ORNL-NSF-EP-44

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ENERGY INTENSIVENESS OF PASSENGER AND FREIGHT TRANSPORT MODES 1950-1970

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Work Supported by the National Science Foundation RANN Program

under NSF Interagency Agreement No. 40-237-70

APRIL 1973

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
Operated by Union Carbide Corporation·For the U.S. Atomic Energy Commission
Contract No. W.7405-eng-26

ABSTRACT

Previous work at ORNL evaluated the energy consequences of changes in freight and passenger traffic levels and shifts in modal mix for the period 1950 to 1970. The research reported here extends this work to include an analysis of changes in energy intensiveness for individual modes during this period.

Examination of individual modes shows that airplanes are energy-intensive and that cars and trucks are less so. Buses, mass transit, railroads, pipelines, and boats are relatively energy-efficient. Railroad energy intensiveness dropped sharply during this 20-year period because of the shift from steam engines to diesel engines. On the other hand, airplane energy intensiveness increased rapidly because of increased speed. Other modes generally showed slight increases in energy intensiveness.

Energy intensiveness of inter-city freight declined during this period because of the large drop in railroad energy intensiveness. However, passenger transport became more energy intensive because of shifts to airplanes and autos and because of a general increase in energy intensiveness for all passenger modes.

Results derived here are summarized in a number of ways to highlight important shifts in energy use patterns for transportation.

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ENERGY INTENSIVENESS OF PASSENGER AND FREIGHT TRANSPORT MODES: 1950-1970

Eric Hirst

INTRODUCTION

This report defines, in detail, historical changes in energy intensiveness (EI)* for passenger and freight modes in the United States from 1950 to 1970. The contributions of changes in: (1) freight and passenger traffic levels, (2) modal mix patterns, and (3) individual modal EI's to changes in total transportation energy use are computed. These data are then used to define the distribution of energy within the transportation sector, both by mode and by purpose of transport.

Transportation is the "lifeline" of society. Without an adequate transportation network, shipment of raw materials and finished goods from farms and mines to factories, stores and homes would be difficult. Personal travel — to and from work, school, shopping centers, and vacations — would also be difficult.

Transportation annually contributes about $200 billion to the U.S. economy, roughly 20% of Gross National Product.[1] More than 10 million people are employed in transportation and related industries, nearly 15% of the civilian labor force.[1] Inter-city freight traffic is sufficient each year to move 11 tons of freight 1,000 miles for every person in the U.S. Total passenger traffic amounts to about 10,000 miles per person annually.

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*EI is defined as Btu/ton-mile for freight and Btu/passenger-mile for passenger traffic. EI is the inverse of energy efficiency, where energy efficiency is the product of two factors: technical efficiency, e.g., seat-miles/Btu, and load factor (percentage of capacity utilized), e.g., passenger-miles/seat-mile.

On the other hand, transportation-caused accidents claim 60,000 lives and cause more than 5 million injuries a year.[1] Transportation is responsible for more than half the total weight of air pollution emissions in the country.[2] Transportation contributes to other environmental problems such as urban congestion, inefficient land use, noise, and pollution caused by extraction, transportation, refining, and use of petroleum.

Between 1950 and 1970, annual fuel use for transportation[3] (almost entirely petroleum) grew from 8,700 to 16,500 trillion Btu, with an average annual growth rate of 3.2%. During this period, transportation accounted for one-fourth of the total U.S. energy budget.[3] In 1970, transportation used more than half the domestic petroleum budget, 23% of which was imported.[3] The National Petroleum Council[4] projects that oil imports will account for 57% of domestic petroleum consumption in 1985.

In 1970, Rice[5] published estimates of EI for various transport modes, giving values typical of mid-1960's performance. Using these estimates, Hirst[6] computed the impact of changes in traffic levels and modal patterns on transportation energy use, ignoring historical variations in EI. In general, variations in EI between 1950 and 1970 were slight. However, as shown later, changes in EI for airplanes and railroads were substantial.

Mooz[7] studied the impact of fuel price changes on inter-city freight traffic. As part of this work, he collected and analyzed considerable data from which he determined EI's for freight modes as functions of time, up to 1968.

The work described here follows directly from that in ref. 6, using the methodology developed in ref. 7. This work shows the considerable variation in EI among freight and passenger modes. The analysis also shows how patterns of energy use changed between 1950 and 1970 in response to increases in traffic, changes in modal mix, and changes in EI for individual modes.

