW Rabbit costs $400 more than the same model with a 5-speed manual transmission (see note [a]).

[f] This estimate, which is likely to be high, is obtained from the estimate of $2.20/kg weight reduction in Richard H. Shackson and H. James Leach, 1980. Maintaining Automotive Mobility: Using Fuel Economy and Synthetic Fuels to Compete with OPEC Oil, Mellon Institute, Arlington (Va).

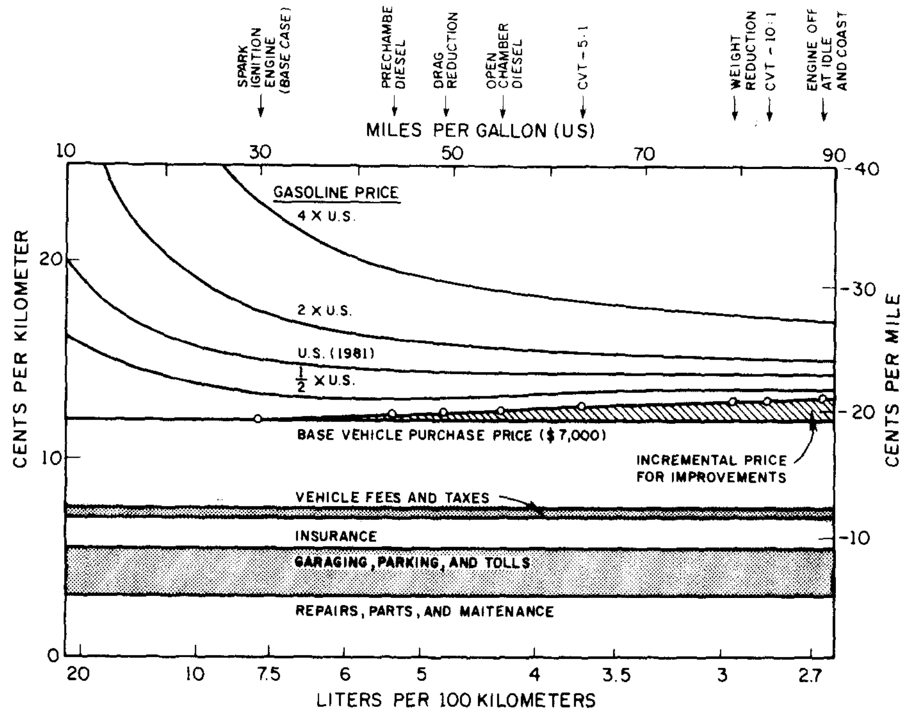

Fig. 8. Cost of driving as a function of fuel economy.

This figure differs from Fig. 7 in that it includes the estimated fuel economy-related increases in the purchase price of the new car. The magnitude of this contribution (indicated by the shading) is relatively small but offsets the small cost savings associated with fuel consumption reductions below about 6 liters/100 km, given 1981 U.S. gasoline prices. If, on average, consumers value future fuel savings at one half of their actual value, this would be the curve perceived by new car buyers in nations with fuel prices double those in the U.S. (e.g. in Western Europe).

6 liters/100 km at 1981 European gasoline prices). As a result, even though the cost to the automobile owner would not be significantly increased if the fuel consumption were reduced to as low as 3 liters/100 km, it will be understandable if, given 1981 fuel prices, considerations such as safety and performance or the reluctance of the auto manufacturers to make the further major investments in fuel economy-related retooling could keep the average fuel consumption of the fleet from declining much below 10 liters/100 km in the U.S. (6 liters/100 km in Europe).

Reduced performance

There is a significant performance penalty associated with the common fuel economy improvement strategy of converting a gasoline engine to a diesel engine of equal displacement [16]. This performance penalty can be substantially eliminated by turbocharging or supercharging the diesel with little loss in fuel economy but the cost of the engine is significantly increased.

Reduced safety

Historically, weight has been inversely correlated with the probability of serious injury or death in U.S. automobile accidents. (See Fig. 9 [17].) There is, therefore, significant public concern, about the safety implications of the vehicle weight reductions and, as a result, some new car buyers are probably purchasing larger, heavier vehicles than they really require.

In principle, the massive retooling which would be required to accomplish average fuel economy improvement as large as those discussed in this paper would provide an opportunity to include safety improvements in the redesigned vehicles. If this opportunity were effectively exploited, there is no obvious reason why the energy efficient vehicles of the future should not be safer than their "gas-guzzling" predecessors.

