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ENERGY CONSUMPTION for TRANSPORTATION in the U.S.

Eric Hirst

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

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FOREWORD

The Oak Ridge National Laboratory is conducting an energy assessment program (particularly electric energy) with regard to environmental impacts. The program is under the auspices of the National Science Foundation, and was started in the summer of 1970. Some of the topics being investigated are: environmental costs of coal mining, toxic element emissions from power plants, price elasticity of energy demand, secondary effects of pollution control measures, ways to increase efficiency of energy use, policies that influence the growth of demand, and current energy consumption patterns.

One of our earlier reports gives a condensed survey of U.S. electricity usage.* In the present report we analyze energy usage in another important sector, that of transportation. In addition, we examine the wide variation in energy-intensiveness of various transportation modes. The extent of this variation implies that energy usage can be significantly affected by policies which shift the patterns of transportation of people and goods.

R. S. Carlsmith
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*Oran L. Culberson, *The Consumption of Electricity in the United States*, ORNL-NSF-EP-5, Oak Ridge National Laboratory (June 1971).

ABSTRACT

Historical, present, and possible future patterns of energy consumption in the transportation sector are examined for inter-city freight and passenger traffic and for urban passenger traffic. The energy-efficiencies among the various transport modes are quite variable. Airplanes are relatively inefficient; cars and trucks are slightly more efficient; and railroads, waterways, pipelines, and buses are quite efficient. The energy implications of changes in the modal mixes for freight and passenger transport are explored using two hypothetical futures.

The energy required, directly and indirectly, for automobiles in American society is also computed. This includes the energy needed to produce gasoline; to manufacture and sell cars; to repair, maintain, and insure cars; to provide replacement equipment; and to build and power cars. When total automotive energy consumption is considered the automobile accounts for about 25% of total U.S. energy consumption. This is equivalent to 7.1 miles/gallon for the average American car.

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ENERGY CONSUMPTION FOR TRANSPORTATION IN THE U.S.

INTRODUCTION

The purpose of this report is to review past, present, and possible future patterns of energy consumption in the transportation sector. Transportation in the United States accounts for a major fraction of both gross national product and total energy consumption. For example, in 1970 automotive retail sales totalled $89 billion,[1] about 9% of GNP. Motor vehicles in the U.S. travelled 1,125 billion miles in 1970,[1] a 56% increase over the 1960 figure. Operating revenues for scheduled airlines was $9.3 billion in 1970.[2] These airlines flew more than 2.4 billion miles that year, a 140% increase over the 1960 mileage. On the other hand, passenger traffic on railroads declined from almost 22 billion passenger-miles in 1960 to 11 billion passenger-miles in 1970.[3]

The transportation of people and goods required 16,500 trillion Btu in 1970,[4] equal to 24% of total U.S. energy consumption. The energy requirements for transportation increased by 52% between 1960 and 1970. This increase is due to increasing levels of traffic and shifts to less energy-efficient* transport modes.

This report examines the relationships between energy consumption and transportation in the U.S. The energy requirements for freight and passenger traffic are computed from 1950 to 1970. Current trends in transportation are then extended to the year 2000. This projection shows how energy consumption for transportation *might* develop, assuming current trends persist.

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*Energy-efficiency is defined here as ton-miles/Btu for freight and passenger-miles/Btu for passenger transport.

A second projection is made assuming a steady, but not revolutionary, shift towards more energy-efficient transport modes. This projection, which is entirely arbitrary, does not consider possible technological changes which might affect energy consumption. Also, the total mileages (passenger-miles and freight ton-miles) are maintained equal to those used in the first projection.

The total energy requirements of the automobile are examined. The energy used, directly and indirectly, to produce gasoline; to manufacture and sell cars; to repair, maintain, and insure cars; and to build highways is computed, as well as the energy content of the gasoline consumed by automobiles.

Table 1 presents total energy consumption and the energy consumed for transportation during the period 1950 through 1970, and Bureau of Mines projections to the year 2000.[4,5] Transportation accounted for about one-fourth of total U.S. energy consumption during the past twenty years and this is expected to continue through the end of the century. The average annual growth rate in transportation energy consumption during the past twenty years was 3.23%.

Table 2 shows the dependence of transportation on petroleum supplies. More than half of U.S. petroleum consumption is used for transportation. During the past two decades, transportation's dependence on petroleum has increased markedly, until now petroleum provides over 95% of the energy input to the transportation sector. Table 2 also shows the importance of foreign petroleum. The National Petroleum Council[6] expects oil imports to account for 57% of domestic demand in 1985, a large increase over the 22% for 1970.

Table 1. Energy Consumption in the U.S., Total and Transportation[a]

Year	Total (10^{12} Btu)	Transportation[b] (10^{12} Btu)	Percent to Transportation
1950	34,154	8,724	25.5
1955	39,956	9.904	24.8
1960	44,960	10,881	24.2
1965	53,785	12,771	23.7
1970	68,810	16,495	24.0
1980	88,075	21,557	24.5
2000	168,600	42,883	25.4

[a]Data from Bureau of Mines (1968, 1971).

[b]Primary energy to the electric utility sector is apportioned among the other users according to their consumption of electricity.

Table 2. Petroleum Consumption in the U.S.[a]

Year	Total (10^{12} Btu)	Petroleum Supply from Imports (%)	Petroleum Supply Used in Transportation (%)	Transportation Energy from Petroleum (%)
1950	13,489	10.6	50.3	77.8
1955	17,524	11.5	52.0	92.0
1960	20,067	17.8	51.7	95.3
1965	23,241	21.4	52.5	95.5
1970	29,617	22.2	53.2	95.5
1980	35,978	—	57.6	96.1
2000	57,600	—	72.3	97.1

[a]Data from Bureau of Mines (1968, 1971).

Hubbert[7] estimates U.S. petroleum resources at about 10^{18} Btu. A petroleum consumption rate of 36×10^{15} Btu/year (the 1980 Bureau of Mines estimate; see Table 2) is equivalent to only a 30-year supply. Hubbert predicts that 80% of the world's oil supply will have been used by about 2025.

The rising energy consumption for transportation, the increasing dependence of transportation on petroleum, the growing level of petroleum imports, and the impending shortage of adequate oil supplies suggest a need to examine the relationships between transportation and energy consumption. This report shows that significant increases in transportation energy-efficiency are possible. These efficiency increases are not dependent on new technologies, nor do they involve a reduction in total freight and passenger traffic. Rather, they involve a shift from energy-intensive transport modes towards more energy-efficient modes.

