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A SUMMARY OF OPPORTUNITIES TO CONSERVE TRANSPORTATION ENERGY

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JUNE 1975
FINAL REPORT

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This report surveys the near term opportunities for energy conservation ›assenger and freight transportation. The present (1972) transportation ›gy flows and modal efficiencies are characterized. A total of 35 possible ›servation measures are discussed and ranked for effectiveness. Their ›ntial fuel savings are projected for 1980 and 1990.

For the more important measures, discussions of costs, timing constraints side effects are included. Improving the efficiency of motor vehicles ›hown to be the single most important approach to transportation energy ›servation, but significant savings in other areas, such as load-factor ›ovement, are possible.

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PREFACE

As one element of an interagency study of energy conserva-
on opportunities, the Transportation Systems Center (TSC) has
rveyed energy use in transportation. The movement of people
d goods is an essential element in our complex society; and,
the 1973 petroleum shortage dramatized, this key element is
th uniquely dependent on, and the major consumer of, petroleum
els.

To aid in the evaluation of proposed research, Federal
licies, and legislation, this study tabulates the service
ovided and energy consumed by each mode of transportation
d examines the potential for increasing the efficiency of trans-
rtation-energy use.

The study was prepared under the sponsorship of the Office
Transportation Energy Policy. It summarizes a large number
earlier studies and presents more recent research results in
ll. In particular, this report is based on <u>Transportation
ergy – Conservation Options</u> (TSC Discussion Paper DP-SP-11,
tober 1973), prepared for the Office of the Assistant Secretary
Policy, Plans, and International Affairs (TPI), and the
fice of the Assistant Secretary for Systems Development and
chnology (TST).

In addition to the help provided by many people in the trans-
rtation industry, TSC wishes to acknowledge the assistance pro-
ded by the Office of Highway Statistics, FHWA.

The following members of the TSC professional staff made
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technical typing.

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EXECUTIVE SUMMARY

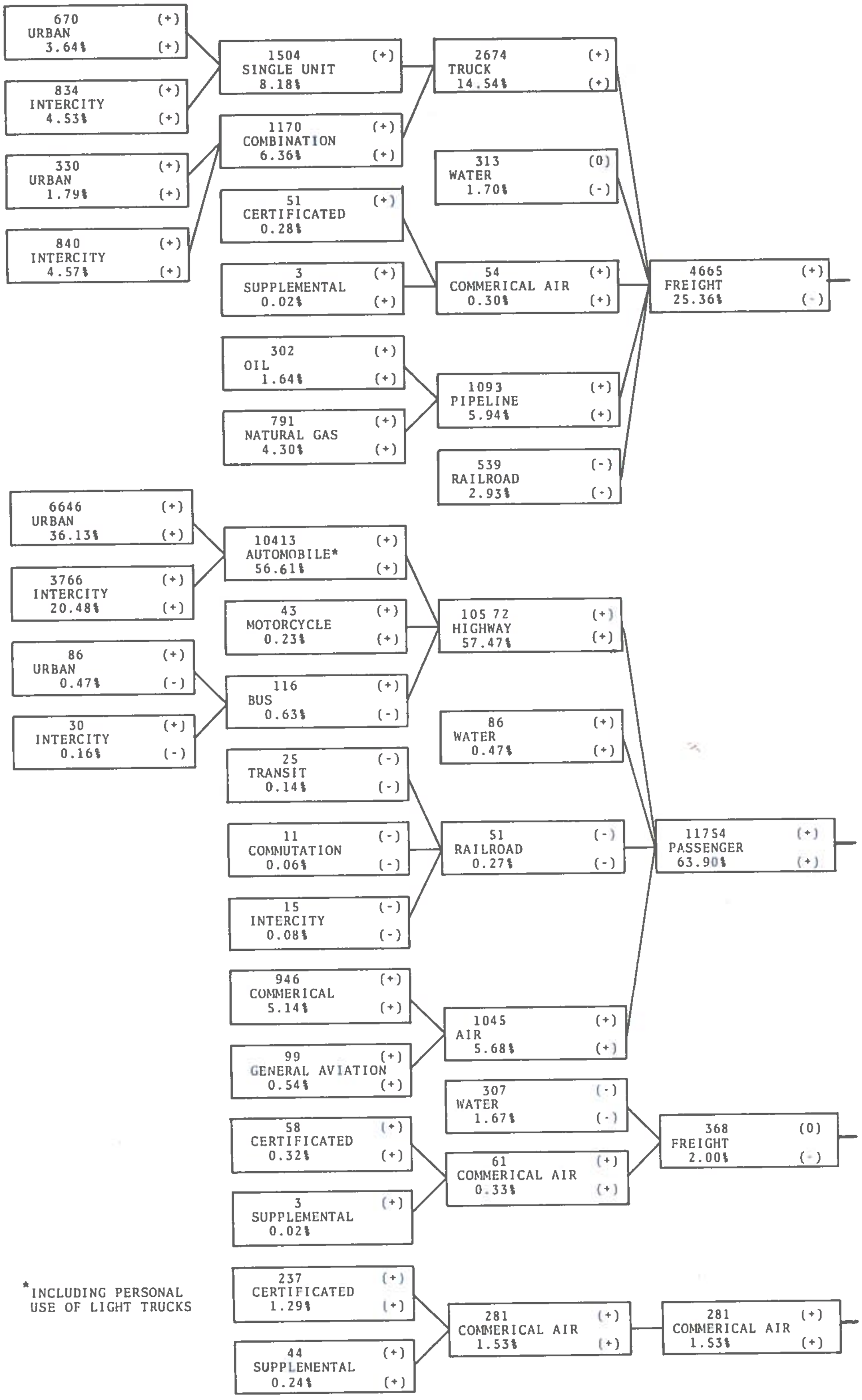
This report describes briefly all of the energy flows asso-
.ted with transportation, characterizes current average energy
'iciencies for the various modes, and projects potential energy
ings from various conservation efforts to the years 1980 and
0. The most important measures, costs, timing constraints,
side effects are discussed.

Figure S-1 summarizes total direct transportation energy
TE)* consumption in 1972. Figure S-2 shows that when indirect
s are included, transportation accounts for more than 40% of
al national energy consumption. Accordingly, a large share of
savings required in the total national conservation effort can
expected to come from this area. Indeed, in the <u>Project Independ-</u>
<u>e Report</u> [1], transportation energy is assumed to grow at less
n 1% per year in the "conservation case" (as compared with
ent historic growth rates of 4 to 5% per year).

There are five approaches to conservation of direct trans-
tation energy: (1) improvement of efficiency of future vehicles
ough design and technology changes; (2) increased load factors;
operational changes (reduced speed, improved maintenance, etc);
service reductions; and (5) diversion of passengers and goods
nore efficient modes. Of these, highway vehicle-efficiency
rovements will be the most important option in the 1980's for
following reasons:

(1) The savings potential of efficiency improvement is much larger than that of any of the other approaches because motor vehicles now consume the major share of transport energy and operate at efficiencies below state-of-the-art. The savings could exceed 30% of TDTE by 1990.

'E includes the energy used to propel vehicles, but not the
ergy required to build and maintain vehicles and guideways,
erate support services, and so on.



*INCLUDING PERSONAL USE OF LIGHT TRUCKS

Figure S-1. Breakdown Chart of the U.S. Transportation System and Its Energy Consumption in 1972

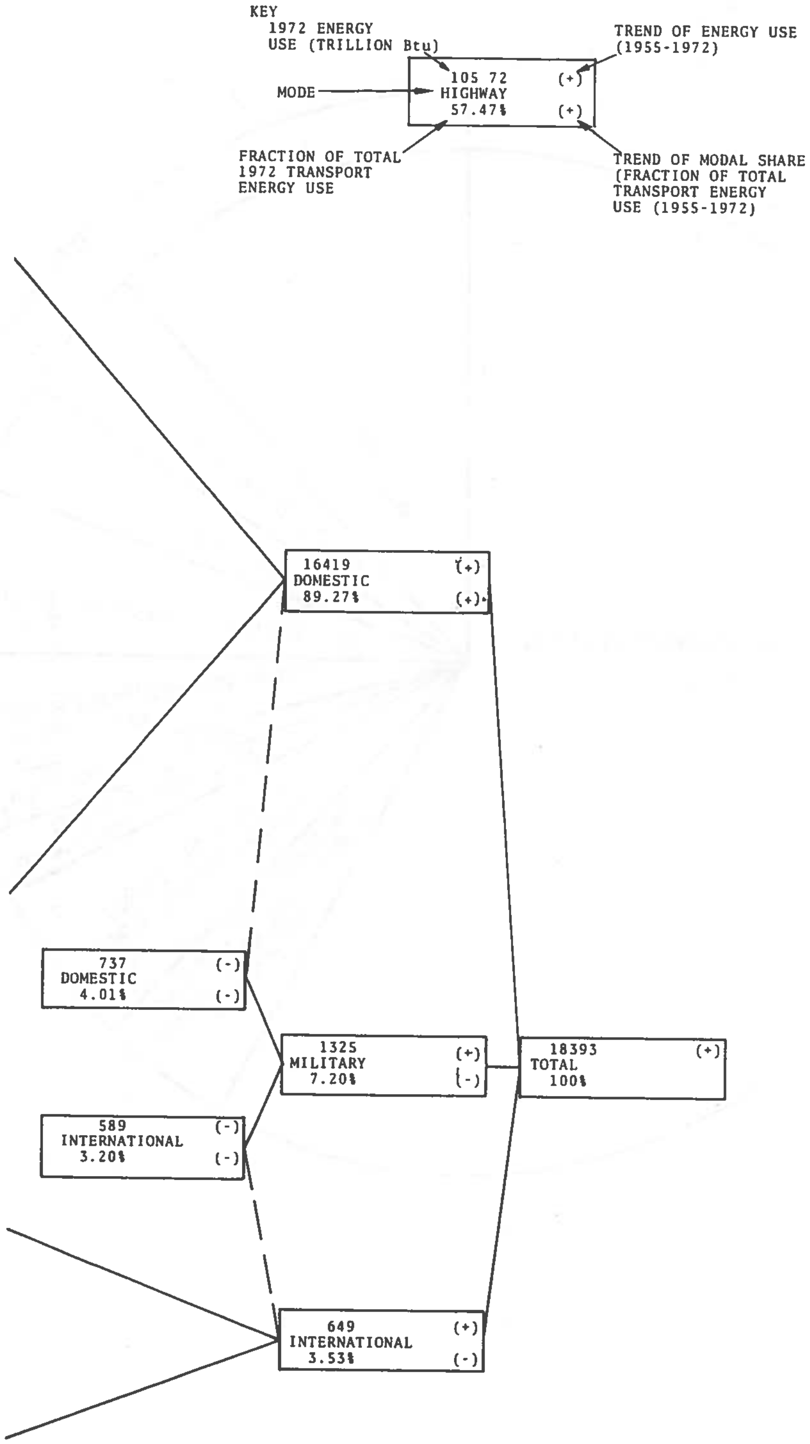


Figure S-1. (Continued)

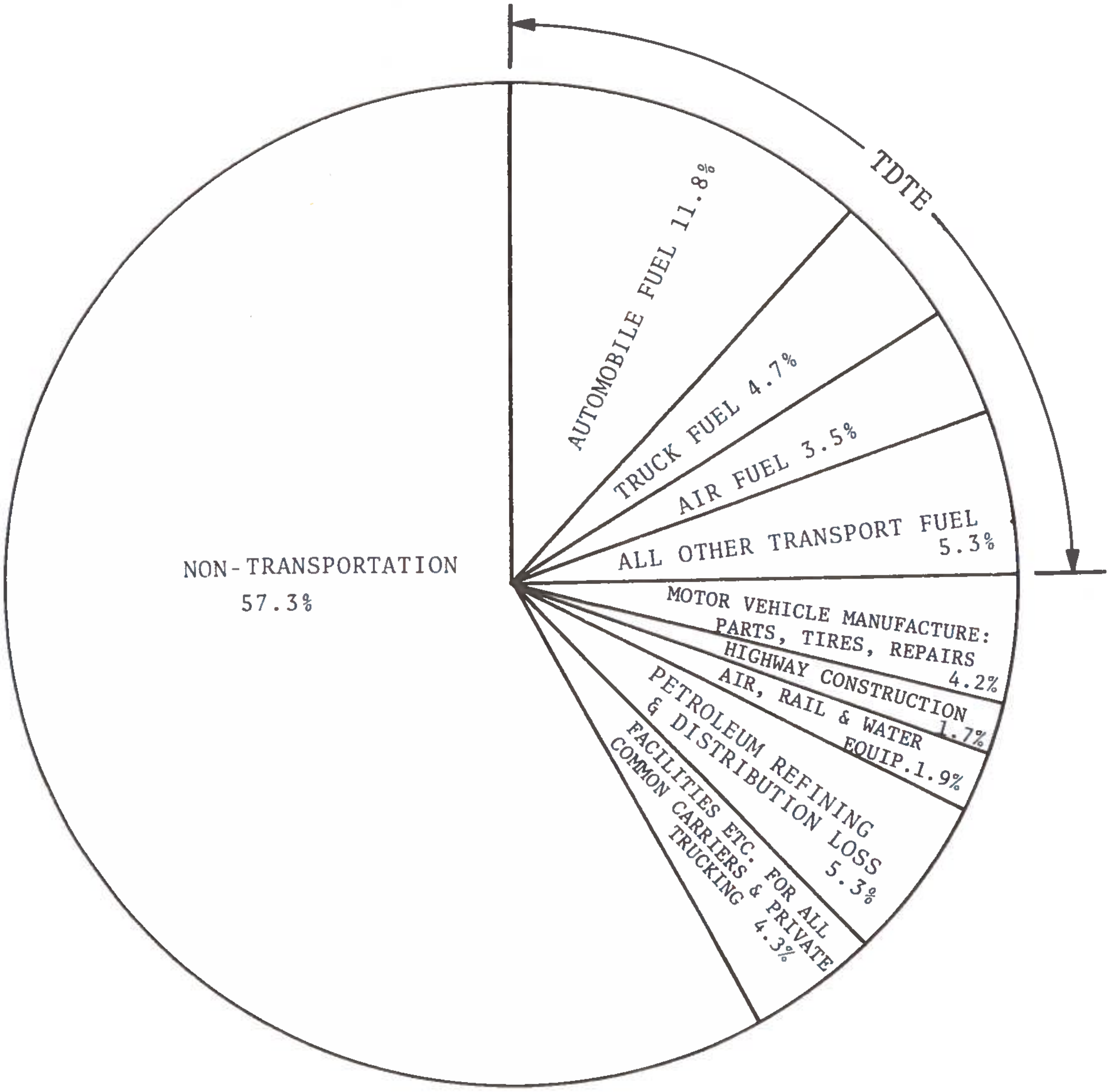


Figure S-2. Distribution of Total National Energy Consumption (Based on 1967 Input-Output Data). (Source: Table 5-1.)

(2) Because efficiency gains have relatively little impact on the quality of the transportation service provided, they do not require changes in the behavior of either consumers or institutions — except for the vehicle manufacturers, of course.

(3) Implementation of efficiency improvements will reduce total cost of transport and is thus favored by market forces.

; major disadvantage of this measure is the relatively long)lementation time -- on the order of twenty years -- required to ılize the full benefit. It should be noted, however, that :ause newer vehicles account for a disproportionately large share miles travelled, the prompt implementation of efficiency-)rovement programs could lower the growth rate in demand for motor ;ls to zero by 1980.

Load-factor improvements are the second most important class options, particularly for aircraft, commuter automobiles, and, ·haps, trucking. Each of these three might generate savings of)ut 2 or 3% of TDTE. Although load-factor improvements tend to .uce the direct costs of transportation, the additional travel ıe and/or inconveniences entailed might render them unattractive many potential users. Their most salient advantage is that y could be implemented very quickly with little or no capital t.

Operational improvements, such as lower speed limits or better ntenance, could conceivably generate savings of up to 5% of E. Since they are generally not perceived as cost-effective by rs, government intervention is necessary for their implementation. the case of the permanent 55 MPH speed limits the injuries and alities avoided represent more significant benefits that the fuel ings.

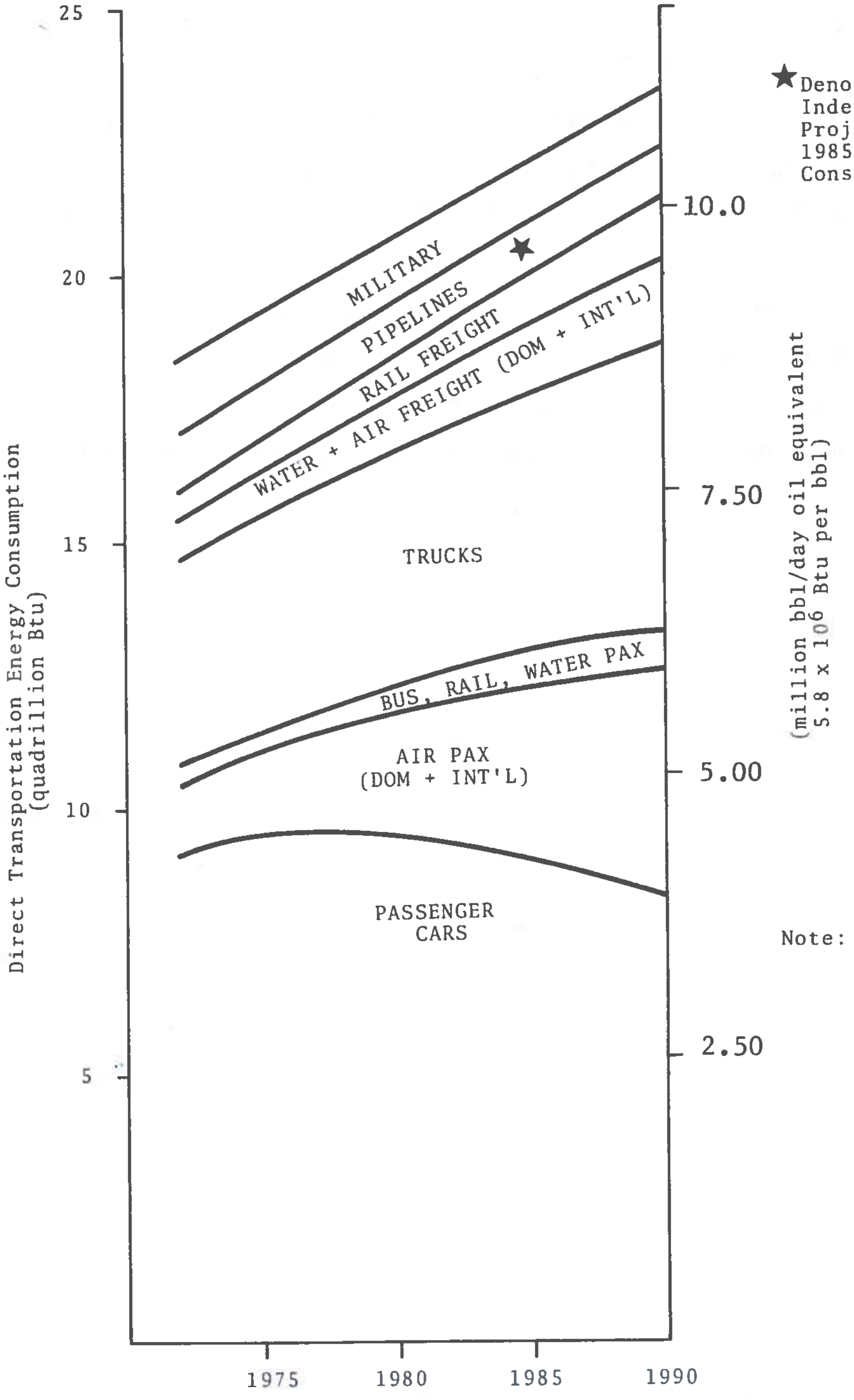
The expected declines in long-run growth rates for air and o travel also constitute a major element in the reduction in ex- ted energy consumption. These rate changes (from 4.8% to 2.6% cars, from 14% to less than 6.3% for air) are related to what appear to be long-term shifts in demographic variables, rates of GNP growth, and relative prices of fuels, which are not discussed in this report. If there were a return to the pre-embargo growth trends, TDTE would be much greater than projected here.