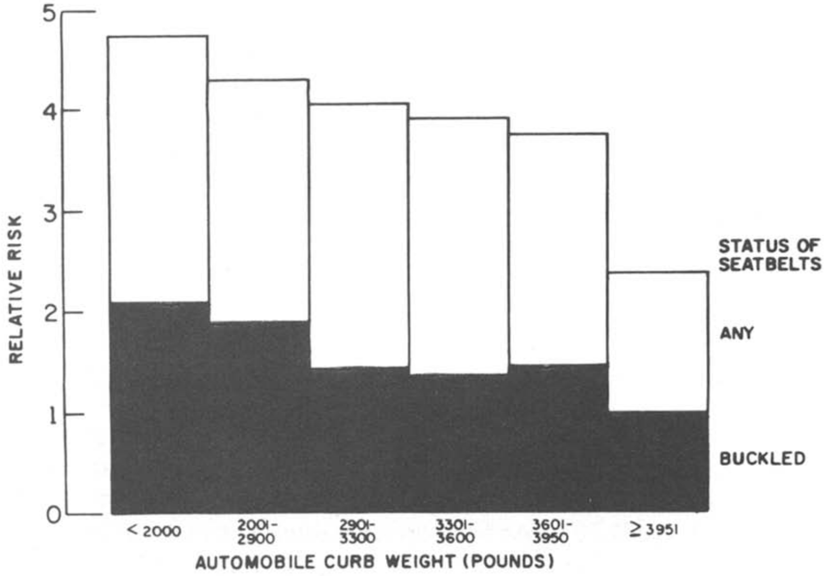

Fig. 9. Risk of serious injury or death to the driver in an accident as a function of vehicle weight.

These statistics are for U.S. passenger cars of model years 1973—1975. Unless weight reductions are accompanied with improvements in crashworthiness, they will bring increased death rates in addition to fuel savings.

Emissions increases

There is some concern in the U.S. about the increase in the concentration of suspended particulates in urban areas which can be expected to result from the increasing popularity of diesel engines in U.S. passenger cars. In the interim, this concern may be addressed at some added cost with exhaust filtration technology. In the longer term, however, the problem could be eliminated, by switching over to methanol in highly efficient spark-assisted engines.

FUEL ECONOMY POLICY

The conclusion to be derived from the above discussion is that the costs of automotive fuel economy improvements are not so large as to overwhelm the benefits — especially the benefits of reduced dependence upon oil imports — but that market "friction" might result in an average automotive fuel economy far below that which might be in the larger social interest. This observation suggests that it would be desirable to develop national policies which would encourage increased automotive fuel efficiency without sacrificing safety or the environment.

The principal policy tools which have been developed thus far to encourage fuel economy improvements are: fuel taxes, fuel economy standards and fuel efficiency-related purchase and registration taxes. An additional possibility would be to provide direct financial incentives to manufacturers — especially if they would otherwise have difficulty raising the capital required for a program of fuel economy-related retooling. Of course, it is also necessary for consumers to have information concerning the energy efficiency of new vehicles if market forces and taxes are to work effectively.

Fuel taxes

The economists' favorite way to discourage excesses which are not in the public interest is to tax them. This policy has been pursued in most oil importing nations other than the U.S. and it probably should be credited for the relatively higher fuel economy of West European and Japanese automobiles. The cost curves in Fig. 8 suggest, however, that if the industrialized nations decided to use increased fuel taxation to reduce the average fuel consumption of their light vehicle fleets by more than one half, it would be necessary for them to commit themselves to a program which will in a predictable way (e.g. over 10—15 years) raise the real price of automotive fuel to more than four times the 1981 U.S. price (twice the 1981 Europe price).

Fuel economy standards

In 1975 the U.S. Congress required by law that the average fuel consumption of new U.S. passenger cars should by 1985 be reduced by approximately 50% to less than 8.6 liters/100 km (corresponding to a fuel economy of more than 27.5 mpg) as measured by the EPA composite (55% urban, 45%

highway) driving cycle. An average standard of about 11 liters/100 km (21 mpg) was established administratively for light trucks by the Department of Transportation.

The U.S. program is unique in having legal force. In 1979, however, the governments of both Britain [18] and Japan [19] made "voluntary" agreements with their automobile manufacturers for improvements of about 10% in average new car fuel economy by 1985. And the governments of both France [20] and West Germany [21] have contributed funding to projects aimed at developing prototype demonstrations of fuel conserving automobiles.