FREIGHT AND PASSENGER TRAFFIC

Inter-City Freight Traffic

Freight is moved by various modes, including railroads, trucks and other motor vehicles, on waterways, through pipelines, and by air. Table 3 gives the energy requirements for freight traffic for each of these modes. The numbers are from Rice* (ref. 8) and are typical of efficiencies during the mid-1960's. More accurate historical data on energy efficiency for freight transport can be obtained from the Interstate Commerce Commission and the Federal Aviation Administration, but this is not necessary for the purposes of this report. We shall see later that the modal energy-efficienci have changed somewhat during the past twenty years. (Except for railroads

*Rice's energy-efficiency estimates for aircraft are apparently too low by 30-50%. His values are adjusted upward in Tables 3 and 5 so that total aircraft energy consumption agrees with FAA data given in ref. 16.

and airplanes, the changes are small.) These historical variations are ignored since we are here concerned only with the energy implications of shifts among the various modes, without regard for changing technologies.

Table 3. Energy-Efficiency for Inter-City Freight Transport[a]

	Ton-miles / Gallon	Btu[b] / Ton-mile
1. Pipelines	300	450
2. Waterways	250	540
3. Railroads	200	680
4. Trucks	58	2,340
5. Airways[c]	3.7	37,000

[a]Data from Rice (1970) as approximate values for mid-1960's.

[b]Assuming 136,000 Btu/gallon.

[c]Value for aircraft adjusted from Rice's value to agree with total aircraft fuel consumption given by Federal Aviation Administration (1970).

Table 3 shows the considerable variation in energy efficiency among the various modes. As an extreme example, consider railroads and airways. The energy requirements per ton-mile by rail are less than 2% the energy requirements by air.

Table 4 presents historical data for 1950-1970 for inter-city freight traffic.[3,9] This table shows total ton-miles and the modal mix for the five modes shown in Table 3. The percentage of total freight traffic carried by rail (an efficient mode) declined steadily during this period. This decline in rail traffic was offset by increases in truck, waterway, pipeline, and airway traffic.

The eighth column in Table 4 indicates total energy consumption for freight transport. These figures are computed using the efficiencies shown in Table 3. The last (ninth) column shows the inverse energy-efficiency for freight transport. Efficiency declined by 13% between

Table 4. Inter-City Freight Traffic and Energy Consumption[a]

Year	Ton-miles Freight (10^9)	Percent of Total Ton-miles: Railroads	Trucks	Waterways	Pipelines	Airways	Total Freight Energy[b] (10^{12} Btu)	Inverse Efficiency (Btu/ton-mile)
1950	1090	57.4	15.8	14.9	11.8	0.03	980	900
1955	1300	50.4	17.2	16.7	15.7	0.04	1180	910
1960	1330	44.7	21.5	16.6	17.2	0.06	1320	1000
1965	1650	43.7	21.8	15.9	18.6	0.12	1680	1020
1970	1930	40.1	21.4	15.9	22.4	0.18	1980	1030
Future I — Continuation of Current Trends								
1980	2400	37	21	16	25	0.4	2620	1090
1990	2900	35	21	15	28	0.7	3470	1200
2000	3400	34	21	15	29	1.0	4430	1300
Future II — Shift to Greater Energy-Efficiency								
1980	2400	41	18	16	25	0.2	2340	970
1990	2900	42	14	16	28	0.1	2500	860
2000	3400	44	11	16	29	0.1	2760	810

[a] Data from Statistical Abstract (1970) and from Transportation Facts and Trends (1971).

[b] Total energy consumption computed using energy-efficiencies in Table 3.

1950 and 1970 because of the increased use of trucks and airplanes and the steady decline in the use of railroads for freight transport. Freight traffic increased by 77% during this period. Thus, total freight energy requirements increased by 102% between 1950 and 1970.

Table 4 also shows two hypothetical projections of freight traffic for the period 1970-2000. The same total mileage is assumed for each year in both futures. However, the assumed modal mix is different for each projection. Future I assumes that current trends in modal mix changes will continue. This yields a continued decline in energy-efficiency, 21% between 1970 and 2000, 31% between 1950 and 2000. Future II assumes an evolutionary shift in modal mix towards greater energy-efficiency. These assumptions yield a marked increase in energy-efficiency, 27% between 1970 and 2000, 11% between 1950 and 2000.

The modal mix projected for Future II results in an energy-efficiency for freight transport in 2000 that is 60% greater than the efficiency for Future I. Thus, a shift from I to II would reduce freight transportation energy requirements from 4430 to 2760 trillion Btu in 2000.

Figure 1 shows total freight energy consumption and inverse energy-efficiency from 1950 to 1970. The two projections to 2000 are also shown.

Inter-City Passenger Traffic

Passenger traffic between cities is carried primarily by automobile and, to a lesser extent, by airplane, bus, and railroad. Waterborne passenger traffic is not considered here because, during the past twenty years, it has never accounted for more than 0.4% of total inter-city passenger traffic.[9] Table 5 gives the energy requirements for the four most