The following (second) section examines traffic carried, energy consumed, and EI as functions of time for automobiles, trucks, airplanes, railroads, buses, urban mass transit, ships, and pipelines. Detailed data and supporting analyses are given in the Appendix. The third section combines data on the individual modes to show how energy use patterns for freight and passenger service changed between 1950 and 1970. The fourth section summarizes these results in a number of ways. The distribution of transportation energy is presented by both mode and purpose of transport. Finally, several nonenergy factors (safety, speed, cost, haul length, and load factor) are briefly discussed.

A few terms are used frequently in this report; to save space the following shorthand notation is used:

EI energy intensiveness, Btu/TM or Btu/PM
IC inter-city
PM passenger-mile(s)
TM ton-mile(s)
VM vehicle-mile(s)
e estimate

This research effort was complicated by data inconsistencies, different definitions used by various agencies, missing data, and unexplained temporal variations in data. Therefore, we often found it necessary to approximate, extrapolate, interpolate, and even guess values. Those numbers in the tables that are particularly open to question have an "e" following the number. Because of these data limitations, results presented here should be used cautiously.*

INDIVIDUAL TRANSPORT MODES

Automobiles

The automobile uses a larger share of transportation energy than all other modes combined, almost 55% in 1970. Similarly, the automobile is the dominant passenger mode; in 1970, autos carried 97% of urban and 87% of IC passenger traffic.

The growing use of automobiles, begun during the 1920's, continued unabated after World War II. Rising personal incomes, increasing availability of autos over a wide price range, shifting demographic patterns, and highway construction all served to increase ownership and use of automobiles — generally at the expense of other passenger modes.

The Federal Highway Acts of 1944 and 1956 provided significant federal funds for highway construction, including the 42,500-mile system of Interstate highways. Between 1950 and 1970, mileage of surfaced roads increased by 50% to about 3 million miles. During this period, the number of registered automobiles more than doubled, reaching 90 million in 1970, while auto travel increased nearly threefold, reaching 900 billion VM in 1970.

These figures attest to the growing importance of the auto in American society. Increased auto usage is both a cause and a consequence

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*Results presented in this report are generally rounded to two significant figures, because greater precision is unwarranted. Because of this rounding, detail may not always add up to totals. However, all results are computed using unrounded figures.

of shifting demographic, industrial, and commercial patterns. The development of suburbia and the increased diffusion of employment has increased dependence on the automobile.

The auto also offers psychological advantages over competing modes. These advantages include comfort, privacy, personal preference in vehicle style, and freedom with regard to routes and schedules.

The total cost of auto travel* is comparable to the fares for competing modes. Urban auto travel costs less than 10 cents/PM, only 15% more than mass transit fares.[8,9] Cars, buses, and trains cost[1,8] about 4 cents/PM for IC travel, compared with 6 cents/PM for airplanes.[1] Further, out-of-pocket costs for auto travel (gasoline, oil, repairs, maintenance, parts, parking, tolls) are only about half the total costs and therefore less than the costs for competing modes.

Table 1 summarizes traffic and energy data for automobiles.[1,2,10-12] Between 1950 and 1970, EI increased by 12%, probably because of higher highway speeds, greater vehicle weight, larger engine size, and the use of additional energy-consuming equipment such as automatic transmissions and air conditioners. During this period total traffic increased by 142%. Together, these two factors account for the 171% increase in auto energy use. About 89% of the increased energy use was due to greater traffic, with the remaining 11% due to higher EI.**

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*Average total cost of auto ownership in 1970 was 11.9 cents/VM.[8] We assume here that urban auto costs are 40% higher than IC costs per VM. Auto occupancy is taken as 1.4 PM/VM in urban areas and 2.4 PM/VM in rural areas, from refs. 11 and 12.

**Let total auto energy use be E, total auto travel T, and changes denoted by $\Delta()$. Then $(E + \Delta E) = (T + \Delta T)(EI + \Delta EI)$. Logarithms are then used to assign additive responsibility to these multiplicative factors; e.g., the contribution of EI changes to total auto energy use growth is $\log(EI + \Delta EI)/\log(E + \Delta E)$.