Although it takes more than four years to implement an automotive fuel economy improvement program, the authors are unaware of any government initiatives that set higher standards for automotive fuel economy in the post-1985 period.

Vehicle taxes

Since new car buyers tend to discount future savings relative to current costs, an obvious strategy to encourage improved fuel economy is through an anticipatory tax on fuel consumption, i.e. a purchase tax on new cars which increases with their projected lifetime fuel consumption. The U.S. is the only country that has explicitly promulgated such a tax — the so-called "gas guzzler" tax. However, Fig. 10 makes clear that the system of rather large purchase and registration taxes which prevails in Europe has the effect of adding a substantial extra cost to the ownership of a vehicle consuming more than 10 liters/100 km (i.e. having a fuel economy of less than 24 mpg) [22]. This effect is much less dramatic in percentage terms, however, since high fuel consumption vehicles in Europe tend also to be high priced luxury cars.

In any case, there is a precedent for large purchase and registration taxes on vehicles and, if fuel efficiency were made an important object of public policy, these taxes could be tied to fuel efficiency. In order to push the market toward the realization of its full fuel efficiency potential, however, it would be necessary to raise the purchase and/or registration taxes of passenger cars with fuel consumption greater than perhaps 5 liters/100 km (fuel economy less than 47 mpg) to levels of several 1981 cents/km or more. This would correspond to several thousand dollars over the lifetime of the vehicle.

Financial incentives for manufacturers

Taxes on both current and future fuel consumption will act to discourage the purchase of energy inefficient vehicles and will, therefore, tend to discourage their manufacture. Fuel economy standards also put pressure on the manufacturer. However, none of the above policy tools directly addresses the problem of manufacturers who have difficulty raising capital for major fuel economy-related retooling.

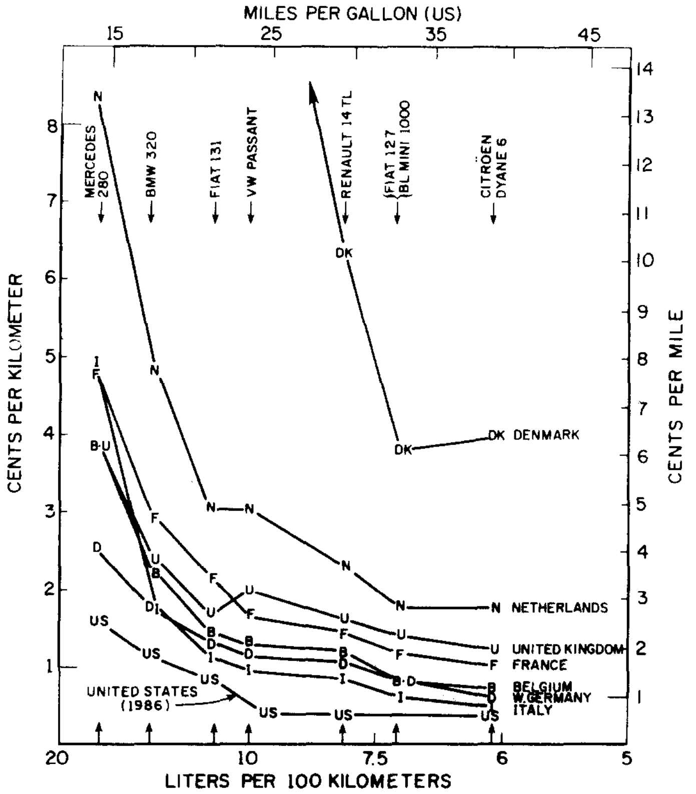

Fig. 10. Vehicle purchase and registration taxes in various nations.

Taxation of automobile ownership is quite high in Western Europe, especially in the case of fuel-inefficient "luxury" cars. Comparison with Fig. 8 suggests that a deliberate policy of high purchase taxes on inefficient vehicles could be more effective in encouraging the purchase of more energy efficient vehicles than fuel taxes. However, the "gas guzzler" tax mandated for U.S. cars in 1986 appears too small to be very effective.

It is possible that this problem will not be as serious in the future as it was recently for U.S. manufacturers, since no future retooling is likely to be as massive. Nevertheless, if automobile manufacturers are to be induced to make major new investments in fuel economy, financial incentives may be found to be necessary.