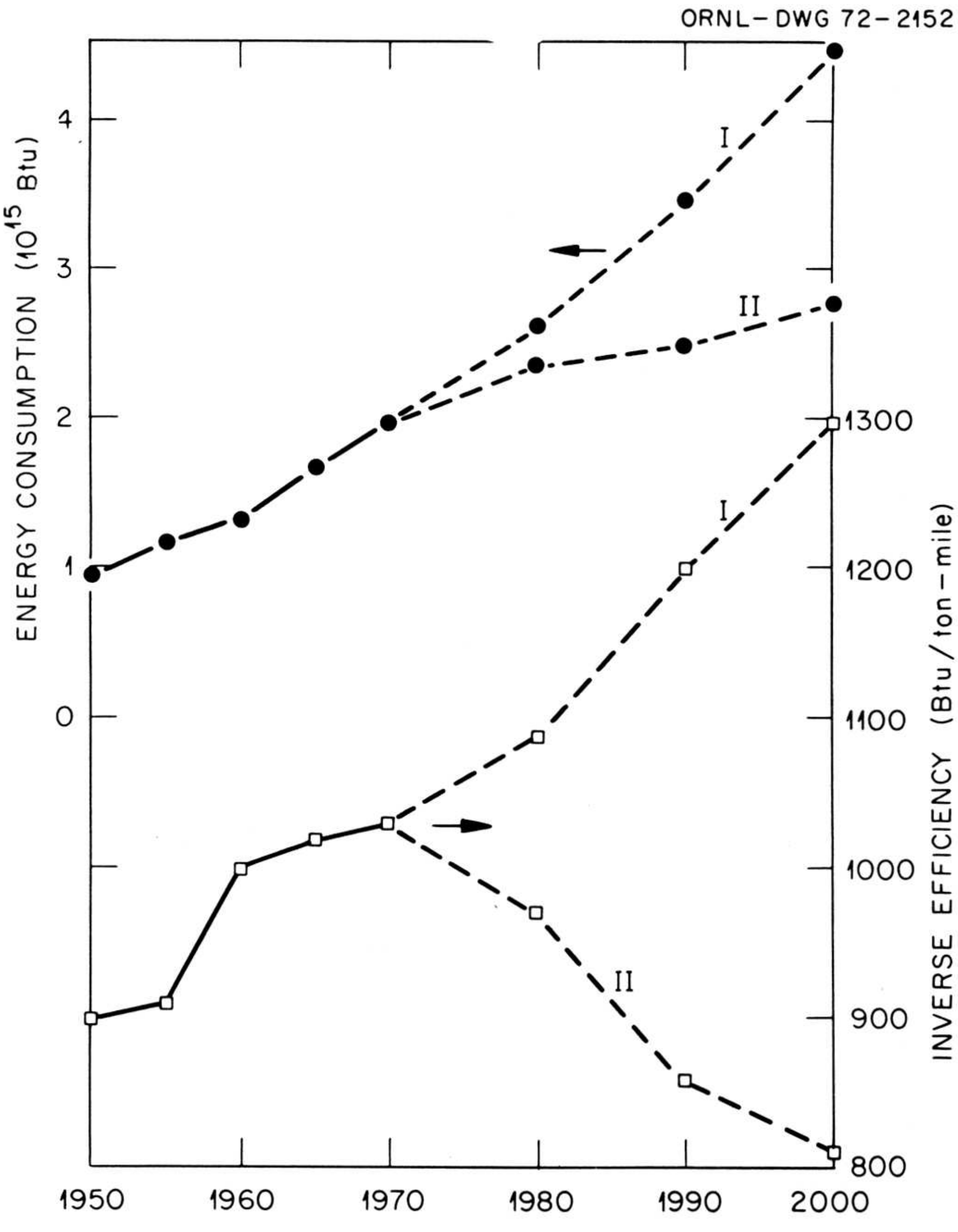

Fig. 1. Energy Consumption for Inter-City Freight Traffic. Data are from Table 4.

common passenger traffic modes. These numbers are from Rice* (ref. 8) and are typical of mid-1960's efficiencies. The variation in efficiency among these modes is considerable, but not as great as for freight transport. Buses are the most efficient modes, airplanes the least. The energy requirement per passenger-mile by bus is 11% the energy requirement for airplane. Airplanes are the least energy-efficient mode for both passenger and freight traffic. Nevertheless, the speed, comfort, and convenience of air travel is producing significant increases in the use of this mode.

Table 5. Energy-Efficiency for Inter-City Passenger Traffic[a]

	Passenger-miles / Gallon	Btu[b] / Passenger-mile
1. Buses	125	1090
2. Railroads	80	1700
3. Automobiles	32	4250
4. Airplanes[c]	14	9700

[a]Data from Rice (1970) as approximate values for mid-1960's.
[b]Assuming 136,000 Btu/gallon.
[c]See footnote c of Table 3.

Table 6 presents historical data for 1950-1970 for inter-city passenger traffic.[3,9] The table shows total passenger-miles for inter-city travel and the modal mix for the four modes considered here. The percentage of passenger traffic moved by automobile is remaining constant, while the fractions moved by bus and train are declining. This decline is offset by rapid increases in airline traffic.

The seventh column in Table 6 indicates total energy consumption for these four modes of inter-city passenger traffic. These figures are computed using the efficiencies from Table 5. The last (eighth) column shows the inverse energy-efficiency for inter-city passenger traffic.

*See footnote on page 4.

Table 6. Inter-City Passenger Traffic and Energy Consumption[a]

Year	Total Passenger-miles (10^9)	Percent of Total Passenger-miles: Automobile	Airplane	Bus	Railroad	Total Energy[b] (10^{12} Btu)	Inverse Efficiency (Btu/passenger-mile)
1950	510	86.8	2.0	5.2	6.4	2,040	4,030
1955	720	89.5	3.2	3.6	4.0	3,000	4,210
1960	780	90.1	4.3	2.5	2.8	3,390	4,340
1965	920	88.8	6.3	2.6	1.9	4,100	4,470
1970	1,180	87.0	9.7	2.1	0.9	5,510	4,690
		Future I — Continuation of Current Trends					
1980	1,710	85	13	1.5	0.5	8,370	4,890
1990	2,240	84	15	1.0	—	11,280	5,040
2000	2,770	83	17	—	—	14,340	5,180
		Future II — Shift to Greater Energy-Efficiency					
1980	1,710	86	7	4	3	7,570	4,430
1990	2,240	85	3	6	6	9,120	4,070
2000	2,770	84	2	7	7	10,970	3,960

[a] Data from Statistical Abstract (1970) and from Transportation Facts and Trends (1971).

[b] Total energy consumption computed using energy-efficiencies in Table 5.

Between 1950 and 1970 energy-efficiency for inter-city passenger traffic declined by 14%. During this period, the volume of traffic increased by 130%. Together, these two factors accounted for a 170% increase in energy consumption for inter-urban passenger traffic.

Two possible futures are also defined and presented in Table 6. Future I yields a continued decline in passenger energy-efficiency, 10% between 1970 and 2000, 22% between 1950 and 2000. Future II yields an increase in energy-efficiency, 18% between 1970 and 2000, a slight increase over the 1950 level.

Future II results in an energy-efficiency for inter-city passenger transport that is 31% higher than the Future I figure in 2000. This represents a savings of 3370 trillion Btu in the year 2000.

Figure 2 shows total inter-city passenger energy requirements computed from 1950 to 1970 and projected to 2000. Also shown are curves of inverse energy-efficiency for this period.

Urban Passenger Traffic

Urban passenger traffic is carried primarily by automobiles. Mass transit typically accounts for about 5% of total urban passenger traffic. In this section we consider only automobiles and buses, since other forms of mass transit account for a very small fraction of total urban passenger traffic.[10] Table 7 shows the urban energy-efficiencies for bicycling, walking, buses and automobiles.[1,8,9] Bicycling is 28 times as energy-efficient as the automobile.

Table 8 presents historical data for 1950-1970 for urban passenger traffic for buses and cars.[9,11] The percentage of passenger traffic moved by cars steadily increased during this period, with a corresponding decline in bus traffic.