Table 1. Automobile Traffic and Energy Consumption[a]

	IC		Urban		Total		Average
	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	Energy 10^{12} Btu	EI Btu/PM
1950	430	3200e	260	7600e	690	3300	4800
1955	630	3300e	310	7900e	950	4600	4800
1960	730	3300e	400	8000e	1130	5600	5000
1965	800	3300e	530	7900e	1330	6800	5200
1970	970	3400e	690	8100e	1670	8900	5400

[a]Source: refs. 1, 2, 10-12. See Appendix for details.

Urban values for EI are much higher than IC values because of poorer vehicle performance (fewer miles/gallon) and poorer utilization (fewer passengers/vehicle) in cities. The data and assumptions used here indicate that EI is 140% higher in cities than in rural areas.*

Trucks

Trucks are the second largest consumer of transportation energy, accounting for more than 20% of the transportation energy budget in 1970. Trucks are used for IC freight transport, local freight movement, delivery of services, personal transport, and agriculture. In 1970, trucks accounted for almost 20% of IC freight and virtually all urban freight traffic.

The growing use of trucks for freight transport is due to increased highway construction and the geographic expansion and distribution of industry, commerce, and residences. In addition, trucks offer speedy delivery, flexibility in routing and scheduling, and door-to-door service.

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*The difference in IC and urban EI values is based, in part, on the assumption that IC fuel mileage is 40% higher than urban fuel mileage (miles/gallon). Unfortunately, we have no data to either support or refute this assumption. Because of this lack, we assumed that the ratio of IC to urban EI values remained constant during this 20-year period.

Because of these factors, trucks are particularly useful for small shipments of high value and short hauls. Trucks dominate IC freight traffic at distances less than 200 miles. The average freight haul by truck is 260 miles, about half the length for railroads, and one-fourth the length for airplanes and boats.[1] Trucks carry large fractions of the total shipments of meat and dairy products, rubber and plastic products, furniture, fabricated metal products, machinery, motor vehicles, and instruments. Trucks also carry major fractions of the following mining products usually for short hauls: sand and gravel, crushed stone, cement, and refined petroleum products.[1,13]

Table 2 summarizes traffic and energy consumption data for trucks.[1,2,10] Because of data gaps, results are presented only for IC freight and other uses. Between 1950 and 1970, truck fuel use increased by 142% due to the 137% growth in truck mileage and the 2% rise in EI.

Table 2. Truck Traffic and Energy Consumption[a]

	IC Freight			Other		Total	
	Traffic 10^9 TM	EI Btu/TM	Energy 10^{12} Btu	Traffic 10^9 VM	Energy 10^{12} Btu	Traffic 10^9 VM	Energy 10^{12} Btu
1950	170	2400e	410e	76	1000e	91	1400
1955	220	2400e	530e	93	1300e	110	1800
1960	290	2900e	820e	98	1300e	130	2200
1965	360	2400	870	140	1800	170	2700
1970	410	2800	1140	180	2300	220	3500

[a]Source: refs. 1, 2, 10. See Appendix for details.

For IC freight trucking, fuel consumption grew by 179% during this period because of a 138% increase in freight traffic and a 17% rise in EI. About 85% of the increased fuel use was due to increased traffic, and 15% was due to greater EI (due in part to higher speeds).

Airplanes

Airplanes are currently the third largest and also the fastest growing transportation energy user. In 1950, aircraft used less than 2% of transportation energy, compared to almost 11% in 1970. In 1950, airplanes carried 2% of IC passenger traffic and 0.02% of IC freight traffic compared to 10% and 0.15%, respectively, in 1970.

Military advances in aviation during World War II spurred postwar growth in air traffic. Technological improvements in commercial aviation included pressurized cabins, larger airplanes, higher speeds, better navigational equipment, and the introduction of jet engines (∿1960).

Between 1950 and 1970, air traffic grew to become the most important IC common carrier passenger mode, replacing railroads and buses, because of technological advances, comfort, increased speed, and imaginative promotion. For example, average airborne speed increased from 180 mph in 1950 to over 400 mph in 1970.[14] Average air fares increased 8% during this period, while bus and rail fares increased 90% and 47%, respectively.[1] However, air travel is still expensive: in 1970, revenue per PM was 6.0 cents for airplanes, 4.0 cents for railroads, and 3.6 cents for buses.[1]

The use of airplanes to carry freight is also growing rapidly, although air freight accounted for only 0.15% of total IC freight in 1970. Because of its high cost, air freight is used primarily for high value products, such as clothing, communication equipment, transportation equipment (not vehicles), instruments, and small machinery.[1]

Table 3 summarizes energy consumption and traffic data for domestic commercial passenger and freight traffic, general aviation, and military aviation.[1,2,14-18] Between 1950 and 1970, commercial aircraft energy use increased by a factor of 21. Commercial air traffic (passenger and freight) increased by a factor of about 12, and EI* increased by 85%. Thus, about 80% of the increased commercial fuel use was due to greater air traffic, and 20% was due to changes in EI. Rising EI was caused by increased speed, partially offset by technological improvements and the use of larger airplanes.