Shifts to more efficient modes offer substantial theoretical savings; however, they are not likely to be induced to a significant degree solely by foreseeable fuel price increases. Service improvements on the efficient modes, general economic forces, and regulatory changes could produce patronage increases sufficient t save up to 5% of TDTE. Such gains would require large increases in the physical plants of the efficient modes, and thus require implementation periods of about the same length as the vehicle efficiency measures. These large capital requirements also mean some mode-shift measures are not necessarily cost-effective in terms of fuel savings alone, although they may be easily justifiable when other benefits are included in the calculation.

Indirect energy consumption in transportation is about two-thirds as great as direct energy consumption. However, apprecia of this fact is relatively new, and opportunities for conservati in this area have not been extensively researched. Such opportu ties exist chiefly in petroleum refining, vehicle manufacture, a mode shifts (for example, indirect energy costs per passenger mi for rail service are lower than those of private autos). The en costs associated with refining fuels for use in transportation r sult in a multiplier effect (about 1.2) for all measures that co serve direct fuel. Extending the service lives of passenger car so that fewer need be produced each year, could reduce their man facturing energy cost by an amount equal to more than 1% of TDTE However, adverse impacts on initial costs and undesirable interactions with technology improvement measures may render this opt unattractive. Indirect energy savings associated with mode shif are not yet sufficiently well understood to permit quantitative estimates of their magnitude.

Military use of transport fuels in 1972 amounted to more th 7% of TDTE. International movement of goods and passengers consumed about 3.5% of TDTE. Significant potential for conservatio in these areas may exist, but the study does not attach any ntitative estimate to the savings, since so little is known about possible conflicts between energy conservation and competing ues such as military aircraft performance.

The study concludes that it is feasible to limit direct nsportation energy consumption to the levels projected for the 85 conservation case" in the Project Independence Report [1]. ure S-3 shows estimates of future fuel consumption by mode, ed on the modal-activity projections from the 1974 National nsportation Report [2], and assuming an ambitious program of icle efficiency improvements (including 25 mpg new cars by 1985). hough 1985 TDTE exceeds the Project Independence target by about (see Figure S-3), partial implementation of load factor, operanal, and mode-shift measures could easily offset this 10%. le S-1 summarizes the potential savings and other impacts of h of the conservation options considered in this report.



★Denotes Project Independence Projection for 1985 TDTE in Conservation Case.

Note: In preparing this figure, only the improvements in mechanical efficiency described in this report were assumed, not the load factor, operational or mode shift measures.

Figure S-3. Projection to 1990 of Direct Transportation Energ Consumption by Mode

TABLE S-1. SUMMARY OF OPPORTUNITIES TO CONSERVE TRANSPORTATION ENERGY

OPTION	FUEL SAVINGS AS % OF TOTAL DIRECT TRANSPORT FUEL[1]		FUEL SAVINGS IN THOUSANDS OF BBL. PER DAY[2]		FUEL SAVINGS PER UNIT OF SERVICE (PM, TM OR VM)		INCREMENTAL COSTS (+) OR SAVINGS (-)				YEARS TO OBTAIN MAXIMUM BENEFITS	TRAVEL TIME (% Change)	EMISSIONS IMPLICATIONS	SAFETY IMPLICATIONS	LIKELIHOOD OF ACHIEVEMENT
							CAPITAL INVESTMENT		TOTAL USER COST						
	1980	1990	1980	1990	% at full implementation	Btu	Billion $	% Change	Cents/ Unit of Service	% Change					
PASSENGER CARS															
VEHICLE EFFICIENCY															
Future Cars															
Modest-off-the shelf improvements (scenario A)[3]	8.2	15.0	848	1689	21	1968/vm	+ 0.05	+ 0.2	- 0.9	- 6	15	none	neutral	neutral	high
Advanced technology (scenario B)	8.7	24.4	894	2740	34	3168/vm	+ 3.7	+ 12	- 1.5	- 11	25	none	neutral	neutral	medium to high
Maximum "off-the-shelf" (scenario C)	10.9	21.7	1121	2440	31	2829/vm	+ 0.9	+ 3	- 1.0	- 7	15	none	neutral	neutral	high
Advanced technology & shift to small cars (scenario D)	13.1	32	1350	3601	46	4227/vm	+ 5.0	+ 17	- 3.0	- 21	25	none	neutral	negative	medium to high
Existing Fleet															
Radial tires (pre-1975 cars only)	0.5	0	47	0	3	270/vm	+ 0.6	+ 20	- 0.1	- 0.7	5	none	neutral	neutral	high
Other retrofits	0.5	0	47	0	3	270/vm	N/A[4]	N/A	0	0	5	none	neutral	neutral	low

TABLE S-1. CONTINUED

OPTION	FUEL SAVINGS AS % OF TOTAL DIRECT TRANSPORT FUEL		FUEL SAVINGS IN THOUSANDS OF BBL PER DAY		FUEL SAVINGS PER UNIT OF SERVICE (PM, TM OR VM)		INCREMENTAL COSTS (+) OR SAVINGS (-)				YEARS TO OBTAIN MAXIMUM BENEFITS	TRAVEL TIME (% Change)	EMISSIONS IMPLICATIONS	SAFETY IMPLICATIONS	LIKELIHOOD OF ACHIEVEMENT
							CAPITAL INVESTMENT		TOTAL USER COST						
	1980	1990	1980	1990	% at full implementation	Btu	Billion $	% Change	Cents/ Unit of Service	% Change					
PASSENGER CARS (cont'd)															
LOAD FACTOR															
Carpools (work trips only) at 47% participation	1.9	1.5	200	174	14	780/pm	negative	N/A	(2 to 4)	-(15 to 35)	1	+10 to 40	-14%^{11}	neutral	medium
Carpools (work trips only) at 70% participation	4.9	3.8	500	436	29	1617/pm	negative	N/A	(2 to 4)	-(15 to 35)	1	+10 to 40	-30%^{11}	neutral	low
OPERATION															
Speed limits 55 mph	1.2	0.9	121	105	8	588/vm	negligible	N/A	-0.5/vm	-3	1	+ 18	minor benefit	significant benefit	high
Better maintenance	0.7	0.6	75	65	1.5	140/vm	~1	N/A	+0.2/vm	+1.4	5	none	significant benefit	none	low
Driving habits	2.4	1.9	250	215	5	463/vm	negligible^2	N/A	-0.4/vm	-2.3	5	negligible	minor benefits	minor benefits	medium
Urban traffic flow	0.4	0.7	98	84	3	318/vm	>1	N/A	-0.2/vm	-1	10	minor benefits	minor benefits	minor benefits	high

TABLE S-1. CONTINUED

OPTION	FUEL SAVINGS AS % TOTAL DIRECT TRANSPORT FUEL		FUEL SAVINGS IN THOUSANDS OF BBL PER DAY		FUEL SAVINGS PER UNIT OF SERVICE (PM, TM OR VM)		INCREMENTAL COSTS (+) OR SAVINGS (−)				YEARS TO OBTAIN MAXIMUM BENEFITS	TRAVEL TIME (% Change)	EMIS-SIONS IMPLI-CATIONS	SAFETY IMPLI-CATIONS	LIKELI-HOOD OF ACHIEVE-MENT
							CAPITAL INVESTMENT		TOTAL USER COST						
	1980	1990	1980	1990	% at full imple-mentation	Btu	Billion $	% Change	Cents/ Unit of Service	% Change					
PASSENGER CARS (cont'd)															
SERVICE REDUCTION															
Short-run (emergency)					*As dictated by circumstance*										
Long-run savings from 2.6% annual growth in VMT vs. 4.8% historic rate	7.9	18.9	819	2130	N/A	N/A	N/A	N/A	N/A	N/A	>20	N/A	major benefit	major benefit	high
BUSES															
VEHICLE EFFICIENCY	.07	.13	7	15	20	121/pm	negligi-ble	N/A	negli-gible	N/A	10	none	none	none	high
AIR PASSENGER															
LOAD FACTOR IMPROVEMENT[5]	2.3	3.7	231	415	28	2174/pm	negative	N/A	0	0	4	0	Propor-tional to fuel savings	none	high
OPERATIONAL IMPROVEMENTS															
Cruise speed reduction	0.2	0.4	25	44	3	233/pm	0	0	0	0	0	2	"	"	high

TABLE S-1. CONTINUED

OPTION	FUEL SAVINGS AS % TOTAL DIRECT TRANSPORT FUEL		FUEL SAVINGS IN THOUSANDS OF BBL PER DAY		FUEL SAVINGS PER UNIT OF SERVICE (PM, TM OR VM)		INCREMENTAL COSTS (+) OR SAVINGS (-)				YEARS TO OBTAIN MAXIMUM BENEFITS	TRAVEL TIME (% Change)	EMIS-SIONS IMPLI-CATIONS	SAFETY IMPLI-CATIONS	LIKELY-HOOD OF ACHIEVE-MENT
							CAPITAL INVESTMENT		TOTAL USER COST						
	1980	1990	1980	1990	% at full imple-mentation	Btu	Billion $	% Change	Cents/ Unit of Service	% Change					
AIR PASSENGER (cont'd)															
Altitude Increase[6]	0.1	0.2	11	19	1.3	101/pm	0	0	0	0	2	0	Propor-tional to fuel savings	none	medium
Ground Engine Use Reduction	0.1	0.1	7	12	0.8	62/pm	0	N/A	0	0	0	0	"	"	high
Ground Towing	0.2	0.4	22	40	2.7	210/pm	N/A[7]	N/A	0	0	N/A[8]	0	"	"	medium
RAIL PASSENGER	0	0.2	0	30	57	2000	N/A	N/A	N/A	N/A	15	none	minor benefit	none	high
WATER PASSENGER															
VEHICLE EFFICIENCY	0.1	0.1	9	11	N/A	N/A	N/A	N/A	N/A	N/A	15	none	none	none	high
SERVICE REDUCTION.	0.2	0.2	11	23	N/A	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	low
DOMESTIC FREIGHT TRUCK															
VEHICLE EFFICIENCY	3.3	8.7	306	888	23[9]	N/A	1	10%	nega-tive	N/A	15	none	neutral	neutral	High
LOAD FACTOR	1.8	2.1	178	221	N/A	N/A	negative	N/A	nega-tive	N/A	5	N/A	minor benefit	minor benefit	Medium
SPEED LIMITS	0.5	0.6	46	66	2.3	N/A	N/A	N/A	+0.4/tm	+4%	1	+9	minor benefit	signifi-cant benefit	High

TABLE S-1. CONTINUED

OPTION	FUEL SAVINGS AS % TOTAL DIRECT TRANSPORT FUEL		FUEL SAVINGS IN THOUSANDS OF BBL PER DAY		FUEL SAVINGS PER UNIT OF SERVICE (PM, TM OR VM)		INCREMENTAL COSTS (+) OR SAVINGS (-)				YEARS TO OBTAIN MAXIMUM BENEFITS	TRAVEL TIME (% Change)	EMIS- SIONS IMPLI- CATIONS	SAFETY IMPLI- CATIONS	LIKELI- HOOD OF ACHIEVE- MENT
							CAPITAL INVESTMENT		TOTAL USER COST						
	1980	1990	1980	1990	% at full imple- mentation	Btu	Billion $	% Change	Cents/ Unit of Service	% Change					
AIR															
INCREASED USE OF P/C LOWER HOLDS	0.1	0.2	9	26	89	23,900/ tm	none	N/A	nega- tive	N/A	N/A	N/A	minor benefit	neutral	High
RAIL															
ELECTRIFICATION	none	0.6[10]	9	150[10]	none	none	up to 15	20	N/A	N/A	20[8]	none	N/A	neutral	Medium
WATER															
OPERATIONAL	0.3	0.3	25	29	15	76/tm	negative	N/A	N/A	N/A	5	N/A	negligi- ble	N/A	High
PIPELINE					*No significant Opportunities for Conservation*										
MODE SHIFTS															
URBAN AUTO TO:															
Urban Bus	0.7	0.8	74	86	43	1358/pm	6	600	N/A	N/A	15	+200	minor benefit	minor benefit	Low
Urban Rail					*limited to a few large cities*										
Bicycle	0.5	0.7	50	80	100	3820/pm	0	0	-6.7	- 100	10	-50 to +50	minor	unknown[14]	Medium
INTERCITY AUTO TO:															
Intercity Bus	0.2	0.2	17	20	29	489/pm	6.8	500	+1.4	+ 56	15	+10 to 50	"	minor benefit	Low
Intercity Rail	—	0.01%	—	1.4 *No significant Opportunities for Conservation*[12]	40	659/pm	N/A	N/A	N/A	N/A	15	none	minor	minor	Medium

TABLE S-1. CONTINUED

OPTION	FUEL SAVINGS AS % TOTAL DIRECT TRANSPORT FUEL		FUEL SAVINGS IN THOUSANDS OF BBL PER DAY		FUEL SAVINGS PER UNIT OF SERVICE (PM, TM OR VM)(1990)		INCREMENTAL COSTS (+) OR SAVINGS (-)				YEARS TO OBTAIN MAXIMUM BENEFITS	TRAVEL TIME (% Change)	EMIS-SIONS IMPLI-CATIONS	SAFETY IMPLI-CATIONS	LIKELI-HOOD OF ACHIEVE-MENT
							CAPITAL INVESTMENT		TOTAL USER COST						
	1980	1990	1980	1990	% at full imple-mentation	Btu	Billion $	% Change	Cents/ Unit of Service	% Change					
MODE SHIFTS (cont'd)															
SHORT-HAUL AIR TO:															
Intercity auto	0.2	0.4	19	40	77	6107/pm	0	0	- 15.5	- 86	5	+0 to 50	minor benefit	minor benefit	HIGH
Intercity Bus	0.2	0.4	24	43	85	6596/pm	0.8	60	- 14.1	- 78	15	+0 to 60	neutral	minor benefit	MEDIUM
Intercity Rail[12]	0.2	0.3	16	28	55	4266/pm	N/A	N/A	- 13.2	- 73	?	+0 to 40	N/A	minor benefit	MEDIUM
AIR FREIGHT TO:															
Intercity Truck				*No significant Opportunities for Conservation*[13]											
TRUCK FREIGHT TO:															
Rail	0.4	1.4	34	141	65%	1244/tm	N/A	N/A	- 2	- 30	15	+25 to 100	minor benefit	minor benefit	HIGH
INDIRECT CONSUMPTION															
REFINING LOSS					*Multiply direct savings by 1.2*										
VEHICLE LIFE EXTENSION	0	1[15]	0	100	N/A	N/A	unknown		N/A	N/A	N/A	none	none	none	Med
MODE SHIFTS					*Not quantified, but probably significant*										

TABLE S-1. CONTINUED

NOTES; N/A = not available (or not applicable)

1. Total direct transportation energy projections were based on the growth rate projected for the "$11/bbl conservation case" of the Project Independence Report, which anticipates implementation of some of the measures described in this report (see page 1-6 for numerical values).
2. Transportation fuel consumption in bbl/day is projected at 8.9 million bbl/day in 1980 and 9.4 million bbl/day in 1990 consistent with the above and assuming 5.8 million Btu/bbl with 95% of TDTE from liquid fuels in 1980 and 92% in 1990.
3. See page 2-5 for scenario definitions.
4. However, retrofitting entire fleet with fuel-economy meters alone would cost several billion dollars.
5. Assuming change is from 50% load factor to 70% load factor.
6. Will require changes to air traffic control procedures and equipment.
7. Preliminary FAA study indicates that the value of the fuel savings would defray capital and operating costs of tow vehicles.
8. Tow vehicles are not now available.
9. Average for all classes.
10. Rail electrification does not necessarily save energy, but does substitute coal or nuclear power for oil. Percentage savings are greater for bbl/day than for TDTE.
11. Applies to pollutants emitted by commuter cars only.
12. Based on 1972 modal averages. Rail service in high density corridors may be more efficient by 1990. See Section 4.4.
13. Based on marginal fuel consumption for lower-hold cargo in passenger aircraft.
14. Depends on degree of separation between bicycle and motor traffic.
15. Although savings might eventually amount to 3% of TDTE, in 1990, 1% is the maximum conceivable savings.

1. INTRODUCTION

While several new energy-supply technologies are emerging, the world, and particularly the United States, appears to be facing a future of dwindling petroleum supplies. Although it is physically possible to accommodate present levels of fuel consumption for some time to come, or even modest growth, recent political decisions by producer countries have cast uncertainty over the supply situation. Regardless of how the current Middle East tensions are resolved, any extrapolation of the 6 and 7% annual energy-consumption growth rates of the late 1960's and early 1970's is likely to lead to situations in the 1980's that are untenable in terms of balance of payments, devaluations, political instabilities, adverse ecological impacts, and possibly even sheer logistics. It appears that society must either leave the processes* of fuel consumption unchanged and scale down its demands for goods and services, or modify the processes so as to derive more goods and services from less petroleum.

If a national policy of energy conservation is adopted, transportation is likely to be one of the major concerns, since it accounts for 53% of total petroleum consumption in the U.S. [48], and more than 40% of total energy consumption when indirect use is included [3].

1.1 OBJECTIVES

This report describes some of the measures by which fuel-consumption growth can be curtailed through increasing the efficiency of energy utilization in transportation. Its objectives are as follows:

- to identify and describe those areas of transportation in which energy consumption can be decreased and to examine the conservation measures involved, including the costs

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* "Processes" refers to social and behavioral, as well as physical, phenomena.

and side effects.

- -- to project expected energy savings for conservation measures and rank them in terms of a common measure; to examine the reasons for lower potential of some measures.
- -- to survey the distribution of transportation energy consumption among modes in 1972, the last year undistorted by the oil embargo and base year for Project Independence forecasts.

The options described in this report are limited to those which could be implemented to a substantial degree by 1990. Excluded from consideration here are certain applications of advanced technology - e.g., personal rapid transit, substitution of advanced communications for personal travel, and non-petroleum-powered system other than rail - which might become significant during the 1990's.

1.2 METHODOLOGY

The initial phase of this investigation involved the collection of data regarding the 1972 energy-consumption and service characteristics of each mode of transportation. Most of these were readily available from government or trade-association publications. For analysis, however, it was sometimes necessary to disaggregate the published data.* Most of these disaggregations were based on unpublished data obtained from the Federal Highway Administration's Office of Highway Statistics and from various trade associations. In some instances, they were estimated on the basis of engineering handbook formulae. From these data figures on energy consumption per unit of service were calculated.

Next, opportunities to reduce energy consumption per unit of service were explored. As many as five classes of energy-conservation measures were considered for each mode:

---

*For example, an increase in truck size and weight limits would save fuel only for that portion of the trucking industry which employs large, five-axle vehicles.

- -- Vehicle Efficiency ... physical improvements in vehicular hardware resulting in less energy consumption per mile of vehicle travel.
- -- Load Factor ... increased passenger-miles or ton-miles per vehicle-mile.
- -- Operation ... changes in speed limits, maintenance practices, etc., intended to result in operation of existing vehicles closer to the maximum efficiency of which they are capable.
- -- Service Reductions ... elimination of some fraction of use of the service in question, either by governmental restriction (e.g., gasoline rationing) or because of long-run changes in the need for service (e.g., a trend toward higher residential densities).
- -- Mode Shift ... diversion of goods or passengers from less energy-efficient modes to more efficient modes.

Based for the most part on other research by the Department of Transportation and other public and private agencies, estimates were formulated of the most likely degree of reduction in energy consumption per unit of service for each possible option. These estimates of savings per unit of service were then multiplied by projections of total demand for service in 1980 and 1990 shown in Table 1-1. For those measures that required hardware changes, a time-phasing factor was also included.* Substantial improvements in vehicular efficiency were assumed in projecting the savings from other measures (e.g., carpooling, mode shifts) involving motor vehicles. To reduce these projections of total savings in 1980 and 1990 to a more readily comprehensible metric, they were divided by projections of total transportation direct energy

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*Time phasing is implicit in the TSC Vehicle Fleet Consumption model used in the calculations for trucks and passenger cars.