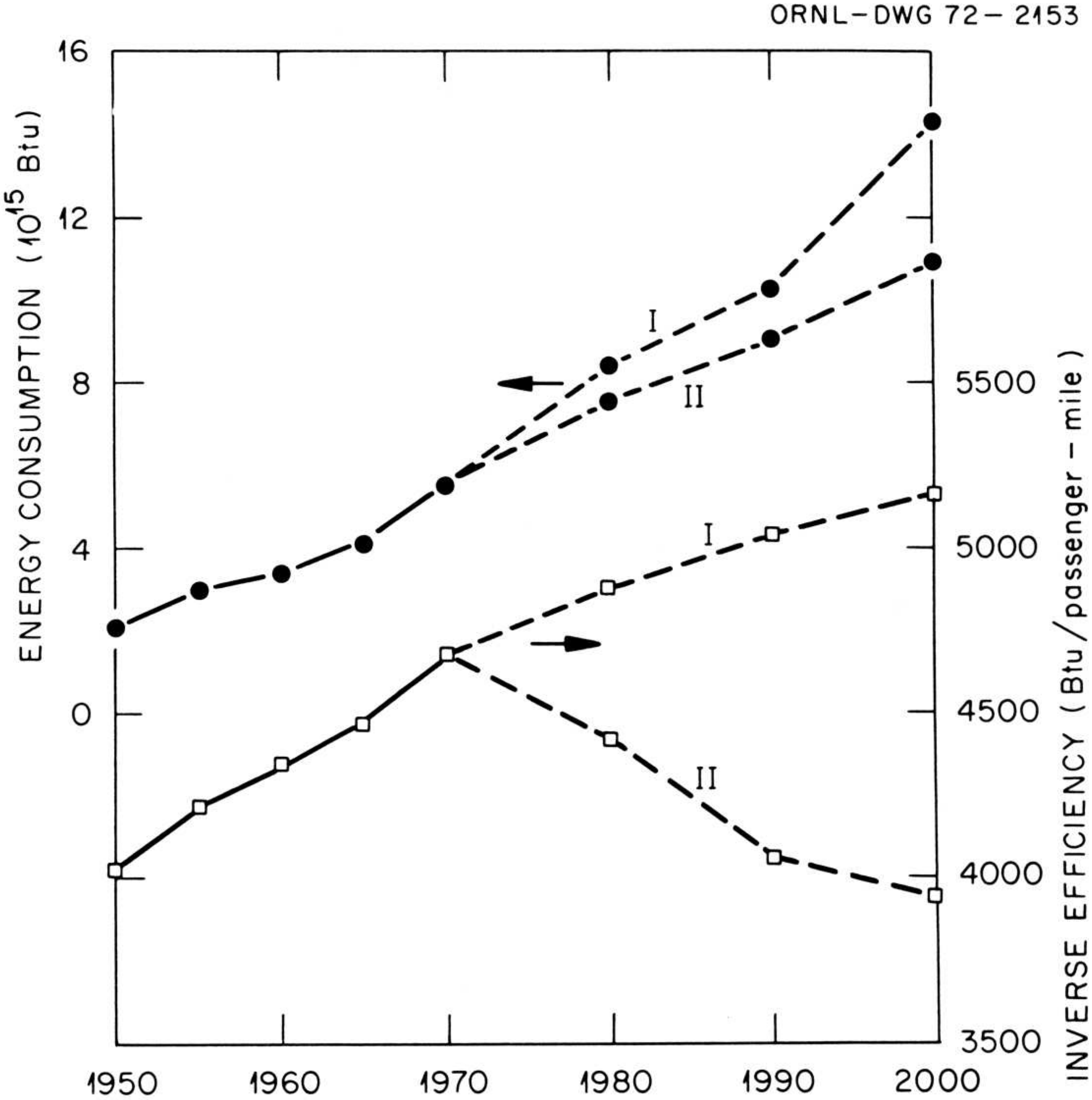

Fig. 2. Energy Consumption for Inter-City Passenger Traffic. Data are from Table 6.

Table 7. Energy-Efficiency for Urban Passenger Traffic[a]

	Vehicle-miles / Gallon	Passengers / Vehicle	Passenger-miles / Gallon	Btu[b] / Passenger-mile
1. Bicycles[c]	—	—	756	180
2. Walking[c]	—	—	450	300
3. Buses	5.35	20.6	110	1240
4. Automobiles	14.15	1.9	26.9	5060

[a]Data from Statistical Abstract (1970) for 1965 and Automobile Facts & Figures (1971).

[b]Assuming 136,000 Btu/gallon.

[c]Efficiencies for walking and bicycling computed as follows: An excess of 225 calories/hour (893 Btu/hr) is required for moderate walking or bicycling, from Rice (1970). Assuming 5 mph by bicycle and 3 mph by foot yields the values given above.

The sixth column in Table 8 shows the total energy requirements for urban bus and automobile traffic. The last (seventh) column shows the overall energy-efficiency of urban passenger traffic.

Between 1950 and 1970, energy-efficiency declined by 4.3%. Total passenger-miles increased by 154%. Together these two factors caused an increase in energy consumption of 166% during this twenty-year period.

Two possible futures for urban passenger traffic are also defined and presented in Table 8. The modal mix assumed in Future I yields a 2% decline in energy-efficiency between 1970 and 2000. Future II assumes that 3% of total urban passenger traffic can be replaced by walking and bicycling.* Future II shows an increase in energy-efficiency of 8% between

*Approximately 54% of all automobile trips are less than 5 miles long,[1] equivalent to 11% of total automobile mileage. Assuming that half of this mileage is for trips less than 2.5 miles in length implies that 5.5% of total automobile mileage is for trips less than 2.5 miles long. This number is supported by surveys conducted for the 1963 Census of Transportation.[12] Here we assume that approximately half of these short trips can be conducted by foot or on bicycle.

Table 8. Urban Passenger Traffic and Energy Consumption[a]

Year	Total Passenger-miles (10^9)	Percent of Total Passenger-miles			Total Energy[b] (10^{12} Btu)	Inverse Efficiency (Btu/passenger-mile)
		Automobiles	Buses	Walking, Bicycles		
1950	388	89.6	10.4	—	1,810	4,670
1955	466	91.5	8.5	—	2,200	4,730
1960	585	92.6	7.4	—	2,790	4,770
1965	764	94.0	6.0	—	3,690	4,830
1970	987	95.4	4.6	—	4,820	4,880
		Future I — Continuation of Current Trends				
1980	1,410	97	3	—	6,970	4,950
1990	1,830	98	2	—	9,120	4,980
2000	2,250	98.5	1.5	—	11,250	5,000
		Future II — Shift to Greater Energy-Efficiency[c]				
1980	1,410	91	6	3	6,590	4,680
1990	1,830	89	8	3	8,420	4,600
2000	2,250	87	10	3	10,180	4,520

[a] Data from Statistical Abstract (1970) and Federal Highway Administration (1971).