Table 3. Domestic Aircraft Traffic and Energy Consumption[a]

	IC Passenger		IC Freight		Subtotal Energy[b] 10^{12} Btu	Domestic Military Energy 10^{12} Btu	General Aviation Energy 10^{12} Btu	Total Energy 10^{12} Btu
	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 TM	EI Btu/TM				
1950	9.3	4500e	0.30	23000e	49e	87e	12e	150e
1955	21	4800	0.49	24000	110	360e	23	490e
1960	32	6900	0.89	35000	250	540	29	820
1965	54	8200	1.9	41000	520	640	43	1200
1970	110	8400	3.4	42000	1060	620	96e	1800e

[a]Source: refs. 1, 2, 14-18. See Appendix for details.

[b]Subtotal Energy is the sum of commercial passenger and freight energy.

Railroads

The fractions of both traffic carried and energy consumed by railroads declined markedly between 1950 and 1970. In 1950, railroads accounted for 47% of IC freight traffic, 7% of IC passenger traffic, and 25% of transportation energy use. By 1970, these values had declined to 35, 1, and 3%, respectively.

*CAB data[14] show that aircraft EI peaked in 1962. Since, then, EI has behaved erratically, dropping to 91% of the peak in 1966 and climbing back up to 97% of the peak in 1970.

Advances made during and after World War II in aviation, highway construction, and pipeline transport hurt railroads. The railroads were unable to meet the challenge of increased competition from other modes because of conservative railroad management, restrictive government regulation and ratemaking, lack of sufficient capital to make improvements, and the direct and indirect government subsidies provided to competing modes. Thus, the fraction of IC freight carried by rail declined rapidly during the 1950's. During the 1960's, the fraction declined more slowly as railroads began to innovate, e.g., the use of railroad flat cars for hauling highway truck-trailers, specially designed railroad cars for shipping automobiles, and unit trains for transporting coal and other heavy commodities.

In 1944 rail passenger traffic reached a peak of 98 billion PM. Since then, passenger traffic has dropped markedly, falling to 11 billion PM in 1970. Several factors account for this dramatic decline including those given above, lack of adequate service (insufficient routes and schedules), slow speed, and the desire of railroad management to eliminate passenger service.

However, recent experiments such as the Boston to New York Turbo Train and the New York to Washington Metroliner indicate that railroads can provide fast, comfortable, popular, and profitable short-haul IC passenger service.

Table 4 summarizes energy use and traffic data for railroads.[1,2,19,20] Between 1950 and 1970, railroad energy consumption for freight declined by 73%, freight traffic increased by 22%, and EI declined by 78%. Railroad EI decreased by almost a factor of 5 due to a shift from coal-burning

Table 4. Railroad Traffic and Energy Consumption[a]

	IC Freight		IC Passenger		Total
	Traffic 10^9 TM	EI Btu/TM	Traffic 10^9 PM	EI Btu/PM	Energy 10^{12} Btu
1950	630	3100	33	7400	2200
1955	660	1200	29	3700	890
1960	600	790	22	2900	540
1965	720	720	18	2700	570
1970	770	670	11	2900	550

[a]Source: refs. 1, 2, 19, 20. See Appendix for details.

steam locomotives to diesel-engine locomotives. (Between 1950 and 1970 the percentage of all locomotives which were diesel grew from 35% to 99%.) Between 1950 and 1970 railroad energy use for passenger traffic declined by 87%, as a result of a 67% decline in traffic and a 61% fall in EI.

Buses

Buses account for about 1% of transportation energy use, distributed among IC, urban, and school buses. In 1950, buses carried 5% of IC and 8% of urban passenger traffic; comparable figures for 1970 were 2% for both classes of service.