TABLE 1-1. TRENDS AND PROJECTIONS OF TRANSPORTATION INDUSTRY ACTIVITY, 1947-90 (From 1972 Base)*

Transportaiton component	Unit of measure	1947	1958	1965	1970	1972	1980	1985	1990
CNP	Billions of 1958 constant dollars	310	447	614	723	791	1,000	1,300	1,550
	Billions of 1971 constant dollars	439	613	870	1,020	1,120	1,540	1,840	2,200
Population[1]	Thousands	145,000	175,000	194,000	205,000	209,000	224,000	236,000	247,000
Aviation									
Domestic passenger	Billion passenger-miles	7.6	27.9	57.9	110	123	207	280	372
International passenger	Billion passenger-miles	1.4	4.6	12.6	27.6	34.3	67.0	97.5	138
Domestic freight	Million ton-miles	116	702	2,010	3,410	3,690	8,500	14,300	24,000
International freight	Million ton-miles	NA	NA	NA	NA	NA	NA	NA	NA
Miscellaneous	Million ton-miles	NA	NA	NA	NA	NA	NA	NA	NA
General aviation:[2]									
Business aircraft	Million hours flown	1.97	5.70	5.52	7.08	7.63	11.0	13.8	17.3
Personal aircraft	Million hours flown	2.62	2.37	4.02	6.81	8.40	9.8	11.7	14.2
Government civilian aircraft	Million hours flown	NA	NA	.62	.89	1.06	1.4	1.9	2.4
Other aircraft	Million hours flown	11.21	3.58	4.63	8.97	9.62	12.0	14.1	16.6
Railroads:									
Passenger[3]	Billion passenger-miles	46.8	23.6	17.6	10.9	8.6	9.6	11.1	12.8
Freight	Million ton-miles	665,000	559,000	709,000	773,000	784,000	919,000	1,030,000	1,160,000
Other	Million ton-miles	NA	NA	NA	NA	NA	NA	NA	NA
Auto travel	Million VMT's[4]	303,000	555,000	732,000	973,000	1,080,000	1,350,000	1,510,000	1,680,000
Truck:									
For hire:									
Intercity	Million ton-miles	45,100	96,300	154,000	220,000	258,000	374,000	444,000	527,000
Local	Million ton-miles	4,500	5,490	7,890	9,740	11,400	15,000	17,400	20,500
Miscellaneous	Million ton-miles	NA	NA	NA	NA	NA	NA	NA	NA

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[1] Includes armed forces abroad and excludes Puerto Rico.
[2] Excludes air taxi service.
[3] Includes all class I and class II rail travel
[4] VMT indicates vehicle-miles travelled.

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*Source: Reference 2.

TABLE 1-1 (CONTINUED). TRENDS AND PROJECTIONS OF TRANSPORTATION INDUSTRY ACTIVITY, 1947-90 (From 1972 Base)*

Transportation component	Unit of measure	1947	1958	1965	1970	1972	1980	1985	1990
Truck									
Private:									
Intercity	Million ton-miles	19,600	81,000	111,000	130,000	134,000	172,000	205,000	244,000
	Million VMT's[4]	NA	NA	15,800	18,300	18,200	22,300	26,200	30,900
Local freight	Million ton-miles	22,600	36,400	63,800	59,700	58,100	96,800	96,800	114,000
	Million VMT's[4]	NA	NA	18,900	17,600	17,100	24,000	28,500	33,600
Nonfreight, private	Million VMT's[4]	NA	NA	78,300	86,200	100,000	144,000	171,000	205,000
Government trucking	Million VMT's[4]	2,930	4,930	8,580	10,800	11,800	17,300	20,800	25,200
Buses:									
Intercity[5]	Billion passenger-miles	24.8	20.8	23.8	25.3	25.6	30.4	33.9	38.0
Miscellaneous and freight		NA	NA	NA	NA	NA	NA	NA	NA
School	Million VMT's[4]	604	1,190	1,700	1,630	2,520	2,330	2,470	2,610
Other	Million VMT's[4]	87	207	246	471				
Urban transit:									
Transit	Million passengers	18,300	7,780	6,800	5,930	5,270	7,740	9,810	11,900
Taxicabs	Million passengers	NA	NA	NA	NA	NA	NA	NA	NA
Domestic water:									
Passenger	Million passenger-miles	NA	NA	NA	NA	NA	NA	NA	NA
Freight[6]	Million ton-miles	385,000	452,000	504,000	622,000	631,000	703,000	802,000	917,000
Miscellaneous		NA	NA	NA	NA	NA	NA	NA	NA
Commercial fishing		NA	NA	NA	NA	NA	NA	NA	NA
Private inboard		NA	NA	NA	NA	NA	NA	NA	NA
Private outboard		NA	NA	NA	NA	NA	NA	NA	NA
Overseas water:									
Passenger	Thousand passengers	650	1,220	1,650	1,730	1,750	1,550	1,300	1,060
Freight and miscellaneous		NA	NA	NA	NA	NA	NA	NA	NA
Pipeline:[7]									
Intercity	Million ton-miles	117,000	235,000	339,000	478,000	529,000	730,000	856,000	1,000,000
Miscellaneous		NA	NA	NA	NA	NA	NA	NA	NA
Transportation services NEC		NA	NA	NA	NA	NA	NA	NA	NA

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[4] VMT indicates vehicle-miles traveled.

[5] Includes all class I, class II, and class III intercity bus travel.

[6] Includes an adjustment for ciruitous water routings for coastwise traffic and excludes intraterratory traffic.

[7] Includes an adjustment for petroleum movements between storage tanks and ports of export.

Note: - NA indicates not available.

Sources: Historical data based on various Federal Government reports and other estimates, adjusted for consistency; projections based on DOT input/output model.

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* Source: Reference 2.

consumption* (TDTE) for those years so that they could be expressed as a percentage of TDTE.

Finally, where appropriate, estimates of costs and secondary effects on safety and environmental quality were prepared. These generally drew upon published reports for the important vehicle-efficiency options, but were calculated by the authors for the remaining tactics.

1.3 CAVEATS

In interpreting the findings presented in this report, the reader should be aware of two major caveats.

First, to facilitate the efforts of others who may wish to replicate the calculations performed in connection with this study, data regarding modal activity and energy consumption, and energy consumption per unit of service, are expressed in numbers of three or more significant digits. The reader should not infer, however, that the data are accurate to three significant figures. At best, some of the data are probably accurate to ± 1%. Maximum accuracy is associated with parameters that are directly linked to financial transactions carried out by small numbers of corporate entities subject to reporting requirements of regulatory agencies, such as fuel purchases by common carriers or revenue passenger-miles carried by air, rail, etc. Total gasoline sales, which are linked to tax receipts, are also well known, but their allocation

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*The growth rate used in these calculations was derived from the projections shown in the Project Independence Report (Reference 1), assuming the Conservation Case and $11-per-barrel oil. The Conservation Case is based upon an achieved 20 mpg efficiency standard for new cars by 1980, plus substantial disincentives for auto use and incentives for increased transit. It results in a growth rate for TDTE of about 0.89% per annum. The projected values are as follows: 19,738 trillion Btu in 1980, 20,628 trillion Btu in 1985, and 21,559 tillion Btu in 1990. These values are slightly greater than those used by the FEA becau of a higher estimate of TDTE in the 1972 base year (18.4 vs 18.1 quadrillion Btu).

among autos, trucks, and non-highway uses introduces some error. Estimates of vehicle miles traveled may contain errors on the order of 5%. Variations in auto occupancy reported in different studies are not well explained; the values cited in this report could conceivably be in error by 10% or more. Transit systems report only the number of passengers carried, not passenger-miles. Estimates of the length of the average transit trip vary widely; hence, the figures reported here may be off by 20% or more. No data at all on oil-pipeline energy consumption have been compiled. The procedures used by the authors, based on engineering handbook formulas and guesses about parameters such as average viscosity and temperature, could easily lead to errors of 50%.

The second caveat is that energy consumption per unit of service varies widely from the modal averages reported here. For example, automobile fuel economy ranges from about 7 mpg for the heaviest cars to more than 28 mpg for the most efficient, while occupancy varies from one to six or more. Energy consumption per passenger-mile can range from more than 20,000 Btu for a large car on a short urban trip with one occupant, to less than 1,000 Btu for a compact carrying six persons on the highway. Similarly, rail passenger service requires more than 10,000 Btu per passenger-mile for certain long-haul luxury trains replete with lounges, dining cars, roomettes, and so on, but less than 2,000 Btu per passenger-mile for bi-level commuter trains. Pumping energy per ton-mile for oil pipelines can vary as much as a hundredfold depending on diameter, flow rate, temperature, viscosity, and terrain.

Despite these wide variations from the average, it is still possible to compute realistic estimates of fuel savings for measures that would have about the same percentage effect on all vehicles, such as the substitution of a more efficient engine, an increase in average load factors, or a reduction in speed limit. However, when mode shifts are considered, one must pay careful attention to just which segments of affected modes might be involved. For example, while average energy consumption per passenger-mile of intercity rail service is less than half that of air service, there is no savings at all in diverting long-distance air passengers to rail if long-distance trains are much more energy-intensive than the average train. Conversely, the potential saving for diversion of air travelers to auto travel is greater than what might be calculated on the basis of overall automobile averages. Moreover, the implementation of the mode shift might require or result in changes in load factors that could enhance or detract fro the energy savings. To attract automobile commuters to transit, for example, it might be necessary to reduce peak-hour load factors. On the other hand, incentives of off-peak transit usage could boost average load factors, cutting average energy consumption per passenger-mile.

2. DOMESTIC PASSENGER TRANSPORTATION

2.1 AUTOMOBILE

2.1.1 Service and Energy-Consumption Data

Automobile service and energy-consumption data for 1972 are given in Table 2-1.

TABLE 2-1. AUTOMOBILE SERVICE AND ENERGY CONSUMPTION, 1972*

	URBAN	INTERCITY	TOTAL
Direct fuel consumed			
thousand bbl/day	3,079	1,680	4,757
million gal/year	47,303	25,818	73,121
trillion Btu/year[1]	5,913	3,227	9,140
percentage of TDTE	32.2	17.5	49.7
Service rendered			
million vehicle-miles/year	557,875	428,532	986,407
million passenger-miles/year	1,059,962[2]	1,111,843[3]	2,171,805
Average efficiency			
Btu/passenger-mile	5,578	2,902	4,208

[1] Conversion factor: 125,000 Btu/gal.

[2] Assumed occupancy, 1.9 passengers.

[3] Assumed occupancy, 2.6 passengers.

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* Sources: Vehicle miles and total gasoline from Reference 4; division of fuel between urban and intercity categories from Reference 5.

2.1.2 Vehicle Efficiency Improvement

2.1.2.1 New Cars - Because of its very large potential for fuel savings, improvement of the efficiency of new motor vehicles has been the subject of considerable study during the past year. The results of the major studies, carried out by the Department of Transportation and the Environmental Protection Agency, are summarized in the document Potential for Motor Vehicle Fuel Economy Improvement: Report to the Congress [6]. Excerpts from it are reproduced below:

> 1. What is the Fuel Economy Improvement Potential by 1980 and 1985?
>
> Fuel economy improvements may be obtained by three major methods. They are: technological improvements in the engine and drive train to increase efficiency and in the tires and body structures to reduce drag and weight; an engine size reduction for the larger cars; and a shift to a larger proportion of small cars in the fleet.
>
> Figure 2-1 indicates that from the 14.0 mpg(1) in 1974 a 25 to 60 percent (17.3 to 22.2 mpg) fuel economy gain is possible for 1980 model cars depending on the improvement strategies used. Because of production constraints, improved technology and engine resizing offer more improvement than the strategy of shifting to small cars by 1980. The 1975 fleet (15.9 mpg) has demonstrated a 13.5% improvement over 1974 (14.0 mpg) by technology. The 1970 fleet averaged 15.4 mpg. Thus a combination of technological improvements in 1975 cars and changes in the model mix (i.e., a larger portion of smaller cars) have recouped the fuel economy lost between 1970 and 1974 due to emission control and added weight.
>
> Estimates of the average mpg for the 1980 car fleet shown in Figure 2-1 vary depending upon which of the above methods are assumed to achieve it (e.g., various forms of technological upgrading, shift in sales mix, and combinations thereof). Each assumes the best feasible effort

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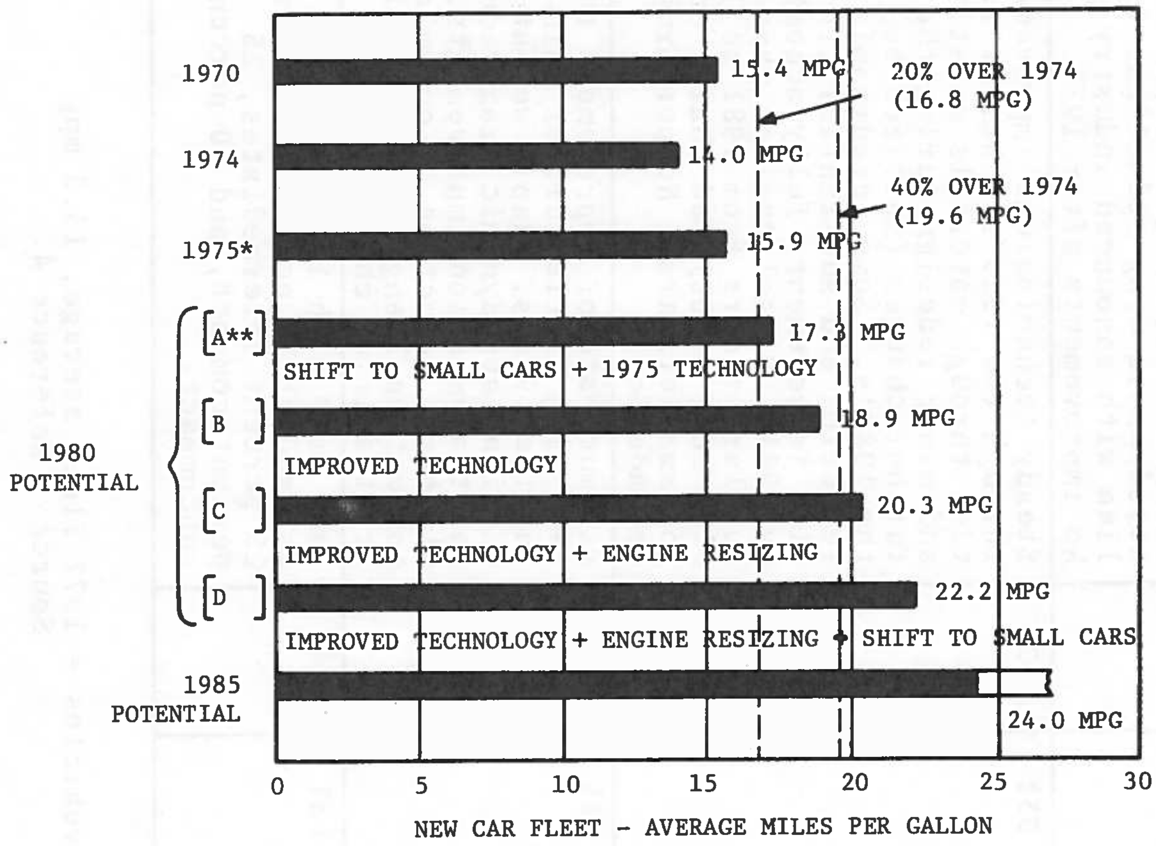
[1] The fleet fuel economy in miles per gallon is based on the miles traveled and fuel used in the city and highway driving schedules developed by EPA. The single number is obtained by assuming that 55% of the driving is represented by the city cycle and 45% by the highway cycle. Finally, the results for individual cars are weighted by the percentage of the production attributable to that car to obtain an average indicative of the fuel economy of the entire fleet.



*1974 New model production mix assumed.

[**These letters correspond to the scenarios in Figure 2-1 Addendum.]

Figure 2-1. Potential for Automobile Fuel Economy Improvement

TABLE 2-2. ADDENDUM TO FIGURE 2-1.

Scenario	PERCENT GAIN IN MPG		FUEL ECONOMY IMPROVEMENTS
	1980	1985	
Baseline	0	0	No improvements in fuel economy relative to base year* vehicles. Minimum changes to meet statuatory emission standards.
A Modest Improvements	28%	27%	Optimized conventional engines, radial tires, slight weight and aerodynamic drag reductions (in line with announced industry goals). No improvements after 1978.
B Gradual Improvement Thru 1980's	33%	52%	Steady technological improvement through the 1980's: Weight reduction through materials substitution and minor redesign during the 1970's further changes (unitized body) in the 1980's. Some aerodynamic drag reduction and substantial transmission improvements fully accomplished by 1984. Diesel engines phased in for larger cars from 1981 to 1989 plus some stratified charge engines for smaller cars. No performance degradation.
C Maximum Improvement by 1980	43%	44%	Maximum rate of improvement through 1980 with little further gain during the 1980's. Rapid weight reduction, aerodynamic drag reduction, and transmission improvements. Displacement reduction of optimized conventional engines, but no diesel or stratified charge engines.
D Scenario B Plus Shift to Smaller Cars	63%	84%	Same as B with 1980 sales mix assumed at 10 percent large cars, 25 percent intermediates, 25 percent compact, and 40 percent subcompact.

Note: Base Year vehicles = 1972 fleet average, 13.5 mpg

Source: Reference 4.

possible. Shift in mix was limited to that possible given the availability of production facilities, but no limitations due to consumer demand were assumed. Some of the technological options considered require further development; however, their implementation is deemed feasible by 1980. Technological options were screened for consumer acceptability prior to their inclusion, but once selected, eventual 100 percent application to the new car fleet was assumed. (See Table 2-2.)

The impact, timing, and cost of emission and safety standards were considered in arriving at the potential gains. The tradeoffs among them are addressed in the following sections. Simultaneous achievement of improved fuel economy, low emissions, and occupant safety will increase the first cost of new vehicles.

2. What are the Economic Costs and Benefits Associated with Fuel Economy Improvements?

A 20% improvement in fuel economy should not result in an appreciable increase in the first cost of cars. Technological improvements should add up to $200 for 30% and up to $400 for 40% fuel economy improvements to new car selling prices by 1980 (in 1974 dollars). Lower operating and maintenance costs would pay for the increased first cost at a discount rate of 10% in about one year of normal use for the largest, and 3 to 4 years for the smallest, cars. The main difference in the pay-back time is due to the greater absolute amount of fuel used by improved large cars over small cars.

Fuel economy improvements require changes which may decrease maintenance costs compared to 1974 cars. Potential increased complexity of the engine system due to emission control may be offset by the improved reliability and low maintenance potential of state-of-the-art improvements combined with the use of unleaded gasoline. [Table 2-3 illustrates the range of savings to the individual automobile owner; over the typical 100,000-mile life of the average car, they amount to a savings of 0.3 to 1.5¢ per mile.]

The effects on the automotive industry of a 20% to 40% improvement in fuel economy by 1980 are requirements for increased capital investment and engineering and manufacturing changes. Such investments range from $50 million per year for a modest increase in fuel economy to $200 million per year for a large increase in fuel economy. The [current level of] capital investment of the domestic industry is $2.0 to 2.5 billion annually.

The savings in gasoline due to fuel economy improvements have potential for dramatic savings in petroleum. For example, using a modest growth rate (2.6%) in vehicle-miles

TABLE 2-3. ESTIMATED 1980 IMPACTS OF FUEL ECONOMY IMPROVEMENTS UNDER SCENARIO C (DOLLARS/CAR)

	% Gain in MPG	Increase of Initial Price	PV[1] of Fuel Savings	PV of Maintenance Savings	Net Savings
SUBCOMPACT	24.4	242	335	213	306
COMPACT	42.6	249	688	308	747
INTERMEDIATE	42.6	249	937	308	966
STANDARD	61.0	296	1,397	389	1,490
LUXURY	61.0	296	1,465	389	1,558

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[1] PV = Present value calculated with a 10% discount rate, gasoline price of 55¢ per gallon, and a ten year period. A 20 percent discount rate would lower the present value of fuel savings by 24 percent

travelled and a fuel economy improvement of 40% by 1980 savings in 1980 alone of $5.0 billion in petroleum demand (1974 dollars) at $11/barrel would ensue.

[Table 2-4 shows projections of total gasoline consumption by passenger cars for alternative implementation scenarios (see Fig. 2-1), given an assumed growth rate in vehicle miles travelled of 2.6% per year. The baseline used was 13.5 mpg, the 1972 average for all passenger cars on the road [4]. It is not directly comparable with mpg figures based on the EPA composite cycle, which are specific to particular model years.]

TABLE 2-4. ANNUAL FUEL CONSUMPTION IN PASSENGER CARS (BILLIONS OF GALLONS)

YEAR	BASELINE	SCENARIO			
		A	B	C	D
1975	81.0	79.5	79.6	79.1	79.0
1980	93.8	80.8	80.1	76.6	73.1
1985	107.2	85.6	78.2	76.8	66.0
1990	122.0	96.1	80.0	84.6	66.8

3. What are the Relationships Between Fuel Economy and Safety?

Safety and fuel economy are related through a vehicle's weight and body structure. Today, a larger car with more crush space and heavier structure provides better protection but poorer fuel economy than the small car.