[b] Total energy consumption computed using energy-efficiencies in Table 7.

[c] The transportation energy required for walking/bicycling is not included in this table because these energies are small relative to motor vehicle energy requirements; see Table 7.

1970 and 2000. The modal mix for Future II yields a savings of 1070 trillion Btu in 2000 relative to Future I, a 10% reduction in urban passenger energy needs for 2000.

Figure 3 shows urban passenger traffic energy requirements and inverse energy-efficiency from 1950 to 1970. The two projections to 2000 are also shown.

Sum of Energy Requirements

The previous three sections considered energy requirements for inter-city freight and passenger traffic and urban passenger traffic. Here we sum these energy requirements and compare this total with actual and projected Bureau of Mines figures for transportation energy requirements.

Table 9 shows the total energy requirements computed here and the Bureau of Mines data from Table 1. For several reasons, the totals computed here are always less than the Bureau of Mines numbers.

First, urban freight traffic is not considered here. Accurate data on the volume of urban freight traffic are not readily available.

Also, many uses of trucks (personal, agricultural, services) are neglected here. In 1970, trucks consumed 25.6 billion gallons of fuel,[11] equivalent to 3.49×10^{15} Btu. Only 28% of this is accounted for by inter-city truck traffic, from Tables 3 and 4. The difference between total truck traffic and that computed here accounts for over half of the discrepancy between actual and computed energy usage.

Other forms of transportation are also neglected such as non-bus urban passenger traffic, private boating, passenger traffic carried by

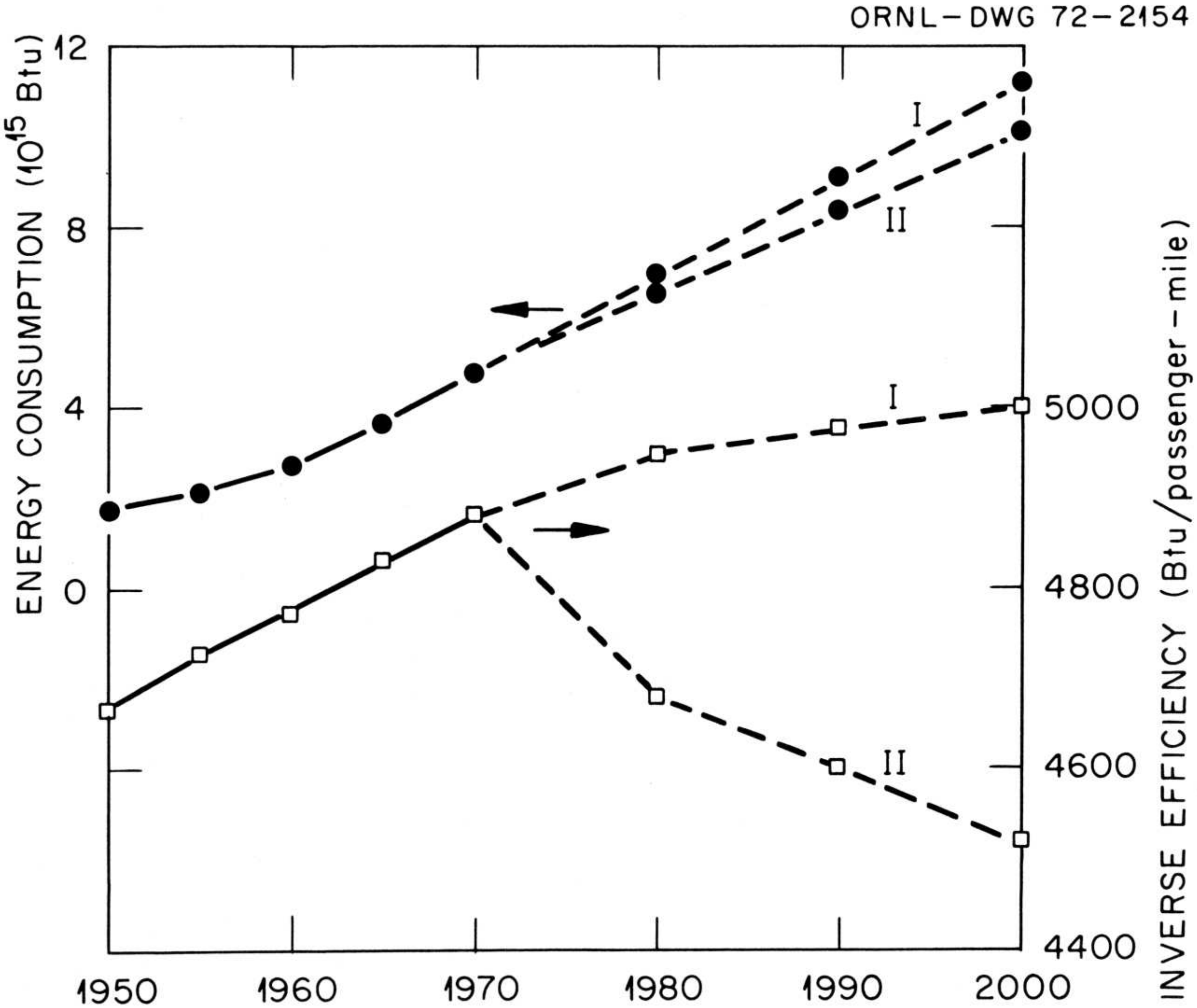

Fig. 3. Energy Consumption for Urban Passenger Traffic.
Data are from Table 8.

Table 9. Total Computed Transportation Energy Requirements and Actual Total[a]

Year	Inter-City Freight (10^{12} Btu)	Inter-City Passenger (10^{12} Btu)	Urban Passenger (10^{12} Btu)	Total Computed (10^{12} Btu)	Total Actual (10^{12} Btu)	Computed/Actual (%)
1950	980	2,040	1,810	4,830	8,724	55.4
1955	1,180	3,000	2,200	6,380	9,904	64.4
1960	1,320	3,390	2,790	7,500	10,881	68.9
1965	1,680	4,100	3,690	9,470	12,771	74.2
1970	1,980	5,510	4,820	12,310	16,495	74.6
			Future I — Continuation of Current Trends			
1980	2,620	8,370	6,970	17,960	21,557	83.3
1990	3,470	11,280	9,120	23,870	—	—
2000	4,430	14,340	11,250	30,020	42,883	70.0
			Future II — Shift to Greater Energy-Efficiency			
1980	2,340	7,570	6,590	16,500		
1990	2,500	9,120	8,420	20,040		
2000	2,760	10,970	10,180	23,910		

[a]Data in 2nd through 4th columns from Tables 4, 6, and 8. Column 5 is sum of preceding three columns. Column 6 is from Table 1, Bureau of Mines data. Last column is the quotient of the two preceding columns.

boat, and general aviation. Together these omissions plus the effects of energy-efficiency variations (discussed in the following section) account for the differences between actual and computed energy requirements.