One obvious incentive would be to give extra tax credits to manufacturers for investments in facilities which are designed to produce especially energy efficient vehicles. Another approach would be to give incentive payments proportional to the annual percentage improvement of the average fuel economy of a manufacturer's products. It would be appropriate to fund these incentives from taxes on automotive fuel consumption or on inefficient cars.

Fuel economy information

In order for the invisible hand of the market to operate properly in encouraging fuel efficiency, new car buyers must have accurate information on the fuel economy of the vehicle that they are considering purchasing. The U.S. has had a federal fuel economy information program for a number of years. Despite the difficulty of producing accurate absolute numbers (because of the continual change in automotive designs, the limited number of preproduction vehicles tested and the artificial nature of the standardized test [23]), this information has provided a relatively good basis for comparison among vehicles.

IMPROVED AUTOMOTIVE FUEL ECONOMY AND THE TRANSITION TO THE POST-FOSSIL-FUEL ERA

It may not be too many decades before the world decides to phase out the use of fossil fuels because of problems associated with the buildup of carbon dioxide in the atmosphere. Will the level of personal mobility currently enjoyed in the industrialized democracies then become unsustainable? Probably not, if a transition has been made to highly energy-efficient vehicles, such as those discussed in this paper.

Consider, for example, the potential for supporting in Europe a fleet of vehicles with gasoline-equivalent energy requirements of 3.5 liters per 100 kilometers (a fuel economy of 68 mpg) and fueled with methanol derived from biomass. Only 1.5 Mg of dry wood would be required to produce enough methanol (at a conversion efficiency of about 60%) to propel such a vehicle 15,000 kilometers [24]. If the amount of wood currently being harvested annually for paper and lumber in Europe (excluding U.S.S.R.) were ultimately converted into methanol instead of being disposed of in some other way, it would be sufficient to fuel approximately one such energy efficient car for every five Europeans [25]. Other organic residues from agriculture and forestry could be made available for conversion into a comparable amount of methanol [26]. Alternatively, intensively cultivated wood energy "plantations" could supply the fuel needs of approximately 10 energy efficient passenger cars per hectare [27]. At this rate, an area of Europe equal to about 15% of that currently devoted to grain production could support 100 million passenger cars [28].

In the post-fossil-fuel era, there may be important competing uses for whatever liquid fuel is available. The above considerations make it plausible, however, that a considerable amount of personal mobility could still be feasible — *given very energy efficient automobiles.*

FOOTNOTES AND REFERENCES

1 U.S. Secretary of Defense Caspar W. Weinberger, testifying before the U.S. Senate Armed Services Committee, March 4, 1981, as reported in the New York Times of March 5, 1981, p. B 11.

2 Fig. 1 appeared originally and is documented in Frank von Hippel, 1983. Global risks of energy consumption. In: C.C. Travis and E.L. Etnier (Eds.), Health Risks of Energy Technologies, Westview Press, Boulder (CO), p. 209.

3 In 1978 the U.S., Canada, Western Europe, Japan, Australia and New Zealand consumed 2.0×10^9 Mg of oil and produced (including natural gas liquids for the U.S.) 0.7×10^9 Mg. British Petroleum, 1978. Statistical Review of the World Oil Industry.

4 Light Truck Fuel Consumption in the Industrialized Democracies. As Table 1 shows, passenger cars in the U.S., Canada, Western Europe, Japan and "Oceana" consumed in 1978 an estimated 0.440×10^9 Mg of oil. Light trucks in these nations consumed approximately an additional 120 million metric tonnes of oil. This latter estimate was obtained as follows:

U.S. The U.S. had in 1978 a population of 25 million *light* trucks [gross vehicle weight (including rated load) less than 8500 lb (3900 kg)], traveling on average about the same distance annually as U.S. passenger cars using about 1.35 times as much fuel per km [5].

Non-U.S. It is assumed that the average light truck fuel consumption per 100 km in other nations is 35% higher than that of the average passenger car as in the U.S. and that light trucks travel on average the same annual distance as assumed for passenger cars in Table 1 (16,500 km in the U.S. and Canada, 15,000 km elsewhere).