Of equal importance to the crashworthiness of cars are the availability and usage rate of effective passenger restraint systems. Even in today's fleet, where the probability of being involved in an accident is relatively independent of car size, the belted occupant of a small car has approximately the same protection as the unbelted occupant of a large car.

Recognizing that present national policy is to reduce the serious injury and death rate on the highways, safety standards which would improve the crashworthiness and effectiveness of passenger restraint systems, especially for small cars, are necessary. If fuel economy improvements are achieved by a shift to a higher percentage of small cars in the fleet without concurrently upgrading their occupant protection capability, it is probable that the serious injury and death rate would rise.

It is important to note that the relationship between weight and safety is opposite to that of weight and fuel economy. Consequently, the fuel economy penalty chargeable to increased occupant safety may be proportionately greater for a small car than for a large car. Bumper standards have added about 140 pounds while safety standards have added about an additional 120 pounds, for a total of 260 pounds of weight added to the average vehicle of today. The fuel economy penalties have been on the order of three to four percent for this additional weight.

Presently identified future safety standards will add approximately 80 pounds to the average vehicle. An advanced notice of proposed rulemaking issued in 1974 (FMVSS No.208) contemplates an upgraded occupant protection standard in the 1980-81 time frame. Such a standard could add 150 pounds or more to the average car. The weight picture for future bumper standards is unclear, because the effects of various possible designs are as yet undefined.

The fuel economy improvement feasible for the 1980 vehicles would be offset in part by the weight penalties of future safety and damageability requirements. It is possible that weight increases have been greater than technically necessary, because the manufacturers have used proven engineering approaches and standard materials to increase structural strength. The increased cost of fuel and the emphasis on fuel economy are now causing the manufacturers to consider alternative designs including lighter weight materials. Such technology advances combined with increased use of effective passenger restraint systems could greatly reduce the weight penalties of upgraded vehicle safety, particularly in vehicles manufactured after 1980.

If engine size reduction for large cars is used to improve fuel economy, there may be no adverse effect on safety. Moderate reductions in acceleration capabilities and top speed characteristics for the large vehicles in the fleet may be beneficial for safety.

4. What is the Relationship Between Fuel Economy and Emissions?

Significant fuel economy improvements are feasible by 1980 compared to 1974 while meeting the statutory HC and CO standards.(1) Significant gains have already been achieved in 1975 with lower emissions of HC and CO than in 1974. Such gains, while maintaining the fuel economy achievable with 1975 HC and CO emission standards, will come at increased first cost for the car and complexity of the engine system.

The issue of the level and cost of the oxides of nitrogen emission achievable by 1980 concurrent with substantial fuel economy improvement is unresolved.

Several alternative engine systems have the potential in 1985 and beyond to improve fuel economy significantly compared to the conventional spark ignition engine. The diesel and Stirling cycle concepts are examples. It would require on the order of 15 to 25 years, respectively, to realize the full benefits of such alternative engines and fuels. The ultimate target level for the oxides of nitrogen standard, as well as emissions for which there is now no standard,

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(1) The 1975 emission standards are 1.5 gm/m HC, 15 gm/m CO, and 3.1 gm/m NO_x. Statutory emission standards, currently applicable in 1978, are 0.41 grams per mile (gm/m) of hydrocarbons (HC), 3.4 gm/m of carbon monoxide (CO), and 0.4 gm/m for oxides of nitrogen (NO_x).

While it is assumed for the purposes of this report that the statutory emission standards for hydrocarbons and carbon monoxide (0.41 gm/m and 3.4 gm/m, respectively) will be required to be met, the public record raises questions about the future NO_x standards.

As regards the emission standard for oxides of nitrogen, it is assumed that the Congress will concur in the Administration's legislative recommendations of March 22, 1974, to the effect that the 1978 and subsequent model year emission standard for oxides of nitrogen be established by the Administrator of EPA after taking into consideration the requirements of air quality, energy efficiency, availability of technology, costs, and other pertinent considerations.

In that context, it is expected that the Administrator would -- as he recommended to the Senate Public Works Committee on November 26, 1973 -- continue the NO_x standard at a level of 2.0 gm/m through the 1981 model year; that beginning in the 1982 model year the emission standard would be at or near 1.0 gm/m; and that EPA would contemplate establishing the 0.4 gm/m NO_x emission standard effective with approximately the 1990 model year.

has a major impact on which alternative engine systems, if any, can realistically be considered by the industry for large scale implementation. An oxides of nitrogen level much below 1.0 to 1.5 gm/m would greatly discourage commitments to the development of the diesel engine or some stratified charge engine concepts which could be offered in new vehicles in appreciable numbers in the 1982-1985 time frame.

5. <u>Do Engineering and Manufacturing Lead Times Forestall the Potential Fuel Economy Improvement?</u>

Present manufacturing capacity is sufficient to permit a model mix in which 60 percent of all new cars would be compacts or subcompacts.

Four years lead time for structural changes, some transmission changes and other component modifications is required in the automotive industry. About six years lead time is required for a new engine configuration of the current type. Eight to fifteen years are required for a major technological advancement and change such as an alternative power system. An additional 10 years may be required to change the total motor vehicle fleet so as to realize the full benefit of such an advance.

Lead times, however, begin from the date on which a manufacturer decides to pursue a given course of action. Current uncertainty about future safety standards and the NO_x emission standard inhibit manufacturers from making firm decisions to commit resources to the development and utilization of fuel conserving technologies.

The DOT/EPA Report to the Congress was published in October 1974, and, as directed by Section 10 of the Energy Supply and Environmental Coordination Act of 1974 (Public Law 93-319), was concerned primarily with the practicability of establishing a fuel economy improvement standard of 20 percent (over 1974 models) for the 1980 model year. Based largely on the work of the DOT/EPA report, the President established a goal for a voluntary fuel economy improvement of 40 percent by 1980 (model year 1981). Commitments were obtained in December 1974 from the auto manufacturers for such improvement. The President proposed setting emission standards at .9/9/3.1 from 1977 through 1981 and dropping HC and CO to 0.41/3.1 in 1982 with the future NOx standard to be determined.

On March 5, 1975, after hearings on delay of the 1977 statutory standards, EPA Administrator Russell Train took note of a newly recognized problem with the catalytic converter - the conversion of the SO_2 normally in the exhaust to SO_3 and hence to H_2SO_4, sulfuric acid . Because of potential serious health problems with sulfuric acid mist emissions which would grow as more catalyst-equipped cars entered the fleet and as emission controls on HC and CO were tightened, the Administrator recommended the following schedule:

1977 thru 1979	1.5/15/2.0
1980 thru 1981	.9/9/2.0
1982 & subsequent	.41/3.4/2.0

He also announced that rulemaking would begin soon for a sulfate standard which could become effective in the 1979 model year.

The sulfuric acid problem raised serious doubts about the continued use of the catalytic converter. If the new sulfate standard were set very low, then the present generation of converters might be unable to comply. Without the catalytic converter, the ability to meet HC, CO, and NOx standards and still achieve fuel economy goals was in serious doubt. On June 27, 1975 the President recommended that Congress amend the Clean Air Act to freeze the emission standards at 1.5/15/8.1 through 1980. For purposes of the report, it is assumed that emission standards will be set compatible with the goal of 40 percent fuel economy improvement.

2.1.2.2 Retrofits to Old Cars - Scores of retrofit devices that purport to improve fuel economy are already offered for sale, while numerous additional ideas and inventions have been proposed in the past year. Under contract to the Department of Transportation, the Aerospace Corp. has undertaken an evaluation of such devices.

Preliminary results of this study indicate that of more than 150 devices initially considered, only a handful merit much attention. All of the remainder are either ineffective or too expensive to be cost-effective for the car owner at any likely fuel price.

Those that are potentially cost-effective (i.e., will pay for themselves with three years' gasoline savings at 65¢/gal) include a combination of ignition and carburetor improvements, which permit leaner burning and intake and exhaust-manifold modifications, which also allow the use of leaner mixtures. In addition, radial tires have already been established as cost-effective, and so were not included in the Aerospace study.

Testing of the improvements mentioned above has only recently begun, and no precise estimates of fuel savings are yet available. The consensus of experts, however, is that mpg improvements on the order of 15% for the ignition, carburetor and manifold modifications (plus 3% for radial tires) are achievable.

Conversion to radial tires has already begun,* but the outlook for implementation of the other fuel-economy improvements is shadowed by two major issues. The first is that an enormous amount of testing and experimentation is required to design the specific carburetor and manifold modifications for a particular engine. This testing would have to be repeated for each engine type for which a modification kit might be offered, so the test-and-design phase might require a few years. The second major uncertainty is consumer acceptance. The cost of the modifications, including installation, should amount to something over $200, which is high enough that costs could be recovered through gasoline savings in three years, but just barely. Whether any substantial number of motorists would be willing to spend $200 to save $200 or more over the following three years is questionable. Hence, the sales-weighted potential of engine modifications must be regarded as much less than 15% improvement in mpg, perhaps something on the order of 3%. This would be in addition to the 3% from radial tires.

The pre-1975 cars to which these retrofits might apply will account for only about a third of the vehicle-miles traveled in

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*Most new cars are now equipped with radials at the factory, while 30% of the replacement market consists of radials. They are expected to dominate the replacement market within three years.

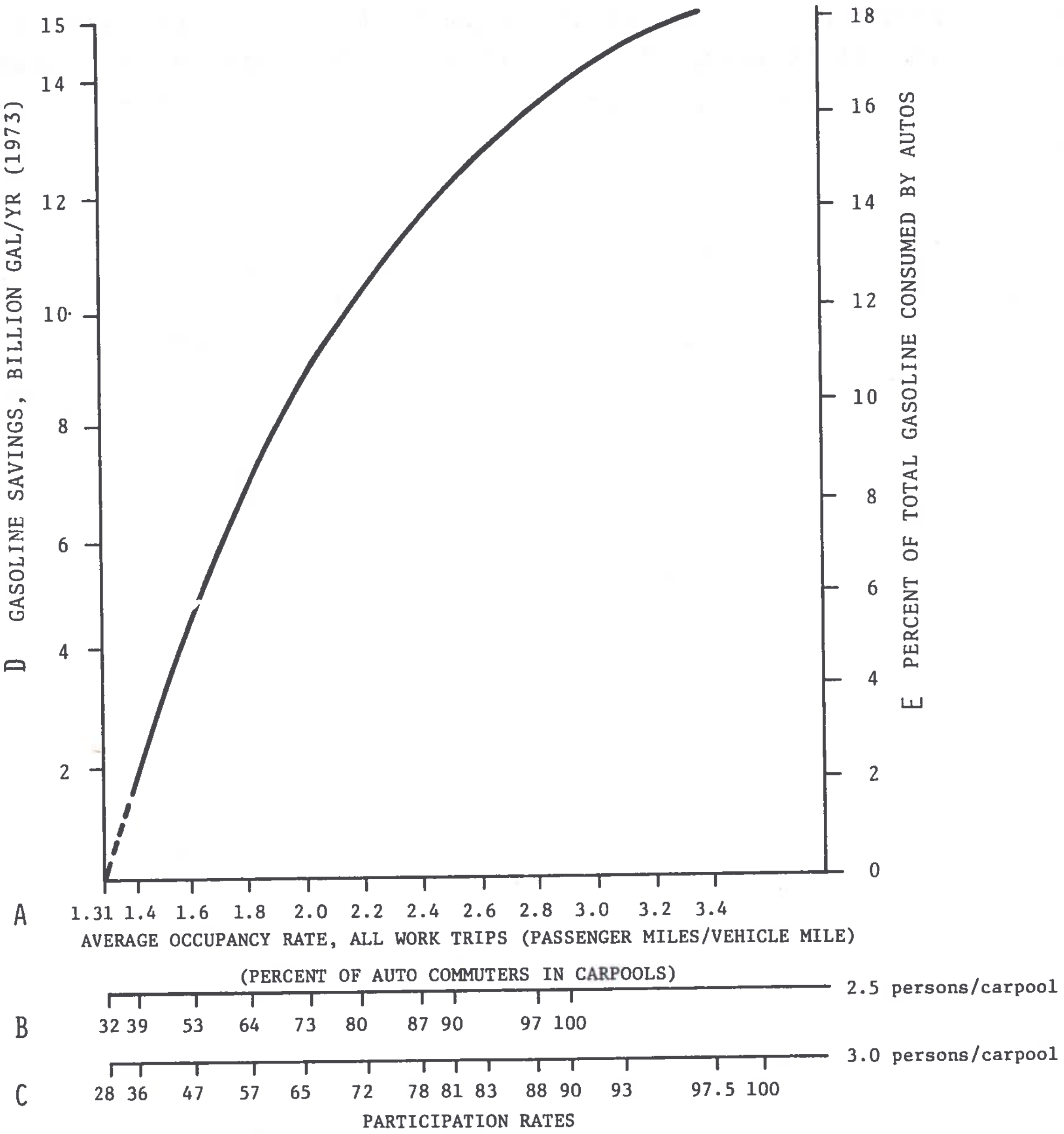
1980, and essentially none of those in 1990. Thus, the savings would be limited to about 0.5% to TDTE in 1980 for radial tires and another 0.5% for modifications. By 1990, the savings would be insignificant.

2.1.3 Load-Factor Improvement

The only load-factor improvement for passenger cars that is known to offer potential for significant fuel savings is work-trip carpooling. Since only about 25% of auto commuters are now regular members of a carpool, there is clearly room for a major expansion of carpooling, with a concomitant major fuel savings.

Unlike most other measures discussed in this paper, carpooling to work can be implemented under emergency conditions within a matter of weeks and with no significant capital expenditure. It offers direct savings to users of $100 to $300 per year, as well as the opportunity in some multi-car households to eliminate altogether the ownership costs of one or more cars. It will relieve air, noise, and aesthetic pollution in direct proportion to the reduction in vehicle-miles. It is available now to people who live in low density suburban and rural areas, where mass transit service is not. Finally, carpooling has already been demonstrated to be effective and acceptable in times of national emergency, notably World War II. Yet there is clearly some loss of independence and privacy entailed in carpooling, a loss that many Americans will not accept at the current low marginal cost of solo driving, about 7¢ per mile. Just how strongly this resistance to carpooling is felt is not known. Whether carpoolers differ from non-carpoolers primarily in terms of their physical travel requirements (e.g., places of origin and destination, or schedule flexibility) or primarily in terms of phychological traits (e.g., need for privacy or status) is a question that can be answered only by rather extensive research.

Furthermore, carpooling to work does increase total travel time for commuters -- typically by periods of five to fifteen minutes per trip, or 40 to 120 hours per year. For commuters who value their time at more than $2 per hour, the cost of delay can



Note: In using this chart one may begin by assuming either an average occupancy rate for all commuter cars (scale A, expressed in passenger-miles per vehicle-mile) or a combination of carpool participation rate and average carpool size (scales B & C). The carpool participation rate is the percentage of auto commuters who belong to carpools, whether as drivers or riders. From the point chosen on scales A, B, or C, a line paralleling the ordinate is drawn to intersect the gasoline savings curve. The savings may be read in terms of either actual gallons, based on 1973 data (scale D, on the left), or percentage of total auto fuel (scale E, on the right).

This chart is taken from Reference 7.

Figure 2-2. Gasoline Savings from Increased Auto Occupancy (Work Trips Only) equal or exceed the $100 to $300 per year savings in direct automobile operating expenses. However, for those commuters who can own one fewer automobile by virtue of their carpooling (thereby saving $600 or more per year), the breakeven time value is pushed up to at least $5 per hour.

Figure 2-2 indicates potential gasoline savings as a function of load factor (expressed in passenger-miles per vehicle-mile) and carpool participation rate for both average carpool groups of 2.5 persons (near the current value) and 3.0 (possibly attainable). Analysis of commuter travel patterns and requirements for business use of autos suggests that the highest achievable participation rate is slightly less than 50%, under non-emergency conditions [7]. Thus, the maximum saving that might have been achieved in 1973 was about 4 billion gallons, or about 2.58% of total transportation fuel. In an emergency, a form of mass hitchhiking might be adopted for all trip purposes, which could increase the potential savings from carpooling by a factor of three or more.

In addition to the direct financial benefits to participants, carpooling can also contribute materially to air quality, and has been identified as a major element in the Clean Air Plan of several cities. Unfortunately, implementation policies, other than voluntary, have met such heated resistance as to create considerable doubt as to whether some of the targets set can ever be achieved. (In Boston, a test case, the target was a 25% reduction in commuter vehicles.)

2.1.4 Speed Limits

Fuel economy in passenger cars varies inversely as a function of speed, although due to differences in engine design, aerodynamics, etc. individual cars may show quite different curves. For example, some vehicles experience improvements in mpg in excess of 10% when they cut back from 65 mph to 55 mph; for others the saving is as little as 3%.

Precise quantification of potential fuel savings would require much more extensive data on fuel consumption as a function of driving conditions, and actual speed distributions by road conditions, than currently exist. Engineering judgment has been used to integrate and interpolate the fragmentary data available. The results for passenger cars are shown in Table 2-5, line 3; they show a savings of 1.8 billion gallons, or 1.2% of 1972 TDTE, for a 55 mph limit, with 100% compliance [8]. Table 2-6 shows the effects of lower levels of compliance.

Of far greater importance than the relatively small fuel savings is the reduction in highway fatalities and serious injuries associated with reduced speeds. This factor has now been recognized as the principal justification for a permanently lower national limit. In addition, there is a small reduction in emissions.

However, it must be recognized that despite the small savings in out-of-pocket costs resulting from lower driving speeds,* there will remain a continuing incentive to violate the limit to save time. For the average car with 2.2 occupants, the breakeven time value is about $1 per person-hour, i.e., persons who assess their time at more than $1 per hour will not find the fuel savings alone adequate compensation for their increased travel time. For those who persist in ignoring the safety implications of speeding, enforcement by fines and other penalties is required.

2.1.5 Improved Automotive Maintenance

Fuel economy of passenger cars deteriorates between tune-ups because of such factors as changes in air/fuel ratio and timing, blockage of the air cleaner or PCV valve, and spark-plug misfire. Proper service procedures correct all these matters and restore autos to their original fuel-economy capabilities. Although firm data on tune-up frequency are lacking, it is generally assumed that the average car is tuned about once in 12,000 miles. If this interval between tune-ups were shortened to 6,000 miles, it is estimated that total auto fuel consumption would be reduced by 1.5% [9], or 0.75% of TDTE. More frequent tuning should also tend to reduce emissions, but the effect has not yet been quantified.

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*These are about 0.5¢ per mile for the average car dropping from 65 mph to 55 mph.

TABLE 2-5. FUEL SAVINGS FOR 100% COMPLIANCE WITH SPEED REDUCTION TO 55 MPH* (1973)

Vehicle Type	Rural Interstate	Other Rural Primary	Urban Freeway	Total - All Roads
Automobiles				
million gallons	716	629	459	1804
percent of auto fuel	0.97%	0.85%	0.62%	2.44%
percent of TDTE	0.49%	0.43%	0.31%	1.23%
Single Unit Trucks				
million gallons	219	192	87	498
percent of single-unit truck fuel	0.99%	0.86%	0.39%	2.24%
percent of TDTE	0.15%	0.13%	0.06%	0.34%
Combination Trucks				
million gallons	106	86	14	206
percent of combination truck fuel	1.23%	1.00%	0.16%	2.39%
percent of TDTE	0.07%	0.06%	0.01%	0.14%
Total				
million gallons	1041	907	560	2508
percent of TDTE	0.71%	0.62%	0.38%	1.71%

---

*Source: Reference 8.

TABLE 2-6. FUEL SAVINGS FOR VARYING COMPLIANCE WITH SPEED REDUCTION TO 55 MPH SAVINGS, AS A PERCENTAGE OF TDTE (Includes auto & trucks)*

	PERCENT COMPLIANCE					
HIGHWAY TYPE	60	65	70	75	80	85
Rural	.43	.46	.50	.53	.57	.60
Other Rural Primary	.37	.40	.43	.47	.50	.53
Urban Freeway	.23	.25	.27	.29	.30	.32
TOTAL	1.03	1.11	1.20	1.28	1.37	1.45

*Source: Reference 8.