Post-World War II highway construction benefited IC buses as well as autos and trucks. The flexibility of bus routing in response to shifting demographic patterns, plus low fares, enabled IC bus traffic to remain nearly constant between 1950 and 1970. On a relative basis, however, IC busing declined because of greatly increased airplane and auto traffic.

Urban bus traffic declined steadily from 1950 to 1970, largely due to increased use of autos, as discussed earlier. Additional factors, common to urban mass transit in general, are discussed in the next section.

Table 5 summarizes energy consumption and traffic data for buses.[1,2,9,10,13] Between 1950 and 1970, IC bus energy use increased by 144%, although traffic declined by 14% and EI increased by 156%. This large increase in EI may be due to data inconsistencies (see Appendix) in the 1950 and 1955 EI estimates.

Table 5. Bus Traffic and Energy Consumption[a]

	IC		Urban		School		Total	
	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	Energy 10^{12} Btu
1950	26	640e	24	3100	14e	760e	64e	100
1955	26	1100e	18	3400	—	—	—	110
1960	19	1500	16	3400	25e	1200e	60e	110
1965	24	1600	15	3500	—	—	—	120
1970	25	1600	13	3700	38e	1100e	76e	130

[a]Source: refs. 1, 2, 9, 10, 13. See Appendix for details.

For urban buses, energy use declined by 36% between 1950 and 1970. Urban bus traffic decreased by 47% and EI increased by 20%. Increased urban bus EI was due to a drop in load factor (from about 25% in 1950 to less than 20% in 1970) and an increase in traffic congestion.

Urban Mass Transit

Urban mass transit includes gasoline-powered buses and electric subways, elevated trains, trolleys, and surface railways. Although urban buses were considered in the preceding section, they are included here to complete the picture of mass transit.

Mass transit in 1970 accounted for 0.5% of transportation energy use and 3% of urban passenger traffic. In 1950 the comparable figures were 1.8% and 15%, respectively. About 60% of mass transit traffic is carried by bus.

The large decline (both absolute and relative) in mass transit traffic was primarily due to the factors accounting for increased use of automobiles cited earlier — suburban development, diffusion of employment, higher personal income, and the comfort, privacy, moderate cost, and freedom of routing and scheduling associated with autos.

As traffic shifted to automobiles, transit revenues declined; therefore, service and equipment worsened. Transit costs rose rapidly because of congestion, taxes, and increased labor costs. Because of reduced revenues and higher costs, funds were not available for modernization, experimentation, and research. Therefore, mass transit often became slow and unattractive.

However, mass transit offers transportation for people who have no access to automobiles (the young, poor, handicapped, and aged). On a PM basis, mass transit causes less air pollution and fewer traffic fatalities, and requires less land than do automobiles. For example, transit systems can move eight times as many people per highway lane as automobiles can. The fatality rate for mass transit is only 12% the rate for urban automobiles.[1,24]

The federal Mass Transit Act of 1964 and the Urban Mass Transit Act of 1970 provide small, but growing sums of money for urban transit systems. In FY 1971, $57 million was spent on urban mass transit,[1] compared with $10 million in FY 1968.

Table 6 summarizes energy consumption and traffic data for mass transit.[9] Between 1950 and 1970, mass transit energy use fell by 53%, caused by a 57% decline in traffic and a 9% rise in EI. For electric transit, energy consumption declined by 66% during this 20-year period, while traffic dropped by 68%, and EI increased by 6%. The rise in EI for electric systems was accompanied by a drop in load factor from 39% in 1950 to 26% in 1970.

Table 6. Urban Mass Transit Traffic and Energy Consumption[a]

	Electric		Bus[b]		Total		Average
	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	Energy 10^{12} Btu	EI Btu/PM
1950	22	3900	24	3100	46	160	3500
1955	13	3800	18	3400	31	110	3500
1960	8.9	3900	16	3400	25	89	3600
1965	7.6	3900	15	3500	22	81	3700
1970	7.2	4100	13	3700	20	76	3800

[a]Source: ref. 9. See Appendix for details.
[b]Data for urban buses also included in Table 5.

Waterways

In 1970, ships on the Great Lakes, in rivers and canals, and along the coastline of the U.S. carried 27% of IC freight and consumed 2.5% of transportation energy. Comparable figures in 1950 were 31% and 3.6%, respectively.