In Japan in 1978, 77% of the 3.4 million commercial vehicles produced were light trucks with less than 2 tons carrying capacity or light vans (classified as light trucks). In France, in the same year, 79% of all registered "utility vehicles" were of less than 1.7 tons carrying capacity [6]. Based on this sample of two of the nations with the largest light vehicle populations, it is assumed that 80% of all trucks and buses outside of the U.S. or 40 million vehicles in 1978 [6] were light trucks. Of these vehicles, about 2 million would be in Canada with annual mileage and fuel economies similar to the U.S. and 20 million would be in Western Europe and Japan.

Using all of the above assumptions (25 million U.S. plus 2 million Canadian light trucks with an average fuel consumption of 25 liters/100 km and driving an average of 16,500 km/y plus 20 million light trucks in Western Europe, Japan, Australia and New Zealand with an average fuel consumption of 13.5 liters/100 km and driving an average of 15,000 km per year), an estimate of total oil consumption by light trucks in the industrialized democracies in 1978 of 0.120×10^9 Mg is obtained (using a density of 860 kg/m^3 for crude oil).

Adding the 0.440×10^9 Mg of oil shown in Table 1 as being consumed by passenger cars, the estimated total oil consumption of all light vehicles in these industrialized nations comes to 0.560×10^9 Mg or 11.2 million barrels per day in 1978.

Based on the above information and Table 1, 3.8×10^{12} passenger car—km and 0.76×10^{12} light truck—km were driven in the industrialized democracies in 1978. The average light vehicle fuel consumption was, therefore, 14 liters/100 km (16 mpg) and the average passenger car fuel consumption was 13.5 liters/100 km (17 mpg).

5 U.S. DOE, 1981. The light duty vehicle model, Fourth Quarterly Report (July 2).

6 U.S. Motor Vehicle Manufacturers Association, 1980. World Motor Vehicle Data.

7 See e.g. C.F. Baes et al., 1976. The Global Carbon Dioxide Problem, Oak Ridge National Laboratory, ORNL-5194.

8 Figs. 4 and 5 have been adapted from Charles Berg and Frank von Hippel, 1981. Light Vehicle Fuel Economy. Scientific American (May), p. 48.

9 The EPA composite fuel economy of new American passenger cars improved from 20.6 to 25.2 mpg (11.5 to 9.4 liters/100 km) between model year 1979 and the first seven months of model year 1981. (Motor Vehicle Quarterly MPG and Market Share Newsletter, 1981. Ridge National Laboratory (June), 1981, p. 4).

10 Fig. 6 appeared originally and is documented in Frank von Hippel, 1981. U.S. Transportation Energy Demand, Princeton University, Center for Energy and Environmental Studies Report, PU/CEES #111.

11 U.S. Department of Transportation, 1980. National transportation statistics 1980, Table 43: Estimated cost of operating a subcompact size 1979 model automobile. One 1979 U.S. dollar is assumed to equal 1.21 1981 dollars.

12 In March 1981, regular gasoline prices in U.S. cents/liter were: France — 69, Italy — 81, U.K. — 73, and West Germany — 62. U.S. Central Intelligence Agency, 1981. International Energy Statistical Review (August 25), p. 20.

13 U.S. Department of Transportation, 1980. The U.S. Automobile Industry, p. 66.

14 Assumed are: six year (straight-line) depreciation, 100% equity financing with up to 10% annual rate of return on investment, a 50% combined federal and state corporate income tax rate, and a 10% investment tax credit.

15 Assuming an average new car on-road fuel economy of 18 mpg (13 liters/100 km) in the U.S. in 1980 and a price of gasoline of \$1.44/gallon (38 cents/liter).

16 The 30% reduction in power-to-weight ratio between the gasoline and a diesel engine powered VW Rabbit would by itself result in a 7% reduction in fuel consumption for a vehicle powered by a naturally aspirated diesel.

17 Fig. 9 is based on data in J.R. Stewart and J.C. Stutts, 1978. Categorical Analysis of the Relationship Between Vehicle Weight and Driver Injury in Automobile Accidents, National Technical Information Service, Springfield VA, Report DOT # HS-803 892.

18 British Fuel-Economy Target Called 'Toughest in the World', 1979. Automotive News (October 15), p. 48. This story states that the 1979 average new passenger car fuel economy in Britain was 8.8 liters per 100 km (26.8 mpg). It is not clear from the article, however, what test procedure was involved.