TABLE 3-1. TRUCK SERVICE AND ENERGY CONSUMPTION, 1972*

	LIGHT TRUCKS (2-axle, < 10,000 lb)			HEAVY-DUTY SINGLE-UNIT TRUCKS (≥ 6 tires, 10,000-33,000 lb)			COMBINATION TRUCKS (> 33,000 lb)		
Direct fuel consumed	URBAN	INTERCITY	TOTAL	URBAN	INTERCITY	TOTAL	URBAN	INTERCITY	TOTAL
thousand bbl/day	368	458	827	272	338	610	162	399	561
million gal/year	5,648	7,026	12,674	4,168	5,186	9,354	2,488	6,112	8,600
trillion Btu/year[1]	706	878	1,533	521	686	1,170	339	831	1,170
percentage of TDTE	3.83	4.77	8.33	2.93	3.73	6.36	1.79	4.57	6.36
Service rendered									
million vehicle-miles/ year	66,425	82,645	149,070	28.541	35,511	64,052	13,485	33,128	46,613
million ton-miles/year	20,250	25,194	45,444	54,102	67,312	121,415	126,493	310,750	437,243
Average efficiency									
Btu/ton-mile	See note 2			9,636	9.636	9,636	2,679	2,679	2,679

[1] The conversion factors are 125,000 Btu/gal for light and heavy single unit trucks and 136,000 Btu/gal for combination trucks

[2] Light trucks are used primarily for personal transportation and services, so simply dividing their total energy consumption by total freight carried would yield a distorted measure of efficiency. For those trucks used strictly as cargo vehicles, efficiency is estimated at 7106 Btu/ton-mile by the FHWA Office of Highway Statistics.

*Sources: Vehicle miles and total fuel from Reference 4;
division of fuel between truck types from Reference 13.

3. DOMESTIC FREIGHT TRANSPORTATION

3.1 HIGHWAY

3.1.1 Service and Energy-Consumption Data

Service and consumption data for 1972 are given in Table 3-1 for various types of trucks.

3.1.2 Vehicle Efficiency Improvement

The recently published report cited in Section 2.1.2.1, Potential for Motor Vehicle Fuel Economy Improvement [6], also addressed itself to trucks. It concluded:

> Light-duty trucks (i.e., trucks of gross vehicle weight up to 10,000 lbs.) are technologically similar to the passenger car and are used extensively for passenger service. Technological improvements for light-duty trucks are basically the same as those described for passenger cars, but are limited to engine improvements, substitution of radial tires for conventionals, and improved transmissions. The following improvements in fuel economy are deemed feasible for the majority of domestic light-duty trucks in production by 1980: engine improvements, 20%; tire improvements, 2.5%; and transmission improvements, 6%. The estimated total sales-weighted fuel economy benefit for the domestic light-duty truck by 1980 is 25% as compared to a 1974 base light-duty truck.

Costs and benefits, and the safety and emissions implications are all similar to those for passenger cars (see Section 2.1.2). As for heavy trucks, the report continued [6]:

> Analyses of available data indicate fuel economy improvements for some individual trucks can be as great as 41% by the 1980 production year. Assessment of such technology applied without cost or production capacity restraint yields an estimate of aggregate reduction in the fuel consumed by the new trucks and buses manufactured in 1980 of 25%.
>
> When considerations of cost benefit tradeoffs to the purchaser and production capacity by 1980 are taken into account, the maximum fuel savings for the new 1980 vehicles is reduced to 18%.

TDTE (equivalent to a 20% reduction in fuel consumption per boat-mile) in any year. More significant savings in marine passenger transport could come from reduced use of pleasure boats and/or the substitution of sail for engine power. Under any conditions of fuel shortage sufficiently severe to result in general gasoline supply restrictions, pleasure boating will probably decline severely, perhaps to the extent of 0.2 or 0.3% of TDTE. The same percentages would apply in future years, if one assumes that demand for pleasure boating will grow at about the same rate as other transportation sectors.

is resolved, future passenger rail service may show efficiency gains large enough to save about 0.2% of TDTE by 1990. Furthermore, an increasing fraction of rail passenger energy will be supplied by coal or nuclear prime movers - possibly sufficient to reduce petroleum consumption in 1990 by the equivalent of another 0.1% of TDTE. Since none of the advanced equipment will be operational by 1980, no savings are shown for that year.

2.5 WATER

Service and energy-consumption data for 1972 are given in Table 2-11.

TABLE 2-11. WATER PASSENGER SERVICE AND ENERGY CONSUMPTION, 1972*

	RECREATION AND BUSINESS[1] BOATING	INTERCITY (COMMON CARRIERS[3])
Direct fuel consumed		
thousand bbl/day	38	N/A
million gal/year	587	
trillion Btu/year[2]	86	
percentage of TDTE	0.46	
Service rendered		
vehicle-miles/year	N/A	
million passenger-miles/year		4300

[1] Business boating refers to commercial operations such as fishing, tourist excursions, etc.

[2] Conversion factor: 125,000 Btu/gal.

[3] Mainly ferries, including Great Lakes

*Sources: Recreation and business boating, Reference 4;
Common-carrier passenger-miles, Reference 19.

Although technology transferred from the automotive industry may result in some improvement in the efficiency of marine power plants, this effect is not likely to amount to more than 0.1% of

TABLE 2-10. RAIL PASSENGER SERVICE AND ENERGY CONSUMPTION, 1972*

	TRANSIT	COMMUTER	INTERCITY	TOTAL
Direct fuel consumed				
thousand bbl/day	N/A	N/A	N/A	8
million gal/year				125
trillion Btu/year[1] (includes kWh)	25	11	15[2]	51
percentage of TDTE	0.14	0.06	0.08	0.27
Service rendered				
million vehicle-miles/year	N/A	N/A	N/A	N/A
million passenger-miles/year	15,344	4,228	4,164	23,925
Average efficiency				
Btu/passenger-mile	1,646	2,493	3,533	2,146

[1] Conversion factors are 138,000 Btu/gal for diesel locomotives and 10,400 Btu/kWh for electric traction.

[2] Adjusted to remove 20% of 1972 passenger-train energy charged to mail and express.

* Sources: Transit fuel consumption, reference 19. Other fuel figures, reference 20. Transit passenger-miles calculated from passenger data in reference 21 by means of the passenger: mile factor of reference 22. Other passenger-miles from reference 19.

during the 1990's primary energy consumption per passenger mile for corridor trains may fall to the vicinity of 1000 BTU.

On the other hand, there is a desire for greatly increased speed in rail service. Since the energy consumed in overcoming aerodynamic drag increases as the second power of velocity, it is possible that a significant portion of the above mentioned savings may be lost.

Depending on how the trade off between efficiency and speed projected 1980 TDTE) and 615 million gallons in 1990 (0.4% of projected 1990 TDTE). Tow vehicles for such a program are not now available, but preliminary results [18] show that the resulting fuel savings would defray operating and capital costs for the tow vehicles.

This program would also reduce airport noise and air pollution. It might, however, increase total travel time because of the slower ground movement.

To date, the FAA has implemented the first of these two ground procedure changes. In addition, procedures to hold aircraft at the gate when departure delays are expected have been implemented; this reduces the fuel wasted while aircraft idle in take-off queues.

2.4 RAIL

Service and energy consumption for 1972 are shown in Table 2-10. To the extent that future intercity rail passenger service becomes relatively more concentrated in corridors such as Boston-Washington, energy consumption per passenger-mile may decline because corridor trains typically carry much less "dead weight" (sleeping cars, dining cars, baggage cars, etc.) than long-haul conventional trains. Furthermore, high-density corridors are prime candidates for electrification, which saves petroleum through substitution of other forms of energy. For new technology trains operating in corridors where the new traffic will support them, the efficiency is much better than noted for the 1972 intercity average. Under typical operating conditions, the Washington/New York Metroliner has an efficiency of 440* BTU (electric) per seat mile, which at a 70 percent load factor is 643 BTU per passenger mile. After adjustment for generating efficiency (33%) and distribution efficiency (91%), this is equivalent to 2141 BTU per passenger mile. The Metroliner design is, in fact, somewhat heavy; and new improved state-of-the-art passenger trains could have an efficiency as low as 360 BTU (electric) per seat mile. Regenerative braking could further reduce energy consumption by 25 to 40% in the 1990 time frame. Thus,

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*Source: Reference 45

29,000 feet, they are separated by 4,000 foot increments. If the optimum altitude for a particular flight is an altitude prohibited for flight in that direction, or if it is occupied by another aircraft, the flight will generally be assigned to a lower altitude. For example, an eastbound pilot refused permission to cruise at 33,000 feet will remain at 29,000 feet until he is able to climb to 37,000 feet. These restrictions are safety regulations, and are due in part to altimeter technology. Improved altimeters have been developed; if they permit relaxed FAA regulations resulting in a 2000-foot cruise-atitude increase (where appropriate), the domestic passenger-fleet fuel use would be reduced 1.3% [16]. This reduction would amount to 165 million gallons of fuel in 1980 (0.1% of projected 1980 TDTE) and 296 million gallons in 1990 (0.2% of projected 1990 TDTE). These changes cannot be made, however, without widespread commercial, private, and military installation of the new and more expensive altimeters [49].

2.3.3.3 Alternative Ground Procedures - A substantial portion of aircraft fuel is consumed while the aircraft is on the ground; in 1971, 4.2% of the domestic passenger-fleet fuel was consumed in taxiing and idling on the ground [16]. Two operational-procedure changes -- reducing the number of engines used on the ground, and towing aircraft on the ground -- have been suggested to reduce fuel consumption.

Turbine-powered aircraft could use fewer engines on the ground -- employing the remaining engines at higher, more efficient power levels -- since turbines require essentially no warm-up time. If all domestic passenger turbine-powered aircraft reduced their ground engine use, air-carrier fuel requirements would be reduced 0.8% [16]. This reduction would save 101 million gallons of fuel in 1980 (0.1% of projected 1980 TDTE) and 182 million gallons in 1990 (0.1% or projected 1990 TDTE).

The FAA is investigating the feasibility of towing aircraft on the ground. If this procedure were employed, the total domestic passenger-fleet fuel requirements would be reduced 2.7% [16]. This reduction would save 342 million gallons of fuel in 1980 (0.2% of "long-range" cruise speed, defined as the speed at which the aircraft's range is 99% of its maximum.

If the domestic passenger fleet reduced cruise speeds by 0.02 Mach, its fuel requirement would be reduced by 1.3% [16]. This would amount to 165 million gallons of fuel in 1980 (0.1% of projected 1980 TDTE) and 296 million gallons in 1990 (0.2% of projected 1990 TDTE). This reduction is less than one might expect, due to the brief cruise time for shorter stage lengths and the fact that half of all domestic airline hops are under 260 miles. The increased travel time resulting from this speed reduction would also be minor -- about two minutes for a 1000-mile hop.

A 0.02-Mach reduction leaves most airplanes well above minimum-fuel-consumption cruise speeds. A system-wide reduction to long-range cruise speed would reduce fuel requirements by 3% [16]. This would amount to 380 million gallons in 1980 (0.2% of projected 1980 TDTE) and 684 million gallons in 1990 (0.4% of projected 1990 TDTE).

These fuel savings, however, would require greater travel-time increases than the 0.02-Mach reduction. The actual change in travel time varies by aircraft type (the larger aircraft currently cruise much nearer long-range speed than smaller aircraft) and trip length. A 0.02-Mach reduction for the Boeing 747 places it very near long-range operation, but a DC-9 cruises 0.09-Mach above long-range cruise speed. On a 1000-mile flight at long-range speed, DC-9 flight time would increase nine minutes, while the Boeing 747 flight time would increase two minutes [16]. However, since the smaller aircraft are used for shorter trips and the larger aircraft are used for the longer trips, the increase in travel time for any given trip should still be small.

2.3.3.2 Increased Cruise Altitude - Aircraft fuel consumption also decreases with increasing altitude, until the optimum altitude for a given aircraft's cruise weight and speed is reached. Aircraft are apparently flown below that altitude, however, as a result of FAA altitude-assignment restrictions. Below 29,000 feet, same-direction flights are separated by 2,000-foot increments; above

6.72% average annual demand growth (1972-1980) will produce 70% load factors in early 1979.

Such a policy would require some aircraft rescheduling - shifting aircraft from low-density routes to high-density routes to accomodate growth in the high-density markets. The resulting reduction of air carrier jet service in low-density markets could be offset by expanding service by commuter airlines. The smaller aircraft used by the commuter airlines could provide the same or improved service frequencies at higher load factors and increased fuel efficiency.

Load-factor improvements should reduce both operating costs and capital-equipment requirements. To the extent that these savings are passed on to the traveler by the airlines, ticket prices should also decrease. If not, the carriers could realize substantial increases in operating profits.

Travel time, excluding waiting time, should not be affected. Waiting time, or the inability to fly at a desired time, probably would increase. The extent of this effect and its importance to quality of service have not been well established.

2.3.3 Operational Improvements

2.3.3.1 Reduced Cruise Speed - Present airline policy is to fix aircraft cruise speed for each aircraft type to minimize airborne operating costs -- crew, fuel, and maintenance -- while providing acceptably fast service. As cruise speed decreases, fuel use decreases; but crew and maintenance costs increase with increased flight time. Thus, minimum-cost cruise speeds are higher than minimum fuel-consumption speeds.

Two cruise-speed reductions for the domestic passenger fleet were analyzed: a 0.02 Mach-number* reduction and a reduction to

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*Aircraft flight characteristics vary with altitude, as does the speed of sound. Hence, an aircraft's speed is stated as the ratio of its airspeed to the speed of sound at the altitude at which it is flying. At 30,000 feet, the speed of sound is 678 mph and 0.02 Mach is 13.5 mph.

Passenger load factors have declined almost steadily for twenty years. In 1951, the passenger load factor for the major domestic carriers was 70%; for the past several years it has been near 50% [15]. This decline was due to several forces, the more important of which were the advent of jet aircraft with their lower breakeven loadfactor, the excess capacity caused by optimistic projections of demand growth, addition of wide-bodied aircraft, and CAB policies on service levels and competition.

Load factors rose sharply in response to the fuel shortage: figures for March 1974, the height of the fuel shortage, show that the combined load factor for domestic trunks and local-service carriers was 58.7%, compared to 49.7% for March 1973 [17]. This rapid increase indicates a potential for substantial load-factor improvement. If a 60% average load factor for domestic service were achieved, fuel requirements would be 16% (16.7%, less some allowance for the added weight per aircraft) less than those for a 50% load factor. If a 70% load factor, which is considered to be a practical upper limit, where achieved, aircraft fuel consumption would be approximately 28% less than with a 50% load factor.

The fuel savings from increased load factors are a function of the magnitude of air passenger travel and aircraft fuel consumption. Assuming constant fuel efficiency and an average annual passenger-mile growth rate of 6.72% between 1972 and 1980,* the fuel saved by increasing load factors from 50% to 70% would be 3550 million gallons (2.3% of projected 1980 TDTE). Assuming an average annual passenger-mile growth rate of 6.34% between 1972 and 1990, jet-fuel consumption for a 70% average load factor would require 6380 million gallons of jet fuel (3.7% of projected 1990 TDTE) less than that for a 50% average load factor.

The time required to achieve a 70% load factor depends upon air-carrier policies, travel growth, and CAB pressure. If air-carrier capacity is held at or near 1973 levels, the projected

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*Domestic air passenger-mile projections for 1980 and 1990 in Reference [2] imply average annual growth rates of 6.72% and 6.34% between 1972-1980 and 1972-1990 respectively.

TABLE 2-9. AIR PASSENGER SERVICE AND ENERGY CONSUMPTION, 1972

Direct fuel consumed[1]	
thousand bbl/day	490
million gal/year	7,536
trillion Btu/year[2]	946
percentage of TDTE	5.2%
Service rendered[3]	
million passenger-miles/year	121,820
Average efficiency	
Btu/passenger-mile	7,766

[1] Passenger-service fuel consumption was computed to be total passenger/cargo aircraft fuel use (Reference 14) minus marginal fuel use for the weight of belly cargo (see section 3.2 for discussion).

[2] Conversion factors: Jet fuel - 125,580 Btu/gal
Aviation gasoline - 111,190 Btu/gal

[3] From Reference 15.

2.3.2 Load-Factor Improvement

The greatest potential for increasing commercial-aircraft fuel efficiency lies in increasing passenger load factors. Jet aircraft fuel consumption is relatively insensitive to increasing weight; the Boeing 727-100's fuel consumption, for example, increases only about 0.3% per additional 1000 lbs. at normal loaded weights. [46] Thus, the additional fuel required for higher payloads is quite small, and improved fuel efficiency is almost directly proportional to increased load factor.*

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*The percentage reduction in plane miles and fuel for a given demand (in passenger miles) is the ratio of the difference in load factors to the new load factor: NLF-OLF/NLF.

Modest improvements in bus engine and drive-train components can be expected to increase fuel economy by 1980 [6]. In the case of transit and intercity buses (which are already dieselized), the fuel-economy gain of the 1980 vehicles is likely to be limited to an improvement of about 20% over the 1972 averages (4.4 mpg for transit and 6.2 mpg for intercity). Through dieselization, school buses (which are predominantly gasoline-powered) could experience mpg gains of about 30% over their 1972 average of 7.4 mpg.

These improvements would all be derived from advances in truck equipment design, and would be implemented on the same time scale as those for trucks. They appear to be cost-effective at current fuel prices.

If these improvements were realized throughout the bus fleet by 1990, the fuel savings would amount to less than 0.2% of 1990 TDTE. By 1980, only a small portion of these savings — perhaps 0.05% of 1980 TDTE — would have been achieved.

Other possible measures, such as reductions in service to increase passenger loading per vehicle, could be counter-productive, in that they would tend to divert passengers to private cars.

2.3 AIR

2.3.1 Service and Energy-Consumption Data

Service and energy-consumption data for domestic air passenger service by certificated carriers (scheduled and unscheduled services) in 1972 is given in Table 2-9. (Supplemental passenger service is excluded.)

numbers of dwelling units of single-family-conventional, single-family-clustered, townhouse-clustered, garden-apartment, and high-rise-apartment would result in a savings of 30%.

Since several decades will elapse before the full realization of the transportation energy savings of these land-use changes, it is difficult to impute a specific numerical value to the savings. But it is clear that, along with lower rates of growth in population and real per-capita income, they underlie the reduced rates of growth of vehicle-miles traveled now predicted. This reduction from the historic rate of 4.8% per annum to the 2.6% now forecast [2] is equivalent to a savings of 7.9% of TDTE in 1980 and 18.9% in TDTE in 1990. While not a conservation opportunity in the sense of an applied "measure", the effect of these factors should be included in overall fuel consumption calculations.

2.2 BUS

Bus service and energy-consumption data for 1972 are given in Table 2-8.

TABLE 2-8. BUS SERVICE AND ENERGY CONSUMPTION, 1972*

	URBAN		INTERCITY	TOTAL
	Transit[1]	School		
Direct fuel consumed				
thousand bbl/day	22	21	14	57
million gal/year	344	320	217	881
trillion Btu/year[2]	47	39	30	116
percentage of TDTE	0.25	0.21	0.16	0.63
Service rendered				
million vehicle-miles/year	1,470	2,359	1,280	5,109
million passenger-miles/year	17,640	52,824	25,600	96,069
Average efficiency				
Btu/passenger-mile	2,681	743	1,170	1,210

[1] Includes airport and sightseeing buses.

[2] Conversion factors are 136,000 Btu/gal for diesel powered transit and intercity, and 125,000 Btu/gal for school buses, which use gasoline.

*Source: Reference 13.

TABLE 2-7. DISTRIBUTION OF AUTOMOBILE TRAVEL BY PURPOSE*

Purpose of Travel	Percentage of Trips	Distribution of Travel (VMT)	Average Trip Length One Way (Miles)
Earning a living:			
To and from work	32.3%	34.1%	9.4
Business related to work	4.4	8.0	16.0
Total	36.7	42.1	10.2
Family business;			
Medical and dental	1.8	1.6	8.3
Shopping	15.4	7.6	4.4
Other	14.2	10.4	6.5
Total	31.4	19.6	5.5
Educational, civic, or religious	9.4	5.0	4.7
Social and recreational:			
Vacations	0.1	2.5	165.1
Visit friends or relatives	9.0	12.2	12.0
Pleasure rides	1.4	3.1	19.6
Other	12.0	15.5	11.4
Total	22.5	33.3	13.1
All purposes	100.0%	100.0%	8.9

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[*] Source: Reference 11.

improvement projects from such sources as TOPICS. It seems likely that at least a decade will be required before the full 15% reduction in stops can be achieved.