Table 9 shows clearly the energy differences between Future I and Future II. A shift from I to II would result in an energy savings of 6,110 trillion Btu in 2000, a 20% reduction. As pointed out earlier, the future modal mix for transportation and the resultant energy requirements may not resemble either Future I or Future II. However, this exercise dramatically reveals the energy incentives for shifting from one modal mix to another. This 20% reduction in energy consumption is derived solely from a shift in the modal mix; not included are potential energy savings from a reduction in total mileage or an improvement in the technical efficiency of individual modes.

The U.S. Department of Transportation recently projected U.S. transportation requirements to 1980, assuming a 3.5, 4.3, and 5.0% annual growth rate in GNP.[13] Table 10 compares our Future I projection for 1980 with the DOT 4.3% projection using multiples of the 1970 values for ton-miles and passenger-miles.*

Table 10. Comparison of Two Transportation Projections for 1980[a]

	This Report	USDOT
Freight Traffic[b]		
Railroads	1.15	1.14
Trucks	1.22	1.45
Waterways	1.26	1.19
Pipelines	1.39	1.33
Airways	2.82	3.16
Total Freight Traffic	1.25	1.43
Passenger Traffic		
Automobiles	1.43	1.48
Airways	1.95	2.35
Inter-City Bus	1.02	1.06
Railroads	0.77	0.48
Local Transit[c]	0.93	1.22

[a]Data presented are the ratio of 1980 to 1970 freight or passenger traffic, as projected in this report for Future I and in Transportation Projections: 1970 and 1980 (1971).

[b]For freight traffic, the DOT ratios are divided by 1.14 (1.43/1.25) so that projections of modal mixes are the same for both methods.

[c]Local transit, in the DOT report, includes all forms of mass transit; in this report only buses are included.

Table 10 shows that, while the projected trends are in agreement, the projected growth rates differ considerably. The Future I projections, for both freight and passenger traffic, are considerably less energy-intensive than the DOT projections.

*The 1980 DOT projection for total freight traffic is 14% higher than the Future I projection. To more easily compare the projected changes in modal mix, the DOT freight projections are divided by 1.14.

Changes in Modal Energy Efficiencies

The preceding sections assumed that the energy-efficiencies for each mode (shown in Tables 3, 5, and 7) remain constant with time. Here, we examine how these efficiencies varied between 1950 and 1970.

The efficiency of railroads increased tremendously after World War II, largely because of the shift from coal-burning steam locomotives to diesel locomotives. One can infer from Summers'[14] figures that the energy-efficiency of rail transportation increased by almost a factor of 5 between 1950 and 1970. It is ironical that as the efficiency of rail transit increased, the fraction of freight and passengers carried by rail declined.

A dramatic decline in energy-efficiency occurred in aircraft. Table 11, based on data from Rice,[15] shows the energy-efficiency for several airplanes. In general, newer planes are less efficient than older ones. This declining energy-efficiency is accounted for by an increase in average speed. Between 1958 and 1968 the average speed of domestic aircraft increased from 219 miles/hour to 369 miles/hour.[16] Thus, the airlines traded energy for speed.

Table 11. Energy-Efficiency of Various Aircraft[a]

Type of Craft	Year	Inverse Efficiency (Btu/seat-mile)	Speed (mile/hr)
DC-3	1940's	2630	150
DC-6	1950's	3130	270
DC-7	late 50's	3030	330
Electra	1960's	3330	400
DC-8	1960's+	4000	525
B-747	1970+	2700	575
SST	proposed	6250	1200

[a]Data from Historical Perspective in Transport System Development (1970).

In 1950 the average car obtained 14.95 miles/gallon.[9] By 1970 this figure had dropped to 13.70 miles/gallon.[11] The energy-efficiencies for buses and trucks also declined during this period, but only slightly.[9] To some extent, the decline in efficiency is due to an increase in average speed. In 1950 the average speed of automobiles on main rural roads was 48.7 miles/hour, while in 1968 the average speed was 60.4 miles/hour.[9]

The increasingly stringent air quality requirements will probably further decrease motor vehicle energy-efficiency. The Environmental Protection Agency expects automobile gasoline mileages to decrease 20-40% between 1968 and 1976 as a direct result of air pollution control requirements.[17] However, these figures are speculative because engines which meet the 1976 air quality requirements are not yet developed.

TOTAL ENERGY COSTS OF THE AUTOMOBILE

Private motor vehicles consumed 65.8 billion gallons of fuel in 1970,[11] equivalent to 8.95×10^{15} Btu. This is equal to about 55% of total transportation energy consumption. However, energy for automobiles is required for much more than direct motive power. Energy is used to produce the gasoline which powers cars; to manufacture and sell cars; to repair, maintain, and insure cars; to provide replacement equipment; and to build and maintain highways. In this section we discuss these additional energy needs.

The calculations of total energy requirements for automobiles are derived for 1968 in the Appendix. Final results are given in Table 12 for 1960, 1968, and 1970.

Energy is required to convert crude petroleum into gasoline and other refined petroleum products. According to Reardon's energy input/

Table 12. Total Energy Requirements for Automobiles in the U.S.[a]

	1960 (10^{15} Btu)	1968 (10^{15} Btu)	1970[b] (10^{15} Btu)
1. Gasoline Consumption	5.60	7.96	8.95
2. Petroleum Refining	1.15	1.64	1.84
3. Automobile Manufacturing	0.78	1.05	0.71
4. Automobile Retail Sales	0.77	0.99	0.82
5. Repairs, Maintenance, Insurance, Replacement Parts, Accessories, Parking, Tolls, Taxes, Etc.	3.03	3.95	4.44
TOTAL (10^{15} Btu)	11.33	15.59	16.76
Total Automobile Mileage (10^9 miles)	588	814	901
Total Energy Required (Btu/mile)	19,270	19,150	18,620
(miles/gallon)	7.06	7.10	7.31
Total U.S. Energy Consumption (10^{15} Btu)	44.96	62.45	68.81
Percent of Total Energy Consumption Devoted to Automobiles	25.2	25.0	24.4

[a]The figures presented here are approximate; see text.