19 According to a private communication in December 1979 from Mr. Iwatake of the Japan Automobile Manufacturer's Association (Washington, D.C.), the Japanese government had that month promulgated the following improvement goals for passenger cars:

Weight category (kg)	Average fuel consumption (liters/100 km)	
	1979	Target (for 1985 ?)
<570.75	5.38	5.05
570.75—827.5	6.94	6.25
827.7—1265.5	9.01	8.00
>1265.5	13.16	11.76

Once again, it is not clear what fuel consumption test is assumed.

20 Jan P. Norbye, 1979. French cut deal on fuel economy, Automotive News, (Nov. 26), p. 10.

21 The prototypes developed in the German Car 2000 program were shown in the 1981 Frankfurt auto show. At about the same time, however, the German government announced that it was not planning to contribute further funding to the program. Richard Feast, 1981. Cars of tomorrow add spice to Frankfurt show, Automotive News, (Sept. 28), p. 1.

22 Fig. 10 is derived from numbers given in Commission of the European Communities, Special Group on the Influence of Taxation on Fuel Consumption, Interim Report, April 8, 1980, Tables 5 and 19b. Tax costs/km are (10% of purchase tax + annual vehicle tax)/(15,000 km). One Jan/Feb 1980 EUA has been assumed to equal 1.3 1981 US dollars. Also shown on Fig. 10 are estimated taxes on U.S. passenger cars in 1986 when the US "gas guzzler" tax comes into full force. These taxes have been added to a base (registration, sales and titling taxes) of 0.58 cents/km (1981 dollars) for cars with fuel consumption greater than 10 liters/100 km (based on numbers for a 1979 "standard size" model automobile [11], p. 103) and 0.38 cents/km for vehicles consuming less than 10 liters/100 km ([11], p. 105). The gas guzzler

taxes have been reduced by 36% to reflect the effect of five years of inflation at an assumed annual rate of 9% between 1981 and 1986. The relative contributions of purchase and registration taxes to the costs shown in Fig. 10 are quite variable but the purchase taxes tend to dominate. For the BMW 320, for example, this share in 1980 was: 64% in Belgium, 39% in W. Germany, 90% in Denmark, 75% in France, 72% in Great Britain, 72% in Italy and 63% in the Netherlands.

23 See e.g., U.S. Environmental Protection Agency, 1980. Passenger Car Fuel Economy: EPA and Road, EPA 460/380010; U.S. House of Representatives, Committee on Government Operations Report, 1980. Automobile Fuel Economy: EPA's Performance; and U.S. D.O.E., Office of Policy and Evaluation, 1981. Impact of Fuel Economy Shortfall: Trends in Technology Weighted EPA vs. On Road MPG.

24 One Mg of dry wood has an energy content of about 20×10^9 joules. A liter of gasoline has an energy content of about 35×10^6 joules.

25 In 1977, approximately 150 million Mg of roundwood (the density of dry wood is about 0.5), was harvested in Europe (not including the U.S.S.R.). The population of Europe in 1978 was 480 million. U.N., 1979. World Statistics in Brief.

26 In the U.S. in 1976, an estimated 0.42 dry Mg of logging residues were generated and approximately 0.24 dry Mg of trees were felled in stand thinning and improvement operations for every Mg of dry wood harvested. U.S. Congress Office of Technology Assessment, 1980. Energy From Biological Processes, Vol. II., p. 14. According to the same reference (p. 68) about 0.2 dry Mg of residues can be collected in the U.S. per Mg of grain harvested. (These residues contain about two thirds as much energy per Mg as wood.) In 1978 approximately 2×10^8 Mg of grain (wheat, barley, corn and oats) were harvested in Europe [25].

27 The current average annual productivity of U.S. commercial forests of about 2.7—5.5 (dry) Mg/ha, could be increased to 4.5—9.1 Mg/ha if the forest land were fully stocked, and could be increased to 6.4—13 Mg/ha with the application of fertilization, genetic selection and other factors. By applying short rotation forestry to fast growing species on "wood plantations", the annual yield could be increased still further to an estimated 10—20 Mg/ha. Thomas B. Johansson, 1981. Wood as an energy resource in the United States, Princeton University, Center for Energy and Environmental Studies, Report # 112 (April).

28 In 1978 the yields of wheat, barley, corn and oats in Europe were respectively 3.5, 3.6, 2.8, and 4.4 Mg/ha for a weighted average yield of 3.7 Mg/ha. U.S. Department of Agriculture, 1979. Agricultural Statistics. It therefore required 60 million hectares of land to raise the 224 million Mg of these grains produced in Europe that year.