2.1.8 Travel Reduction

Table 2-7 shows a breakdown of passenger-car use by trip purpose, which clearly indicates that a substantial portion of auto travel is conducted for discretionary purposes. Whenever gasoline is in short supply, it is this travel that can be expected to bear the brunt of the cutback in auto use, as was indeed evident in the winter of 1973-74.

Rather large gasoline savings, amounting to several billion gallons per year, can be achieved through travel reduction. So long as the period of forced travel reduction is relatively brief, no fundamental damage to the economy is likely to result, but hardships within certain sectors, notably recreation and auto sales and service, are apt to be severe. Hence, this option cannot be regarded as politically viable except in emergency situations, such as the Arab oil embargo.

Over the long run, there is reason to believe that the growth in demand for automotive travel will be much slower than has been characteristic of the past decade, even without explicit disincentives to auto use. Of particular importance are the increases in the cost of single-family, detached houses relative to other housing, and the decrease in family size. Both of these are associated with a trend toward higher residential densities, which in turn are associated with less automobile use than is characteristic of traditional suburban development. In a recent study [12] it was estimated that a high-density planned community would generate 44% fewer vehicle-miles of travel than one characterized by traditional sprawl. Even a community whose housing consisted of equal

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*From 1965 to 1972, the annual growth rate in passenger car miles traveled was 4.82%.

and analyze existing traffic flows and modify signal cycles to maximize flow for the current traffic conditions.

Not only does improved traffic flow reduce travel time, it also improves automobile operating efficiency. If a steady speed of 25 mph can be maintained, energy consumption per vehicle-mile is only about 60% as much as it is in normal stop-and-go city driving.

Theoretical calculations suggest that a 1% reduction in the number of stop-go cycles in a typical urban trip will cut fuel consumption by 0.2% [10]. By arbitrarily assuming that traffic flow improvement programs such as the FHWA's TOPICS (Traffic Operations Program to Increase Capacity and Safety) will eventually yield a 15% reduction in the number of stops per typical urban journey, one can anticipate a savings of about 3% of urban auto energy usage. This would have been almost 1.0% of TDTE, had such measures been fully implemented in 1972. Since more than a decade will be required for installation, and since automobile fuel consumption in the future will represent a smaller share of TDTE, savings estimates for flow improvements are limited to 0.4% of TDTE in 1980 and 0.7% of TDTE in 1990. Since emissions are highest during acceleration, traffic-flow improvements will tend to improve air quality somewhat. These improvements may be significant elements in the Clean Air Plans of some central business districts. Reduced congestion may also tend to lower the incidence of "fender-benders" in urban driving and the associated property-damage costs. The safety implications for freeways are not clear, however, inasmuch as the number of accidents will probably be reduced, but severity may increase because of the higher speeds associated with freely flowing traffic.

Expenditures over the next decade on flow improvement projects may exceed one billion dollars, paid out of Federal and State gasoline tax revenue. However, flow improvement projects are generally performed for reasons other than fuel savings and, hence, may be viewed as a net benefit for the motorist worth about 0.2¢ per mile to the automobile owner in fuel and reduced maintenance. Timing is largely contingent upon the amount of money made available for

The potential savings to a particular motorist depend on just how bad his habits are and to what extent he might be willing to change. Thus there are no meaningful estimates of fuel savings, other than that they are relatively small and that their realization would be paced by the introduction of fuel meters in new cars beginning late in this decade.

Finally, it should be noted that the driving style that favors fuel economy also lowers emissions slightly, and the avoidance of jackrabbit starts, tailgating in city traffic, and sudden stops will also reduce minor accidents. However, the motorist who watches his fuel-economy meter at highway speeds will find that the most efficient thing to do is to tailgate trucks and station wagons, which could lead to some increase in serious accidents.

2.1.7 Traffic Flow

Throughout the country, highway engineers are exploring various means of eliminating bottlenecks, increasing flow rates, and minimizing trip times. In general, these efforts can be expected to reduce energy consumption, although where successful, they tend to increase the attractiveness of the automobile compared to its more energy-efficient competitors. At present many techniques are being used to maximize flow by reducing delays at intersections. Some cities have coordinated traffic-control devices at several intersections on major arterials to maximize flow along that arterial. New York, for example, has established north-south one-way streets with lights timed so as to permit a vehicle moving at a fixed speed to travel their entire length without stopping. Synchronization of signals to a speed that minimizes energy consumption can be accomplished easily. Many communities permit a right turn on a red traffic light, which reduces idling time.

Computer tools have been developed that permit coordination of signals to maximize flow throughout an area, as opposed to maximizing flow along particular arterials. Adaptive traffic control devices have been developed, and are currently being tested (Washington, D.C.), that continuously detect, quantify, For the average motorist, a 1.5% reduction in fuel consumption amounts to a savings of about $7 per year. Unfortunately, one extra tune-up per year is likely to add at least $30 a year to maintenance costs, clearly rendering the measure cost ineffective from the point of view of the consumer. Gasoline prices of more than $2 a gallon would be required to generate an economic incentive for tune-ups at 6000-mile intervals. Hence, there is little likelihood that any significant savings of fuel will ever be achieved through improved maintenance. For a motorist willing to bear the expense, 6000-mile tune-up would raise the net cost of driving by 1.4%, or about 0.2¢ per mile.

2.1.6 Driving Habits

In the course of fuel-economy tests, differences in mpg as large as 20% have been demonstrated to result from differences in drivers' behavior. However, empirical data on the quality of the driving habits of the general population are unavailable, so only conjectural estimates of potential fuel savings are possible at this time. Since most drivers are assumed to be neither especially good nor especially bad with regard to driving habits, the potential fuel-economy improvement is considered to be much less than 20%, probably something on the order of 5%. It is doubtful that any gain can be achieved at all, however, without some means of instructing each driver individually as to how his habits affect fuel consumption. This task would be best accomplished through installation of a fuel-economy meter in every car, which would provide the necessary instant feedback. Although the simple manifold vacuum gauges now being advertised as fuel-economy meters are inadequate and sometimes misleading, the development of accurate, low-cost instruments is well advanced. These instruments should be ready for introduction in some new cars by 1976 or 1977. By 1980, they should be available in any quantity needed. Manufacture and installation of these devices as integral parts of the fuel-metering systems of future new cars could be accomplished for about $15. However, retrofitting the existing cars would probably cost at least $50 per vehicle.

> On the sales weighted average basis the 1980 new vehicle fuel economy improvements also appear to be 18% (based on assessment of four representative vehicles). More importantly the 1980 intracity vehicles exhibit fuel economy improvement potential of only 14-17%; hence manufacturers with a preponderance of such vehicles would find it extremely difficult to comply with a legislated 20% fuel economy improvement...
>
> The analysis found the most significant payoff technology options to be: increased utilization of diesel engines (vs. gasoline engines); optimized cooling systems (including variable speed fan drives); radial tires (or wide-base singles) and engine power and speed derating. Greater fleet-wide improvements could be realized by 1980 if production of diesel engines and radial (or wide-base single) tires could be expanded more rapidly than present trends indicate.
>
> No environmental or safety degradation could be identified with the suggested technology options. Noise would be reduced by the cooling system and tire changes but somewhat increased by the expanded diesel engine use. Exhaust emissions are substantially reduced by the substitution of diesel engines, and are not expected to increase as a result of other options. On the other hand, industry has expressed concern over the detrimental effects on fuel economy of existing and proposed safety, emission and noise regulations. There is uncertainty as to future emission standards to be applied to trucks and buses. Therefore, estimates of their impact on fuel consumption of 1980 vehicles are not attempted. There is no fuel economy penalty associated with current EPA or California standards using best technology.

While these efficiency improvements will raise the purchase price of trucks by amounts ranging from $400 to more than $1,000 they are cost-effective. Indeed fuel prices are already well above the economic breakeven point for many contemplated improvements [23].

3.1.3 Load-Factor Improvement

In the interest of reducing both cost and energy consumption, consideration is being given to proposals to increase truck load factors (expressed in ton-miles per vehicle-mile). One method, which has already been implemented to some extent,* entails raising statutory limits on vehicle size and weight. Another approach

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*The Federal Aid Highway Amendments of 1974 raised Federal limits on interstate highways, but did not require the states to raise their own limits.

requires removal of certain regulatory constraints that result in circuity or empty backhauls. The ICC has begun removing some of these constraints and the President has proposed legislation eliminating many more of them. Investigation of both methods is still in a preliminary stage, so the savings described below must be regarded as tentative.

In the course of discussion of the 55-mph speed limit, representatives of the trucking industry indicated that increasing vehicle weight limits and size limits about 10% would offset the productivity losses associated with the speed limit. If, in fact, all state weight limits are revised upward to conform with the new Federal limits, an increase in load factor of five to ten percent on large intercity freight trucks (5-axle combination) could be achieved. Applying this increase to the 1972 data for heavy intercity trucking yields a savings of about 250 to 500 million gallons of fuel, or 0.18% to 0.37% of TDTE.

With regard to the possibility of regulatory changes, it has generally been the position of the certificated carriers that present regulations do not result in excessive empty mileage, at least in their own operations. They argue that any improvement in utilization from less stringent regulations would be insignificant. If there are appreciable gains to be made in this area, they would have to come among the exempt and private carriers, for whom useful data are quite scarce.

Some light has been shed upon potential energy savings, however, by a recent study of fourteen private trucking operations [24]. It was found that about 29% of mileage operated annually by these carriers could be eliminated if certain regulations restricting intercorporate hauling were removed. Applying this value to 1.361 billion gallons of fuel used by private intercity combination trucks in 1972 [13] yields annual savings of 395 million gallons, or about 0.3% of TDTE.

In local trucking, factors such as service quality so dominate the issue that no quantitative analyses of possible fuel savings have been attempted. On the basis of reductions of 25% in vehicle-miles traveled observed by some local trucking firms as a result of careful route engineering and terminal revisions, Peat, Marwick, Mitchell estimated [25] that for the local-trucking industry as a whole, a 10% reduction in VMT might be achieved yielding a savings of about 1.2 billion gallons, or about 0.9% TDTE.

Summing up the total potential energy savings from increased truck load factors, one arrives at a value of about 1.4% of TDTE. While these gains could be achieved as early as 1980, their realization must be regarded as problematical because of the many conflicting factors impinging upon the decisions of the state legislatures regarding weight limits and upon trucking companies regarding operating practices. To the extent that the gains are realized, a small reduction in truck emissions will ensue, as well as some decline in accidents because of reduced vehicle-miles traveled. On the other hand, higher truck weights have been a source of concern, because of possible increased accident risks and increased wear on highways. These issues are currently under exploration by the FHWA Task Force on Truck Load Limits.

3.1.4 Speed Limits

As is the case for automobiles, truck fuel economy on the highway has been improved by reducing average speed. Estimates of the impact of full compliance with the 55-mph limit for both single-unit and combination trucks are included in Table 2-3. It is evident that for a given speed reduction, the fuel-savings percentage for trucks is greater than that for passenger cars. This results from the relatively high aerodynamic drag associated with the boxy shapes characteristic of trucks. The estimates of total fuel savings associated with various degrees of compliance with the 55 mph limit shown in Table 2-4 include those from trucks.

Among the beneficial side effects of lower truck speeds are reduced emissions and lower frequency and reduced severity of accidents. However, the lower speeds are not cost-effective for truckers, since their fuel costs decrease by only about 0.03 cents per ton-mile while their other costs (driver wages, equipment amortization, etc.) increase by more than 0.3 cents per ton-mile.

The net result is an increase in average total cost of about 4%, assuming a change in average line-haul speed from 60 to 55 mph.*

3.2 AIR FREIGHT

Table 3-2 presents 1972 service and consumption data for scheduled air-freight services.

TABLE 3-2. AIR FREIGHT SERVICE AND ENERGY CONSUMPTION, 1972**

	Air Freighter	Lower Hold	Total
Direct fuel consumed			
thousand bbl/day	24	3	26
million gal/year	364	39	402
trillion Btu/Year[1]	46	5	51
percentage of TDTE	0.2%	--	0.3%
Services rendered			
million ton-miles/year	1,691	1,561	3,252
Average efficiency			
Btu/ton-mile	27,000	3,100	15,527

[1] Conversion factor: Jet fuel - 125,580 Btu/gal.
Aviation gasoline - 111,190 Btu/gal.

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*The American Trucking Association reported average expenses of $1.32 per intercity vehicle-mile in 1972 [26]. (This is equivalent to 10.2¢ per ton-mile for average load factor of 12.94 ton-miles per vehicle-mile, estimated by the FHWA Office of Highway Statistics [13]. Of this $1.32, about 50¢ (driver wages, vehicle licenses, and amortization) may be regarded as proportional to vehicle-hours.)

**Ton-mile data are from reference 15. Ton-miles include all freight, express and mail on scheduled flights. The ton-mile split between freighters and passenger/cargo lower holds is from reference 27. Fuel data are based on ton-miles and estimated average fuel consumption. Freighter fuel efficiency is from reference 28; lower-hold fuel efficiency is from reference 29.

Air transportation is generally considered to be the most fuel-intensive mode of freight movement; as a result, it is a frequent target of strategies aiming to reduce transport fuel consumption (the most common of which is shifting air cargo to intercity truck transport — see Section 4.6). The savings potential of all these strategies is very limited because the share of transportation energy consumed by air cargo service is so small. In 1972, scheduled air-cargo service consumed only 0.3% of TDTE. Assuming an 11% annual growth rate [2] and no efficiency improvements, air cargo service can be expected to consume 1.5% of 1990 TDTE. This is a substantial increase, but even with this optimistic forecast, air-cargo fuel consumption remains relatively unimportant.

Air freight is carried in two ways — by air freighter and in the lower hold of passenger/cargo (P/C) aircraft. The fuel consumption for each type of service cannot be determined directly from available data. Hirst [28] reports that air freighters consumed 27,000 Btu per ton-mile in 1970, and the figures presented here are based on that estimate. 1972 CAB data indicate that air-freighter service by all-cargo carriers (20% of scheduled air-freighter services) consumed 22,500 Btu per ton-mile; this higher efficiency may be due to higher load factors for these carriers. If this consumption is representative of air-freighter flights by the P/C carriers (who operate both P/C aircraft and the bulk of air-freighter aircraft), the estimates of fuel consumption for air-freighter service may be as much as 17% too high.

Hirst [28] estimated average air-cargo fuel consumption -- for both freighter and P/C service -- as 42,000 Btu/ton-mile. Implicit in this estimate is the assumption that passenger and cargo traffic are equally responsible for the use of the P/C aircraft. Contrary to this, it is assumed here that passenger traffic provides the incentive for P/C flights and that freight carried in the lower hold of these aircraft is responsible only for the marginal fuel consumption required to lift its weight. Marginal fuel consumption varies with the type of aircraft, flight stage length, flight profile, etc.; on the basis of aircraft manufacturer's performance data and a representative set of operating conditions, the average marginal fuel consumption for lower-hold freight is estimated to be 3100 Btu/ton-mile, which is equivalent to 40.5 ton-miles per gallon [29].

Conservation opportunities in air cargo are limited by the small amount of fuel consumed and the characteristics of the service. Load factor has no bearing on lower-hold cargo fuel consumption, which is purely a function of the cargo's weight. Freighter fuel consumption per ton-mile could be reduced by increasing load factors, but substantial improvements seem unlikely since they would require substantial service frequency reductions, which conflict directly with the principal selling point of air cargo. Estimated savings that could be realized from operational changes in the P/C fleet are discussed in Section 2.3. For air freighters, the operational change with the most potential is a cruise speed reduction. It is estimated that this change would reduce P/C fleet fuel requirements by 3% (see Section 2.3); if this reduction also applied to the air freighter fleet, its fuel requirements would be reduced by 68.5 million gallons of jet fuel in 1990 – only 0.04% of 1990 TDTE.

The one change that could save a modest amount of fuel is one that is likely to occur anyway due to economic pressures – increased use of lower-hold freight capacity by the P/C carriers at the expense of air freighter services. The substantial growth in air-cargo service during the 1960's can be attributed primarily to two factors: a declining price of the service in constant dollars, and the large increase in capacity provided by the narrow-bodied freighters coupled with their unitized loading/unloading capability. Continuation of this growth since 1970, when the wide-body passenger aircraft were introduced, can be attributed to the greatly increased capacity of the wide-bodied lower hold and the continued price decrease made possible by the reduced operating costs and service times of their containerized lower-hold systems. Further growth of domestic air-cargo service will also be tied to these two factors [29].

CAB data [27] indicate that lower-hold capacity was used to carry 48% of air-cargo ton-miles in 1972. If the share of ton-miles carried in P/C aircraft lower holds increases to 60%, 1980 fuel savings will be 143 million gallons of jet fuel (0.1% of projected TDTE) and 1990 savings will be 404 million gallons of jet fuel (0.2% of projected TDTE).

3.3 RAIL

Rail service and energy-consumption data for 1972 are presented in Table 3-3.

TABLE 3-3. RAIL FREIGHT SERVICE AND ENERGY CONSUMPTION, 1972*

Direct fuel consumed	
thousand bbl/day	252
million gal/year	3,874
trillion Btu/year[1]	539
percentage of TDTE	2.93
Service rendered	
vehicle-miles/year	N/A
ton-miles/year	785,000
Average efficiency	
Btu/ton-mile	676

[1] Conversion factors: 138,000 Btu/gal, 10,400 Btu/kWh

*Source: Reference 19, adjusted to remove passenger train use.

Dramatic improvements in rail energy efficiency occurred during the postwar years through dieselization. That technology is now mature, so that only very minor additional gains are possible, mainly through turbo-charging more locomotives. However, significant *petroleum* savings may eventually be achieved through rail electrification - perhaps as high as 2% of TDTE. The subject is being studied by several major railroads at the moment. While the case for electrification is not so compelling as to demand immediate implementation, it is widely believed that long-term trends in fuel prices (i.e. higher rates of increase for liquid fuels than for electricity) may ultimately result in the construction of catenary over the high-density lines in the U.S., which constitute 10-25% of the track mileage but are responsible for 80% or more of rail ton-mileage. Because of the enormous construction costs involved,* electrification will necessarily be a slow process, with major construction projects beginning in the late 1970's and running through the 1990's.

The current generation of electric locomotives exhibits about the same overall efficiency as the diesel-electrics, hence they offer no energy savings - only a petroleum savings. However, the next generation of electric locomotives, which should begin to enter the fleet in the 1980's is expected to incorporate regenerative braking resulting in an overall energy savings of 25 to 40%. Assuming that electrification is justifiable on lines carrying 80% of the ton-mileage and that implementation is half complete by 1990, the petroleum savings should amount to about 150 thousand bbl/day, while the energy savings could be equal to as much as 0.6% of 1990 TDTE.

Besides these technology changes, it is also possible that the rail traffic mix may shift more toward bulk commodities hauled in unit trains, These trains operate as efficiently as 300 Btu/ton mile. An increasing market share for them will improve the overall rail efficiency rating, but this effect has not been quantified.

3.4 WATER

Water-freight service and energy-consumption data for 1972 are shown in Table 3-4.

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*Estimated by TSC staff at $300,000 per mile in dollars discounted back to 1974 (or $15 billion for the 50,000 miles which might eventually be electrified). Electric locomotives are no more expensive than the diesels they will gradually replace as the latter wear out. Capital expenditures for electric generating plants have not been estimated, but may impose a major constraint.

TABLE 3-4. WATER FREIGHT SERVICE AND ENERGY CONSUMPTION, 1972*

	LOCAL	LAKEWISE	RIVERS & CANALS	COAST-WISE	TOTAL
Direct fuel consumed					
thousand bbl/day	N/A	N/A	N/A	N/A	146
million gal/year[3]					2,237
trillion Btu/year[1]					313
percentage of TDTE[1]					1.70
Service rendered					
million miles/year[2]	1,300	73,100	177,500	351,500	603,500
Average efficiency					
Btu/ton-mile	N/A	N/A	N/A	N/A	509

[1] Conversion factor: 140,000 Btu/gal

[2] Source: Reference 19.

[3] Source: Reference 30.

Available data suggest, that in terms of direct energy consumption per ton-mile, water carriers are the most efficient of all freight modes. (However, since there is often greater circuity in water routes than land, the net energy cost of a movement between a particular city pair may be about the same whether material is transported by water or rail or pipeline.) Some additional efficiency improvement can be expected to result from the economies of scale associated with the trend toward larger vessels and tows, and from certain operational changes such as switching barges in and out of tows without stopping. A 10-20% efficiency improvement might be achieved, but because total marine energy consumption is only 1.7% of TDTE, the savings would amount to only 0.2 or 0.3% of TDTE.