[b]The 1970 figures are low for manufacture and sale of automobiles. This is probably due to the economic condition of the country that year, and may not represent a long-term secular decline in automotive energy consumption.

output analysis* for 1963,[18] the production of 1 Btu of refined petroleum requires a total input to the petroleum refining sector of 1.150 Btu. In addition to this direct energy consumption, other sectors consume fuel for purposes which, indirectly, contribute to the production of refined petroleum. For example, energy is used to extract crude petroleum from oil wells, and energy is needed to manufacture the equipment used to drill for oil.

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*For an introduction to input/output analysis see W. Leontief, *Input-Output Economics*, Oxford University Press, New York, 1966.

The total energy required to produce 1 Btu of refined petroleum (direct plus indirect use) is 1.206 Btu.[18] Thus, 0.206 Btu is consumed in the production of 1 Btu of refined petroleum. In 1968, 7.96×10^{15} Btu of gasoline was consumed by automobiles.[9] Hence, 1.64×10^{15} Btu was consumed in the production of this gasoline.

In 1968, 8.82 million cars were manufactured in the U.S. with a total wholesale value of $19.35 billion.[9] In 1963, the manufacture of transportation equipment required 5850 Btu/$-shipped in terms of 1968 dollars.[18] In addition to this direct energy consumption, an additional 48,420 Btu/ $-shipped was required, indirectly, by steel manufacturers, iron miners, and so on. The total (direct plus indirect) energy coefficient for the manufacture of transportation equipment was 54,270 Btu/$-shipped (1968 dollars). Thus, the total energy used to produce cars in the U.S. in 1968 was 1.05×10^{15} Btu.

During 1968, 9.66 million cars were sold by retail dealers, including domestic and foreign cars.[1] The average new car price, excluding taxes, was $2910.[9] Thus, retail sales of automobiles totaled $28.1 billion in 1968. The Commerical, Financial & Services sector accounted for 35,200 Btu/$ of sales in 1968.[18] Thus, 0.99×10^{15} Btu was consumed in the retail sales of cars in 1968.

So far, we have considered the energy used to power cars, to produce gasoline, and to manufacture and sell cars. To compute the energy needed for repairs and maintenance, replacement parts, accessories, oil, insurance, parking and tolls, and the tax-supported construction of highways, we shall resort to a very approximate method.

In 1968 the average cost of an automobile was 11.02 cents/mile, including 2.81 cents for depreciation and 1.50 cents for gasoline.[9] Thus, 6.71 cents/mile was spent for the other functions listed in the preceding paragraph.

On the average, 72,260 Btu was consumed per dollar of GNP in 1968.[5,19] Multiplying 6.71 cents/mile times total automobile mileage for 1968, 814 billion miles,[9] times 72,260 Btu/$, gives 3.95×10^{15} Btu consumed in 1968 for these automotive functions.

Adding these energy requirements gives a total of 15.59×10^{15} Btu for American cars in 1968; see Table 12. Of this total, 51% is consumed directly as gasoline. On a per mileage basis, the American automobile consumed, directly and indirectly, 19,150 Btu/mile. This is equivalent to only 7.10 miles/gallon.

Table 12 shows that the energy requirements for American cars have remained nearly constant over the past decade, both in terms of total Btu/mile, and in terms of % of total U.S. energy consumption.

The preceding discussion of Table 12 shows the importance of non-direct energy consumption in transportation. Detailed data are not available for other transport modes; hence, we cannot compute the total energy costs for these modes. However, the ubiquitous automobile accounts for much more indirect energy consumption than does any other transport mode.

The analysis in this section contains several approximations. Therefore, conclusions based on this analysis should be made cautiously. The input/output coefficients used here are based on a highly aggregative study.[18] Comparisons between the more detailed and accurate 1967 census data[20] and

Reardon's 1963 numbers[18] reveal some discrepancies (see the Appendix). In all cases, we have used Reardon's numbers because they provide a lower estimate of the automobile's total energy requirements.

The computation of energy required to repair, maintain, insure, etc., automobiles is rather crude. Detailed energy input/output tables do not yet exist which would allow one to disaggregate the energy consumption for these several functions. Since this accounts for about 25% of the total automotive energy requirement (see No. 5 in Table 12), the deficiency in computational accuracy may be important.

NON-ENERGY FACTORS

It is clear from this report that there are considerable energy incentives for certain shifts in transportation modes. Air quality considerations may provide additional incentives. In 1969, transportation accounted for 52% (by weight) of total air pollution in the U.S. Transportation was responsible for 112 million tons of carbon monoxide, 20 million tons of hydrocarbons, and 11 million tons of nitrogen oxides.[21] A reduction in fuel consumption (through changes to more efficient modes) brings a proportionate reduction in air pollution.*[22]

Given these energy and, perhaps, air quality incentives why are trends in transportation modes changing as they are? The reasons are manifold and complex and definitely beyond the scope of this report. However, the 1971 U.S. Department of Transportation Statement on National Transportation Policy[21] offers some interesting clues which we shall mention.

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*To a large extent, however, air pollution incentives for energy conservation in automobile transportation were removed by recent amendments to the Clean Air Act. This Act set stringent standards for automobile emissions which, <u>if met</u>, will reduce these emissions by a factor of 20 between now and the end of this century.

This report discusses the institutional arrangements, particularly policies of the federal government, which influence transportation. Some forms of transportation, particularly railroads, are "regulated in minute detail . . . while other forms operate free of any effective economic regulation." Only during the past few years have automobiles been regulated by the federal government with regard to safety and air pollution.

In addition to regulation, the federal government influences transportation modes by financing capital equipment in certain transportation facilities, and subsidizes the operation of certain transportation services. For example, the Federal government finances 90% of the cost of the Interstate Highway System, and much of the remaining highway construction. Such federal financing runs at an annual rate of $5 billion. In addition, the Federal Aviation Administration spends about $150 million a year on airport development and airway systems. The Airport and Airways Development Act of 1970 authorizes annual grants of over $500 million for these purposes.

Railroads, on the other hand, receive almost no federal financial support. This situation is now changing with establishment of the National Railroad Passenger Corporation (AMTRAK) — "a quasi-public corporation formed to spearhead the rebirth of an economically viable rail passenger service." In 1970 public transit received $175 million in federal funds. "However, the recent Urban Mass Transportation Act authorizes a five year $3.1 billion program. . ."

Federally funded research and development has been unevenly distributed among the various modes. In fiscal year 1970, $658 million was spent on transportation R & D. Of this, 3.5% was spent on railroads, 6.4% on urban mass transit, while 65% was spent on air and 17% was spent on highway programs.