3.5 PIPELINE

Pipeline service and energy-consumption data for 1972 are given in Table 3-5.

TABLE 3-5. PIPELINE SERVICE AND ENERGY CONSUMPTION, 1972*

	OIL	NATURAL GAS	TOTAL
Direct fuel consumed			
thousand bbl/day	N/A	N/A	N/A
million gal/year			
trillion Btu/year	317	791	1,093
percent of TDTE	1.64	4.30	5.94
Service rendered			
vehicle-miles/year	N/A	N/A	N/A
million ton-miles/year	480,000	300,000[1]	757,000
Average efficiency			
Btu/ton-mile	660	2,637	1,528

[1] Conversion to ton-miles/year uses a factor estimated by TSC staff, assuming the average distance from source to market to be the same as for oil

*Sources: Oil ton-miles, Reference 19; pumping energy, TSC staff estimate from engineering-handbook formulas. Gas pipeline volume and pumping energy, Reference 31.

Oil pipelines are relatively efficient carriers already and can be further improved only through increases in their effective diameters ("looping"). Such increases will take place only gradually, and only if product flows increase significantly, which seems doubtful. Gas pipelines rank rather poorly on a Btu/ton-mile scale, but their high energy consumption results directly from the low density of gaseous products. Significant changes in efficiency are not anticipated, although decline of gas supplies may reduce absolute energy consumption quite substantially during the 1980's.

In large sizes (38", 25 million tons per year) coal slurry pipelines have an efficiency equal to or better than unit trains, roughly 300 Btu/ton-mile. While no appreciable net energy saving is involved in using pipelines to move new coal production, the use of electric power for pumping saves petroleum.

4. MODE SHIFTS

4.1 URBAN AUTO TO BUS TRANSIT

Table 4-1 compares consumption and service data for these two modes.

TABLE 4-1. URBAN-AUTO AND BUS-TRANSIT SERVICE AND ENERGY CONSUMPTION, 1972*

	Urban Auto	Bus Transit
Direct fuel consumed		
thousand bbl/day	3,077	22
million gal/year	47,303	344
trillion Btu/year[1]	5,913	47
percentage of TDTE	32.2	0.3
Service rendered		
million vehicle-miles/year	557,875	1,470
million passenger-miles/year	1,059,962	17,640
Average efficiency		
Btu/passenger-mile	5,578	2,681

[1] Conversion factors are 124,950 Btu/gal for gasoline and 138,690 Btu/gal for diesel fuel.

*Sources: Automobile vehicle-miles, Reference 4. Urban-auto fuel, calculated from References 4 and 5. Auto passenger-miles, and all bus data, from Reference 13.

Approximately 37% of the energy consumed in transportation in the U.S. during 1972 was used for urban passenger transportation. Of the 1.2 trillion urban passenger-miles traveled, 96% were provided by private automobile and private truck, 1.5% by bus, and 1.5% by rail. Since the efficiency of the urban bus (passenger miles per gallon) is more than twice that of the automobile, the diversion of urban travel from automobile to bus appears to offer substantial fuel savings.

This potential would be even greater if the low average load factors (12 passenger-miles per vehicle-mile in 1972, or about 30%), were improved. Average load factors could be increased somewhat by service improvements and economic incentives, as evidenced by the fact that the 1960 average load factor was 19; but, to a large extent, urban bus load factors are limited by the substantial "temporal" peaking characteristics exhibited in urban travel. This phenomonon is the result of the American work-hour pattern, which requires the vast majority of workers to travel to and from work within one or two hour periods. Public transit trips are the most highly peaked, and becoming even more so; for bus service, one peak hour is typically 10 to 15 percent of total daily travel [22]. Busses used to transport peak-hour loads must either be withdrawn from service or operated at low load factors during off-peak hours. Even during peak hours, the traffic is so uni-directional that back hauls must be run at very low load factors.

Although average bus load factors could be raised by pulling equipment out of service during off-peak hours, this would not increase the passenger-miles carried per bus per year, and could decrease total passenger-miles per bus by reducing overall service frequencies and discouraging demand. Improving the productivity of urban buses (average load factor and annual passenger-miles per bus) to any substantial degree will require not only increased patronage, but also major changes in urban lifestyles - such as varying work hours and increased residential densities. The potential fuel savings of this mode shift are limited by the availability of bus equipment and the annual productivity of urban buses. In 1972, there were 49,075 buses in use for urban public transit [22]; on the average, each bus provided 359,000 passenger-miles of service during the year at an average load factor of 12 passenger-miles per vehicle-mile. Currently, urban-bus production in the U.S. is 3,400 a year - most of which are replacement equipment. Full one-shift production capacity is estimated at 7200, and two-shift capacity near 14,000 [32]. With the addition of imports, and use of smaller buses where possible, it is estimated that 12,000 buses could be put into "new" services each year, given sufficient motivation. If this were done, and if annual productivity for all buses climbed back to its 1960 average of 557,638 passenger-miles per bus, a moderate amount of projected urban-auto travel could be diverted to bus-transit services. By 1980, 50.4 billion urban-auto passenger-miles (3.9% of projected 1980 urban-auto travel) could be diverted; by 1990, 121.7 billion passenger-miles (7.2% of the projected 1990 urban-auto travel) could be diverted. The cumulative discounted cost of the buses through 1990 is $5.9 billion.

The fuel saved by this diversion is a function of vehicle fuel consumption and vehicle load factor for both buses and autos. On the basis of the analysis presented in section 2.1 and 2.2, and assuming the ratio of urban-auto to intercity-auto fuel efficiency remains constant, 1980 and 1990 urban-auto fuel consumptions were estimated to average 13.9 and 20.7 vehicle-miles per gallon respectively. Assuming constant urban-auto occupancy rates (load factor) and bus fuel consumption rates, and increased bus load factors of 19 passenger-miles per vehicle-mile, the net energy savings per passenger-mile diverted would be 2825 Btu in 1980 and 1358 Btu in 1990. These figures are based on a substantial improvement in urban-auto fuel consumption, which averaged only 11.8 vehicle-miles per gallon in 1972.

For the diversion capacities and net fuel savings estimated, 1980 fuel savings would be 1,139 million gallons of gasoline (0.7% of 1980 TDTE) and 1990 savings would be 1,323 million gallons of gasoline (0.8% of 1990 TDTE). These estimates indicate that the bus-equipment (and resulting diversion-capacity) additions made in the 1980's would produce diminishing fuel savings per passenger-mile diverted because of the increases in urban-auto fuel efficiency.

The energy savings achievable from diversion of urban-auto travel would be of only moderate importance because of the limitation on new bus-equipment production, and the expected improvements in urban-auto fuel efficiency. Even without the equipment constraint, the fuel savings a massive diversion would produce are small in comparison to the capital costs required. This, of course deals only with marginal fuel savings; bus systems - and their attendant improvements in traffic congestion, air quality, safety, and mobility - are an important urban resource.

4.2 URBAN AUTO TO RAIL

Table 4-2 compares consumption and service data for these two modes.

TABLE 4-2. URBAN-AUTO AND RAIL SERVICE AND ENERGY CONSUMPTION, 1972

	Urban Auto[1]	Rail Transit[2]	Commuter Rail[3]
Direct fuel consumed			
thousand bbl/day	3,077	N/A	N/A
million gal/year	47,303	N/A	N/A
trillion Btu/year[4]	5,913	25	11
percentage of TDTE	32.2	0.1	0.1
Service rendered			
million vehicle-miles/year	557,875		
million passenger-miles/year	1,059,962	15,344	4,228
Average efficiency			
Btu/passenger-mile	5,578	1,646	2,493

1. See footnote to Table 4-1 for sources.
2. Fuel data from Reference 21; passenger-mile data calculated from passenger data in Reference 21 using passenger-mile/passenger ratio of Reference 22.
3. Fuel data from Reference 20; passenger-mile data from Reference 19.
4. Conversion factors are 124,950 Btu/gal for gasoline, 138,690 Btu/gal for diesel fuel, and 10,400 Btu/KwHr.

Rail transit (surface rail, subway, and elevated) accounted for an estimated 15.3 billion passenger-miles in 1972 (about 1.3% of total urban travel), while commuter-rail service provided an additional 4.2 billion passenger miles (about 0.4% of urban travel). Although these services consume less fuel per passenger-mile than the automobile, the potential for expanded use of urban rail services is limited by the small number of cities with population-density patterns capable of supporting rail-transit systems. In the long run, use of rail transit could induce greater urban concentration and thereby reduce average trip lengths and fuel consumption; the investment required is so large, however, that construction of rail transit systems cannot be justified solely by their potential fuel savings.

4.3 URBAN AUTO TO BICYCLE

Table 4-3 compares consumption and service data for these two modes. The automobile data are for trips of 5.5 miles or less, since longer trips are poor candidates for diversion.

TABLE 4-3. URBAN-AUTO AND BICYCLE SERVICE AND ENERGY CONSUMPTION, 1972

	Urban Auto[1]	Bicycle
Direct fuel consumed		
thousand bbl/day	1,049	0
million gal/year	16,127	0
trillion Btu/year[2]	2,015	0
percentage of TDTE	11.0	0
Service rendered		
million vehicle-miles/year	158,436	N/A
million passenger-miles/year	301,029	N/A
Average efficiency		
Btu/passenger mile	6,694	-

[1] The sources of the urban-auto data are given in the footnote to Table 4-1. The portion attributable to short trips was determined from reference 11.

[2] The conversion factor for gasoline is 124,950 Btu/gal.

Diversion of automobile passenger travel to the bicycle is often suggested as a fuel-conservation tactic, since short auto trips (less than 5.5 miles one way) constitute more than half of all automobile trips,* and fuel savings per passenger-mile would be 100%. This tactic's fuel conservation potential is limited, however. First, even though short trips constitute over half of all automobile trips, they constitute only 16% of auto passenger-miles.* Second, significant diversion seems unlikely, since climate, trip purpose, safety, physical ability, and especially social custom are strong barriers to widespread acceptance.

If 70,000 miles of urban bikeways were constructed (a figure comparable to the total route-miles of transit systems) during the next decade at a cost of about $1 billion,** about 5% of auto short-trip passenger-miles could be diverted to bicycle by 1980 (1.3% of urban-auto passenger-miles) and about 8% could be diverted by 1990 (2.4% of projected urban-auto passenger-miles). These estimates were made under the assumption that the diversion would be maximum for trips less than one mile (10% diversion in 1980, 20% diversion in 1990) and would decrease linearly to zero for trips over 5.5 miles in all years.

The fuel savings for such a shift are a function of the projected urban-auto fuel consumption. As discussed in the previous section, average urban-auto fuel consumption is projected to be 13.9 and 20.7 vehicle-miles per gallon in 1980 and 1990, respectively. The fuel consumption for short auto trips, which involve the most stop-and-go driving, is higher than the urban average, however. Hirst reports that gasoline consumption for trips of five miles and under is 20% higher than the urban average [33]. Assuming this relationship continues, projected auto fuel consumption for short trips is 11.54 and 17.23 vehicle-miles per gallon for 1980 and 1990 respectively. Using these estimates, and assuming the average auto occupancy remains at the 1972 level of 1.9 passengers for urban travel (for both short trips and all urban

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*Based on trip-length distribution data in Reference 11.

**Based on average costs of $15,000/mile (Reference 47), which assumes no right-of-way acquisition cost, i.e. bikeways would be built on public lands such as existing streets (by closing them to through traffic or removing parking), park lands, river banks, utility and transit rights of way.

trips) [33], the fuel savings for the diversion estimates described would be 772 million gallons of gasoline in 1980 (equivalent to 0.5% of projected TDTE) and 1234 million gallons in 1990 (0.7% of projected TDTE).

The potential savings for a shift to bicycling are not large. However, their cumulative discounted value exceeds the cost of constructing the bikeways, and the added benefits of exercise, relief of traffic congestion, and reduction of air and noise pollution make bicycling an option to be encouraged.

4.4 INTERCITY AUTO TO INTERCITY BUS OR RAIL

Table 4-4 compares consumption and service data for these three modes. The automobile data are for trips exceeding 50 miles one way.

TABLE 4-4. SERVICE AND ENERGY CONSUMPTION FOR INTERCITY AUTO, BUS, AND RAIL TRAVEL, 1972

	IC Auto[1]	IC Bus[2]	IC Rail[3]
Direct fuel consumed			
thousand bbl/day	953	14	N/A
million gal/year	14,656	217	N/A
trillion Btu/year	1,831	30	15
percentage of TDTE	10.0	0.2	0.1
Service rendered			
million vehicle-miles/year	243,643	1,280	N/A
million passenger-miles/year	631,034	25,600	4,164
Average efficiency			
Btu/passenger-mile	2,902	1,170	3,533

[1] Base data from section 2.1.1.

[2] Data from Reference 13.

[3] Fuel data from Reference 20; passenger-mile data from Reference 19.

[4] Conversion factors are 124,950 Btu/gal for gasoline and 138,690 Btu for diesel fuel.

Diverting intercity automobile travel to current rail systems seems to have little conservation potential; 1972 intercity-rail fuel consumption exceeded intercity automobile fuel consumption by 631 Btu per passenger-mile. However, new technology trains, which may eventually be employed in some of the denser corridors, could produce substantial fuel savings for intercity travel (see Section 2.4). Intercity rail fuel consumption on these trains could be as low as 1000 Btu per passenger-mile by 1990, saving 659 Btu per passenger-mile diverted (based on 1659 Btu/pm for IC auto travel in 1990 - see Section 2). In addition, rail-system energy requirements will be increasingly supplied by non-petroleum resources - such as coal-generated and nuclear-generated electricity - further reducing petroleum consumption. It is difficult to say how extensively new-technology rail systems will be employed, but if it is assumed that new-technology rail systems sufficient to provide passenger services equal to total 1972 rail travel are put into service by 1990, 4.2 billion intercity passenger-miles could be diverted from automobile travel. Total fuel savings would be equivalent to 22 million gallons of gasoline or 0.01% of projected 1990 TDTE. It is clear that these new systems cannot be justified solely by their conservation potential.

Diverting intercity automobile travel to intercity bus service offers more immediate reductions in per-passenger-mile fuel consumption. Since the time and inconvenience required to access the bus system makes diversion of short intercity auto trips unlikely, we have chosen trips with one-way distances greater than 50 miles as potentially divertible trips; in 1972, these trips accounted for an estimated 631 billion passenger-miles* and consumed 10% of TDTE.

The potential of this diversion tactic is limited by the availability of intercity coaches; the 1972 fleet comprised 22,700 coaches and accounted for only 25.6 billion passenger-miles (2% of total intercity auto travel). Current U.S. coach production is 700 per year, and imports total 300 per year [34]. Assuming that this production/import level could somehow be quadrupled, and that

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*Based on trip-length-distribution data in Reference 11.

replacement and normal-growth equipment could also be provided, the intercity bus fleet could be almost doubled by 1980. If this were accomplished, 3% of the 1980 passenger-miles for automobile trips exceeding 50 miles in one-way trip length could be diverted to bus service. If 68,100 additional new buses were added between 1980 and 1990 (four times the number in the 1972 fleet), 76.8 billion passenger-miles (8% of 1990 automobile passenger-miles on trips exceeding 50 miles) could be diverted to intercity bus service.

The fuel that would be saved by these diversions is a function of vehicle fuel consumption and vehicle load factor, for both buses and automobiles. On the basis of the analyses in Sections 2.1 and 2.2, and provided the ratio of urban to intercity auto fuel efficiency remains constant, 1980 and 1990 intercity-auto fuel consumption should average 19.5 and 29.1 vehicle-miles per gallon, respectively. Assuming that occupancy rates for intercity-auto travel do not change, and that intercity-bus load factors and fuel consumption average the same as in 1972, the net energy saving per passenger-mile diverted would be 1305 Btu in 1980 and 489 Btu in 1990. These figures are based on a substantial improvement in inter-city auto fuel consumption, which averaged 16.6 vehicle-miles per gallon in 1972.

For the estimated diversion capacities and net fuel savings described, 1980 fuel savings would be 267 million gallons of gasoline (0.2% of projected 1980 TDTE) and 1990 fuel savings would be 301 million gallons of gasoline (0.2% of projected 1990 TDTE). As in the case of shifting urban-auto travel to transit buses, the bus equipment (and resulting diversion capability) added during the 1980's produces diminishing fuel savings per passenger-mile diverted as a result of the expected improvements in automobile fuel efficiency.

The cost of the new bus equipment would be $1.7 billion by 1980 and an additional $5.1 billion between 1980 and 1990 (figures based on $75,000 per coach). The auto-travel diversions discussed could be handled with somewhat less new equipment if bus-company operating-procedure changes increased bus load factors, or annual revenue miles per bus, or both. Even with these enhancements, however, this tactic offers small fuel savings in comparison to the required capital costs.

4.5 SHORT-HAUL AIR TO INTERCITY AUTO, BUS, OR RAIL

Table 4-5 compares consumption and service data for these four modes. The air-travel data are for trips shorter than 300 miles one-way.

TABLE 4-5. SERVICE AND ENERGY CONSUMPTION FOR SHORT-HAUL AIR TRIPS AND INTERCITY AUTO, BUS, AND RAIL TRAVEL, 1972

	Short-Haul Air[1]	IC Auto[2]	IC Bus[3]	IC Rail[4]
Direct fuel consumed				
thousand bbl/day	27	1,684	14	N/A
million gal/year	414	25,818	217	N/A
trillion Btu/year[5]	52	3,227	30	15
percentage of TDTE	0.3	17.5	0.2	0.1
Service rendered				
million vehicle-miles/year	N/A	428,532	1,280	N/A
million passenger-miles/year	6,700	1,111,843	25,600	4,164
Average efficiency				
Btu/passenger-mile	7,766	2,902	1,170	3,533

[1] Fuel data for short-haul trips derived from Reference 14; breakout of passenger versus freight consumption made according to references 15, 28, and 29. The fuel data are based on the assumption that fuel consumption per passenger-mile on short-haul trips is the same as the system average, because smaller aircraft are used for shorter stage lengths. (See Reference 16.)

[2] Sources described in the footnote to Table 2-1.

[3] Sources: Reference 13.

[4] Fuel data from Reference 20, passenger-mile data from Reference 19.

[5] Conversion factors are 125,580 Btu/gal for jet fuel, 111,190 Btu/gal for aviation gasoline, 124,950 Btu/gal for motor gasoline, and 138,690 Btu/gal for diesel fuel.

The diversion of intercity passenger traffic from air travel, the most fuel-intensive mode, to any of the three principal ground modes would save substantial fuel per passenger-mile. The potential for instituting such a shift lies in the short-haul markets (under 300 miles), where ground-transportation times are, or could be, competitive with air-travel times (including airport-access times). Diversion of medium-haul travel (over 300 miles) and long-haul travel from air to ground modes is impractical due to the unacceptable differences in trip time.

Short-haul trips constitute a large portion of the air-passenger market -- 23% of passenger trips in 1972 -- but the total travel on all short-haul trips constituted only 5.5% of air passenger-miles in 1972 [14] Since fuel consumption is directly related to passenger-miles of travel, the conservation potential of this tactic is limited. We estimate the long-term short-haul share of air passenger-miles to be approximately 7% -- the same as the 1968 share [35] -- due to the stability of business travel and the importance of discretionary travel (pleasure, vacation, family business) in long-haul markets. If 50% of this travel could be diverted to ground modes in 1980 through 1990, 0.2% to 0.4% of TDTE could be conserved.

If 50% of short-haul travel were diverted solely to intercity auto, to intercity bus, or to intercity rail, the fuel savings would be as shown in Table 4-6.

TABLE 4-6. FUEL SAVINGS FOR DIVERSION OF 50% OF SHORT-HAUL AIR TRAVEL TO GROUND MODES

Mode Diverted To	Million Gallons of Jet Fuel	Percentage of TDTE
	Savings - 1980	
IC Auto	298	0.2%
IC Bus	371	0.2%
IC Rail	240	0.2%
	Savings - 1990	
IC Auto	617	0.4%
IC Bus	666	0.4%
IC Rail	431	0.3%

Note that these savings are based on the automobile fuel-consumption projections discussed in Section 2.1, 1972 load factors for all four modes, and 1972 fuel efficiencies for air, bus, and rail. As discussed in Section 2.4, rail technology available by 1990 could lower intercity rail fuel consumption to approximately 1000 Btu per passenger-mile, an efficiency comparable to that of intercity buses. It is difficult to estimate how extensively such rail systems will be employed by that time, but to the extent that they are employed, the savings shown for rail in 1990 will approach those shown for intercity bus.