In addition to federal regulation and federal financial support, social factors such as comfort, convenience, versatility, and speed help to determine modal mix patterns. If current trends continue, unit energy consumption (per passenger-mile or per ton-mile) will continue to increase. However, other factors, such as fuels scarcities, rising energy prices, urban congestion, safety, air pollution, noise pollution, land-use requirements, and the changing role of the federal government, may combine to shift transportation modes towards greater energy-efficiency.

SUMMARY

This report discusses historical patterns of energy consumption for inter-city freight and passenger traffic and for urban passenger traffic. The types of transport and modes considered here account for more than two-thirds of the total energy consumed by transportation. The energy-efficiency among various transport modes is quite variable. Airplanes are inefficient; cars and trucks are slightly more efficient; and railroads, waterways, pipelines, and buses are quite energy-efficient.

Table 13 shows the distribution of energy within the transportation sector for 1960 and 1970. Automobiles consume more than 50% of the transportation energy. Trucks are the second largest energy users, consuming about 20% of the total. The percentage of energy devoted to aircraft jumped from 4% in 1960 to 7.5% in 1970.

Evolutionary shifts in the modal mixes for freight and passenger traffic could reduce transportation energy consumption, as shown by the two projections hypothesized here. A change from Future I (continuation of present trends) to Future II (shift towards more efficient modes) would

reduce transportation energy consumption by over 6 × 10^{15} Btu in 2000, a 20% savings relative to Future I consumption.

Table 13. Distribution of Energy Within the Transportation Sector[a]

	% of Total Energy			
	1960		1970	
1. Automobiles				
urban	25.2		28.9	
inter-city	27.6		26.4	
		(52.8)		(55.3)
2. Aircraft				
freight	0.3		0.8	
passenger	3.0		6.7	
		(3.3)		(7.5)
3. Railroads				
freight	3.7		3.2	
passenger	0.3		0.1	
		(4.0)		(3.3)
4. Trucks				
inter-city freight	6.1		5.8	
other uses[b]	13.8		15.3	
		(19.9)		(21.1)
5. Waterways, freight	1.1		1.0	
6. Pipelines	0.9		1.2	
7. Buses	0.7		0.5	
8. Other[c]	17.3		10.1	
Total	100.0%		100.0%	
Total Transportation Energy Consumption (10^{15})	10.9		16.5 Btu	

[a]Data from Tables 1, 3-8.

[b]Data from Federal Highway Administration, Highway Statistics.

[c]Includes passenger traffic by boat, general aviation, pleasure boating, and non-bus urban mass transit, as well as the effects of historical variations in modal energy-efficiencies.

This report also examines the total energy required, directly and indirectly, to operate automobiles in the U.S. Approximately 19,000 Btu/mile is consumed, of which only about one-half is consumed directly as gasoline to power cars.

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APPENDIX

DETAILS OF AUTOMOBILE ENERGY COST CONSUMPTION

DETAILS OF AUTOMOBILE ENERGY COST COMPUTATION

1. Gasoline Consumption: In 1968, 58.5×10^9 gallons of gasoline was consumed by passenger cars.[9] With 136,000 Btu/gallon,[8] this is equal to 7.96×10^{15} Btu.

2. Petroleum Refining: According to Reardon's I/O analysis[18] for 1963, the direct and inverse (direct plus indirect) energy coefficients for the production of refined petroleum are:

direct	0.150 Btu consumed/Btu output
inverse	0.206 Btu/Btu

Reardon's 1963 values can be compared with data from the 1967 Census of Manufactures.[20] The direct coefficient from the Census is 0.185 Btu/Btu. No inverse coefficient can be readily estimated from the 1967 data. Neither value includes the energy content of non-fuel outputs from petroleum refining (such as waxes, lubricants, asphalt). Including these products would reduce the direct coefficients considerably.

With Reardon's value (since it is lower than the Census value), the energy required to produce the petroleum used by cars is:

$$(0.206 \text{ Btu/Btu})(7.96 \times 10^{15} \text{ Btu}) = 1.64 \times 10^{15} \text{ Btu} .$$

3. Automobile Manufacturing: In terms of 1968 dollars, Reardon's direct and inverse energy coefficients for the manufacture of transportation equipment are:

direct	5850 Btu/\$-shipped
inverse	54,270 Btu/\$-shipped

In 1967, the direct energy consumption for the manufacture of motor vehicles and equipment was 8040 Btu/\$-shipped (again in terms of 1968 dollars). Dollars shipped refers to manufacturers' value, not that of the retail buyer. Reardon's direct coefficient is 23% less than the 1967 direct coefficient.

Automobile production in 1968 was 8.82 million units, with a wholesale value of $\$19.35 \times 10^9$.[9] Thus, the energy consumed in the manufacture of automobiles was:

$$(54{,}270 \text{ Btu/\$-shipped})(\$19.35 \times 10^9) = 1.05 \times 10^{15} \text{ Btu} .$$

4. Automobile Retail Sales: In terms of 1968 dollars, Reardon's direct and inverse coefficients for Commercial, Financial & Services are:

direct	16,900 Btu/$-sold
inverse	35,200 Btu/$-sold

No comparable figures can be obtained from the Census of Manufactures.

In 1968, retail sales of automobiles totalled $\$28.1 \times 10^9$.[1,9] Thus, the energy consumed in the sale of automobiles was:

$$(35{,}200 \text{ Btu/\$-sold})(\$28.1 \times 10^9) = 0.99 \times 10^{15} \text{ Btu} .$$

5. All Other Automotive Expenses: To evaluate the energy requirements for other automotive functions, we first compute the average energy expenditure in the U.S. per dollar of Gross National Product. In 1968, total U.S. energy consumption was 62.45×10^{15} Btu,[5] and the GNP was $\$864.2 \times 10^9$.[19] Thus, on the average, 72,260 Btu was consumed in 1968 per dollar of GNP.

The average cost of an automobile in 1968 was 11.02 cents/mile.[9] Of this total, 1.50 cents was used for gasoline (Nos. 1 and 2 above), and 2.81 cents was devoted to depreciation (Nos. 3 and 4). The remaining 6.71 cents/mile was used for repairs, maintenance, replacement parts, accessories, oil, insurance, parking, tolls, and taxes. The energy expenditure to satisfy these requirements is roughly:

$$(\$0.0671/\text{mile})(814 \times 10^9 \text{ miles})(72{,}260 \text{ Btu}/\$) = 3.95 \times 10^{15} \text{ Btu} .$$

Summing the energy values for 1 through 5 gives 15.59×10^{15} Btu consumed in 1968 for the automobile. Total automobile mileage in 1968 was 814×10^9 miles.[11] Thus, 19,150 Btu/mile is the energy required, directly and indirectly, for automobiles. This is equivalent to 7.10 miles/gallon.