Of these three mode shifts, diversion to auto would require the least time and investment; the vehicles would be available, thus requiring no additional fixed cost, and the increased highway usage would not be large enough (less than 1% of projected IC highway passenger-miles in both years) to require significant highway investment. At 1972 load factors, diversion would require 6268 buses in 1980 at a cost of $470 million (assuming $75,000 per bus), and another 5000 buses at an additional $375 million by 1990. Diversion to rail would be even more expensive.

Although this tactic has limited potential in absolute terms, it could contribute to fuel conservation and would require little new capital investment. In addition, the other benefits might more than outweigh the minimal increases in travel inconvenience such a shift would necessitate. Short airplane stages are expensive, and they may hinder the more important, long-haul flights by increasing airport surface traffic, delays, and noise and air pollution. Door-to-door travel times for short trips by these modes are comparable, although air still has the advantage for all but the shortest trips. Increasing airport congestion at the major hubs, plus the improvement of service levels for the other modes, may soon add the extra incentive necessary to make this an attractive and feasible option [16].

4.6 AIR FREIGHT TO INTERCITY TRUCK

Table 4-7 compares consumption and service data for these two modes.

TABLE 4-7. AIR-FREIGHT AND INTERCITY-TRUCK SERVICE AND ENERGY CONSUMPTION, 1972

	AIR FREIGHT[1]		
	Air Freighter	Lower Hold	IC Truck[2]
Direct fuel consumed			
thousand bbl/day	24	3	695
million gal/year	364	39	10,678
trillion Btu/year[3]	46	5	1,438
percentage of 1972 TDTE	0.2	--	7.8
Service rendered			
million vehicle-miles/year			65,264
million ton-miles/year	1,691	1,561	393,702
Average efficiency			
Btu/ton-mile	27,000	3,100	3,653

[1] Ton-mile data is from Reference 15. Ton-miles include all freight, express, and mail on scheduled flights for both all-cargo and passenger/cargo carriers. The ton-mile split between freighter and lower-hold is from Reference 27. Fuel data are based on ton-miles and estimated average fuel consumption. Freighter fuel efficiency is from Reference 28; lower-hold fuel efficiency is from Reference 29.

[2] These data are for intercity freight service by combination trucks and heavy-duty single-unit trucks. Sources, references 4 and 13.

[3] Conversion factors are 125,580 Btu/gal for jet fuel, 111,190 Btu/gal for aviation gasoline, 124,950 Btu/gal for motor gasoline, and 138,690 Btu/gal for diesel fuel.

Air transportation is generally considered to be the most fuel-intensive mode of freight movement; as a result, it is the target of strategies to reduce transport fuel consumption. The strategy most frequently proposed is shifting air cargo to intercity truck transport. The savings potential of all the strategies is very limited because the share of transportation energy consumed in air cargo service is so small. In 1972, scheduled air cargo service consumed only 0.3% of TDTE. Assuming an 11% annual growth rate [2] and no efficiency improvements, air cargo service can be expected to consume 1.5% of 1990 TDTE. This is a substantial increase, but even with this optimistic forecast, air cargo fuel consumption remains relatively unimportant.

Air freight is carried in two ways - by air freighter and in the lower-hold of passenger/cargo (P/C) aircraft. The fuel consumption for each type of service cannot be determined directly from available data. Hirst [28] reports that air freighters consumed 27,000 Btu per ton-mile in 1970, and the figures presented here are based on that estimate. 1972 CAB data indicate that air-freighter service by all-cargo carriers (20% of scheduled air-freighter services) consumed 22,500 Btu per ton-mile; this higher efficiency may be due to higher load factors for these carriers. If this consumption is representative of air-freighter flights by the P/C carriers (who operate both P/C aircraft and the bulk of air-freighter aircraft) the estimates of fuel consumption for air-freight service may be as much as 17% too high.

Hirst [28] estimated average air-cargo fuel consumption - for both freighter and P/C service - as 42,000 Btu/ton-mile. Implicit in this estimate is the assumption that passenger and cargo traffic are equally responsible for the use of P/C aircraft. Contrary to this, it is assumed here that passenger traffic provides the incentive for P/C flights, and that freight carried in the lower hold of these aircraft is responsible only for the marginal fuel consumption required to lift its weight. Marginal fuel consumption varies with the type of aircraft, flight stage length, flight profile, etc,; on the basis of aircraft manufacturer's performance data and a representative set of operating conditions, the average marginal fuel consumption for lower-hold freight is estimated to be 3100 Btu per ton-mile, which is equivalent to 40.5 ton-miles per gallon [29].

Combination-truck fuel consumption for intercity transport averaged 2305 Btu per ton-mile in 1972; single-unit truck fuel consumption for intercity transport averaged 9636 Btu per ton-mile.

On the basis of relative ton-miles carried, 1972 truck fuel consumption for intercity freight transport averaged 3653 Btu per ton-mile. Studies by Hirst [28] report a lower figure - 2800 Btu per ton-mile for 1970 - but he considered only combination trucks.

The amount of fuel saved by shifting freight from air to truck transport would depend on whether the cargo would have been carried by air freighter or in a P/C aircraft's lower hold. During the late 1960's, approximately 45% of air-cargo tonnage was carried in lower holds; in 1972, this figure had risen to 59% [29]. The growth in lower-hold cargo parallels, and is responsible for, the overall growth in air cargo that has occurred since 1970. This growth is a result of the effort made by the combination carriers to utilize the new containerized lower-hold capability of wide-bodied aircraft, and to capitalize on the system economics this capability offers [29]. The shift in carrier emphasis from freighter service to lower-hold service, and the continued price decrease made possible by this system, have increased the share of divertable surface traffic transported by air. If it is principally this same traffic (carried at 3100 Btu per ton-mile) that would be diverted to truck transport, the fuel savings produced would be minimal, or perhaps negative. The projected 10% and 20% improvements in truck fleet average fuel consumption imply average consumptions of 3321 and 3044 Btu per ton-mile in 1980 and 1990 respectively (see Section 3.1). Without any aircraft fuel-efficiency gains, savings would be negative until the end of the 1980's, and even then would be small.

4.7 TRUCK FREIGHT TO RAIL

Table 4-8 compares consumption and service data for these two modes. In this case, only combination-truck data were used.

Since railroad freight transportation requires only a fraction of the fuel per ton-mile required by trucks, and since the two modes are suited to carry many of the same kinds of freight, concern for energy conservation has naturally included consideration of shifting some portion of intercity truck traffic back to rail.

TABLE 4-8. TRUCK-FREIGHT AND RAIL SERVICE AND ENERGY CONSUMPTION, 1972

	Combination Truck[1]	Rail[2]
Direct fuel consumed		
thousand bbl/day	490	252
million gal/year	7,537	3,874
trillion Btu/year[3]	1,008	539
percentage of TDTE	5.5	2.9
Service rendered		
million vehicle-miles/year	39,863	
million ton-miles/year	437,243	785,000
Average efficiency		
Btu/ton-mile	2,305	676

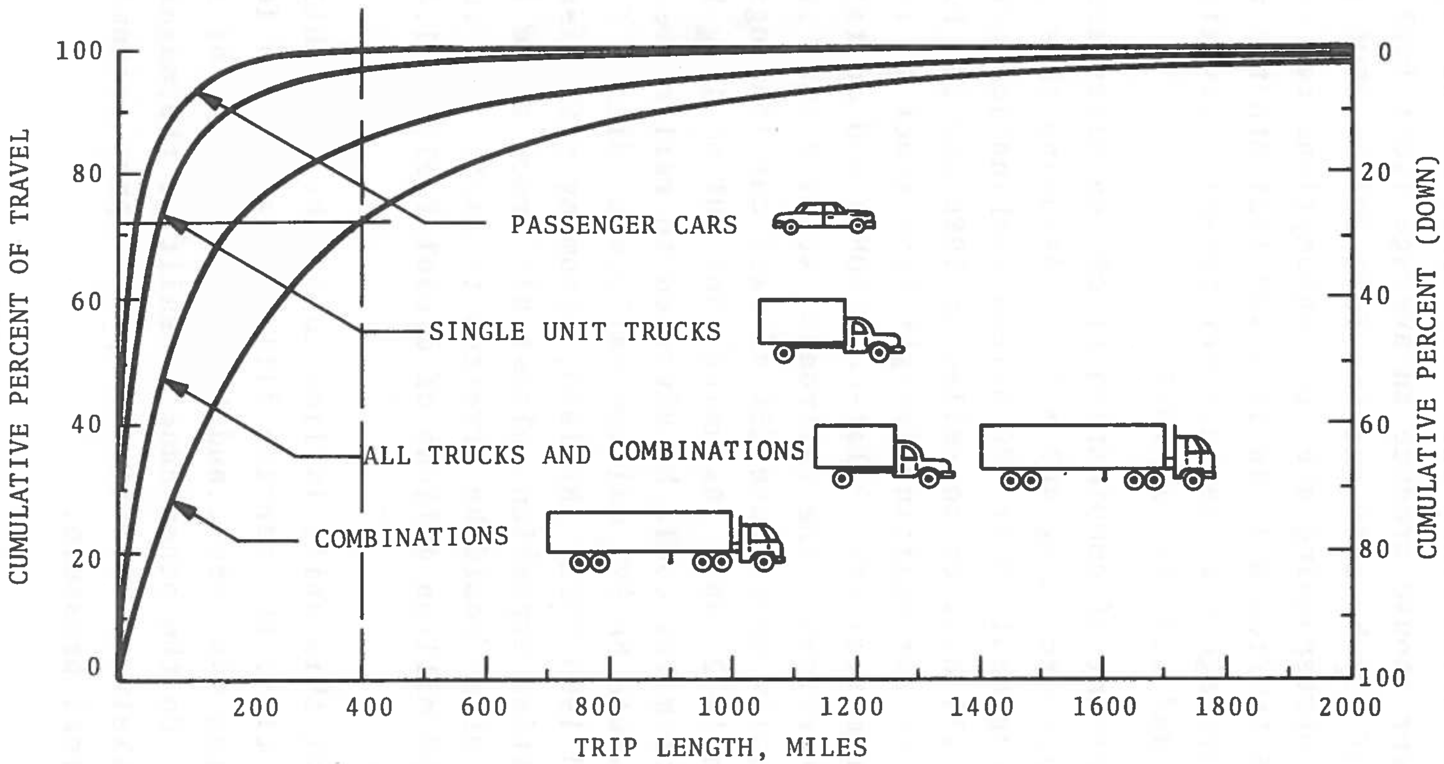
[1] From Reference 13; excludes non-freight use of combination trucks.

[2] From Reference 19, adjusted to reflect freight only.

[3] Conversion factors: 138,690 Btu/gal for diesel fuel, and 124,950 Btu/gal for motor gasoline.

Traffic diverted would be principally long-haul truck traffic; the times required to access intermodal facilities make diversion of shorter-trip-length traffic unlikely. Current trip-length distributions also show that the cost advantages of rail outweigh other service disadvantages only for longer distances: rail freight dominates markets for trip lengths exceeding 400 miles while trucks dominate markets under 400 miles [22].

The traffic that might be diverted to rail would come almost exclusively from combination trucks, which account for almost all truck ton-miles for trips over 400 miles [13]. See Figure 4-1. The net fuel savings will be the difference between rail and combination truck fuel efficiencies. Overall rail-freight fuel efficiency is projected to improve somewhat during the latter part of the next decade (see Section 3.3). However, the fuel consumption per ton-mile of diverted truck freight was assumed to be equal to



Source: Federal Highway Administration

Figure 4-1. Vehicle-Miles by Length of Trip the 1972 average because TOFC service, which is expected to be a continuously increasing share of rail traffic during this period (discussed below), adds the extra dead weight of the trailer to the rail flat car. Combination-truck fuel efficiency can be improved by 20%; fleet turnover should produce an average fleet fuel efficiency improvement of 10% by 1980 and the full 20% by 1990 (see Section 3.1). The corresponding average consumptions for combination trucks are 2095 Btu/ton-mile in 1980 and 1921 Btu/ton-mile in 1990. The net, average fuel savings per ton-mile diverted will be 1418 Btu in 1980 and 1244 Btu in 1990.

Twenty-eight percent of combination truck ton-miles are currently logged on trips exceeding 400 miles. Assuming this distribution continues, long-haul (over 400 miles) combination-truck ton-mileage will be 171 billion ton-miles in 1980 and 241 billion in 1990.* The impetus for shifting freight from truck to rail service will come from trailer-on-flat-car (TOFC) and container-on-flat-car (COFC) services. The railroads estimate that these services will eventually constitute 25% of rail car loadings, up from less than 5% in 1972 [36]. Assuming that 30% of long-haul combination-truck ton-miles could be diverted to rail service by 1980, fuel savings would be 523 million gallons of diesel fuel, or 0.4% of projected 1980 TDTE. By 1990, assuming sufficient equipment and facilities expansion, almost all truck cargo for trips exceeding 400 miles could be diverted to rail. The fuel savings would be 2160 million gallons of diesel fuel, or 1.4% of projected 1990 TDTE.

The potential of this shift is limited by the availability of equipment and facilities; the service differentials, as a function of trip length, of the two modes; and the small portion of long-haul truck mileage. On the other hand, a shift of the magnitude described here is likely to be effected by transport economics and require little external pressure.

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*Based on projections in Reference 4.

5. INDIRECT ENERGY CONSUMPTION

Through calculation of an energy coefficient* for each sector of the U.S. economy, it has recently become possible to apply input-output techniques to estimating the indirect energy costs associated with various forms of economic activity [3, 37]. These indirect energy flows are quite large in the transportation sector; they can be attributed chiefly to the following:

- refining and distribution losses of transport fuels
- construction and maintenance of vehicles and equipment
- construction, operation, and maintenance of fixed transportation-related facilities such as highways, airports, truck terminals, tracks, and ports.

Table 5-1 shows that in 1967, while direct consumption in transportation amounted to 25.3% of the total energy consumption for all purposes, indirect uses associated with transport added another 17.4%, bringing transport's share up to 42.7% of the total.

The reader is cautioned that the development of an input-output methodology for energy is still in its early stages. The preliminary results reported here are incomplete and may contain errors of 20% or more. This section is intended principally to convey a qualitative understanding of the significance of indirect energy costs. Of decidedly secondary importance are the crude estimates of some of the potential energy savings, which are likely to be substantially changed in the course of subsequent research and analysis.

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*Defined as the number of Btu's required to produce one dollar's worth of output.

TABLE 5-1. DISTRIBUTION OF TOTAL NATIONAL ENERGY CONSUMPTION (BASED ON 1967 INPUT-OUTPUT DATA)*

ENERGY USES	PERCENTAGE OF TOTAL NATIONAL ENERGY CONSUMPTION
DIRECT TRANSPORTATION	
Auto fuel	11.8
Truck fuel	4.7
Aviation fuel	3.5
All other transportation fuel	5.3
Subtotal	25.3
INDIRECT TRANSPORTATION	
Motor-vehicle manufacture, parts, tires, repairs, etc.	4.2
Highway construction and maintenance	1.7
Air, rail, and water equipment	1.9
Fuel refining and distribution losses	5.3
Facilities and operations of all common carriers plus private trucking	4.3
Subtotal	17.4
TOTAL	42.7

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[*] Sources: Total national energy consumption in 1967 is given as 58.265 trillion Btu in Reference 38. Direct energy consumption is from Reference 30, except that oil-pipeline energy was adjusted to 660 Btu/ton-mile. Indirect energy consumption was calculated from coefficients given in Reference 37 by multiplying then by industry sales from Reference 39 or modal revenues from Reference 40.

5.1 FUEL EXTRACTION, REFINING, AND DISTRIBUTION

For every Btu of refined petroleum fuel consumed in the U.S., about 1.21 Btu of primary energy must be extracted from the earth [37]. Refinery fuel and gaseous feedstocks account for almost three-quarters of this loss; the remainder is associated with development and operation of oil fields, with shipment of crude oil to refineries and petroleum products to markets, and with evaporation.

Because of these losses, a multiplier effect is associated with any measure that conserves refined fuels. On a Btu basis, each unit of refined fuel saved will, on the average, reduce crude-oil requirements by a factor of about 1.15. The difference between 1.15 and 1.21 (the total primary energy multiplier) is accounted for by the natural gas, electricity, steam, and coal used in refining and shipping petroleum.

For different end products, however, there are significant variations from this 1.15 average with the amount of processing required; the multiplier is higher for gasoline than for diesel fuel or heavy oil because gasoline requires complex processing such as catalytic cracking or alkylation. When calculations are made in volume units (e.g., bbl/day), the multiplier must also be adjusted to account for differences in energy content per unit volume.

Although conservative use of refined products is the most important means of minimizing energy losses in petroleum refining and distribution, there is also a good prospect for efficiency improvement in the refining process itself. One major oil company has reported steady progress in reducing refining energy per barrel of throughput by about 5% in each of the past several years [47]. By 1980, refining losses may be about 25% smaller than they are today [42], thereby reducing the multiplier to about 1.15 (total primary energy, Btu basis). Increased use of middle-distillate-burning engines in the 1980's (e.g., diesel, Stirling, stratified charge) could also reduce refining losses [43].

5.2 VEHICLE MANUFACTURE

Although the service lives of vehicles for most transport modes are measured in hundreds of thousands or millions of miles, conventional passenger cars and light trucks are not nearly so durable. The average auto provides only about 100,000 miles of service before it is replaced. The manufacturing energy cost of replacement is about equal to the direct energy consumption of 20,000 miles of driving. It follows that extending the useful life of cars and trucks (eventually cutting the production rate) would cut their total energy consumption - assuming, of course, that the manufacturing and maintenance energy burden of the extended-life vehicles were not appreciably greater than those of conventional cars. Motor-vehicle manufacturing energy amounts to about 20% of their direct fuel use [37], so extending vehicle life by 3 years could eventually save the equivalent of about 3% of the energy used directly by motor vehicles.

If such longer-lived vehicles were introduced in the 1980's (concomitant with the introductions of alternative engines) the savings in manufacturing energy would not be realized until the 1990's when conventional vehicles would require replacement. Hence the potential annual savings achieved in 1990 would be insignificant. During the 1990's, however, the savings might reach the equivalent of 1% of TDTE, or proportionately greater for still longer lived vehicles. Although no cost-effectiveness studies have been made, it should be recognized that longer service lives can be expected from certain auto components likely to be introduced to improve fuel economy, such as diesel engines and aluminum body parts.

5.3 MODE SHIFTS

The ratio of indirect energy consumption to direct consumption varies significantly among modes. In general, the common carriers, which achieve relatively high utilization of their vehicles, exhibit lower indirect energy costs than do private modes. Hence, the long-run total energy savings resulting from some of the mode shifts described elsewhere in this report differ considerably from the savings in direct fuel consumption alone.

Table 5.2 compares direct and indirect energy costs for five modes. Because of differences in certain assumptions, especially load factors, the direct energy-consumption values are not directly comparable with the figures shown elsewhere in this report.

TABLE 5-2. DIRECT AND INDIRECT ENERGY COSTS OF AIR, RAIL, AND AUTO TRANSPORTATION, 1971*

	Btu/PASSENGER-MILE OR TON-MILE		
	DIRECT	TOTAL	TOTAL/DIRECT
PASSENGER[1]			
Air	7,200	9,800	1.37
Rail	2,300	4,000	1.72
Auto	3,400	5,900	1.96
FREIGHT			
Air	53,600	80,000	1.45
Rail	800	1,600	1.70

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*Source: Reference 44.

[1] Passenger load factors: air, 48.5%; rail, 37.1%; auto, 2.9 passenger-miles per vehicle-mile, including driver.

Since most of the indirect energy is embodied in vehicles and structures, with service lives of ten years or more, most of the savings in indirect energy resulting from mode shifts will not be realized immediately. Rather, they will be manifested as reduced energy consumption for construction of additional-capacity or replacement vehicles in future years.

Since indirect energy costs have been calculated for only a few modes at this writing, it is not possible to estimate the total savings from all of the possible mode shifts which may occur over the next two decades. In general, however, the total long-run fuel savings appear to be at least 20% greater for a shift from private cars to common-carrier ground modes than the savings in direct fuel alone.

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