Ships are used primarily to carry raw materials, agricultural products such as grains, coal and oil, semi-finished manufactured goods such as steel and iron products, chemicals, and heavy machinery. (The 0.3% of IC passenger traffic carried by ship is ignored here.)

Waterway freight prices are quite low, 0.3 cents/TM in 1970, compared to 1.4 cents/TM for railroad and 7.5 cents/TM for truck.[1] To some extent, these low prices reflect government subsidies of waterways through construction and dredging of locks, harbors, and rivers.*

On the other hand, waterway transport is much slower than either truck or air transport, and routes are restricted to waterways of sufficient depth. In 1970, IC waterway mileage totalled 26,000 miles compared to 210,000 miles of railway, 670,000 miles of IC primary and secondary highway, 290,000 miles of airway, and 220,000 miles of oil pipeline.[1,21]

Table 7 summarizes energy use and traffic data for domestic waterborne freight.[1,7,16] Between 1950 and 1970 energy consumption for IC waterway freight increased by 31%, traffic grew by 41% and EI declined by 7%.

Table 7. Domestic Waterway Freight Traffic and Energy Consumption[a]

	Traffic 10^9 TM	EI Btu/TM	Energy 10^{12} Btu
1950	420e	730	310
1955	480	690	330
1960	480	620	300
1965	490	450	220
1970	600	680e	410e

[a]Source: refs. 1, 7, 16. See Appendix for details.

Oil Pipelines

Oil pipelines accounted for 20% of IC freight traffic and about 1% of transportation energy in 1970. In 1950, pipelines carried 10% of IC freight and used less than 1% of transportation energy.

Pipelines are used primarily for cross-country transportation of crude oil, refined petroleum products, and natural gas.** Construction

*IC truck freight is also subsidized through government highway construction

**Only oil pipeline traffic is considered here. Coal, water, and gas traffic are ignored.

of large, long-distance pipelines during World War II encouraged later use of pipelines. Pipelines range in size from 2-in.-diam gathering lines to 48-in.-diam long-distance transmission lines. Pipeline transport is characterized by large volumes, very low cost [0.27 cents/TM in 1970 (ref. 1)], slow speed, and limited flexibility in terms of pickup and delivery points and in types of material transported.

Table 8 summarizes traffic data and energy use estimates for oil pipelines.[1,2,5,7,22] Accurate estimates of a national average pipeline EI are not available. Pipeline EI depnds on product density, viscosity, and flow rate, as well as pipeline diameter, elevation changes, and pumping efficiency. Based on very limited data,[5,22] we use here a value of 450 Btu/TM for the entire period of 1950 to 1970. See the Appendix for a fuller discussion.

Table 8. Oil Pipeline Freight Traffic and Estimated Energy Consumption[a]

	Traffic 10^9 TM	Energy[b] 10^{12} Btu
1950	130	58e
1955	200	91e
1960	230	100e
1965	310	140e
1970	430	190e

[a]Source: refs. 1, 2, 5, 22. See Appendix for details.

[b]EI assumed constant at 450 Btu/TM.

FREIGHT AND PASSENGER TRAFFIC

In this chapter, we examine aggregate traffic and energy consumption patterns for IC freight and passenger traffic and urban passenger traffic from 1950 to 1970. The purpose of this analysis is to see how changes in traffic and EI experienced by each mode combined to determine EI for the entire transportation system.*

Inter-City Freight Traffic

Figure 1** summarizes EI trends for freight modes (on a semi-log scale). Pipelines and ships are the most efficient modes, followed closely by railroads. Trucks are only one-fourth as efficient as railroads and airplanes are only one-sixtieth as efficient as trains.

Between 1950 and 1970, the steady decline in the percentage of IC freight carried by rail (Table 9) was offset by increases in truck, pipeline, and airplane traffic. The ninth colum of Table 9 shows energy consumption for IC freight, computed using EI values given in Fig. 1 and the preceding chapter. Between 1950 and 1960, energy use dropped because EI for freight trains fell by a factor of 4. Between 1960 and 1970, energy use increased because railroad EI changed only slightly while the shift from trains to airplanes and trucks continued.

Between 1950 and 1970, energy use for IC freight declined by 12% in spite of a 64% increase in total freight traffic. Overall EI declined by 46% during this period, but were it not for the decline in railroad EI, overall EI would have increased as freight traffic shifted to modes with higher (and growing) EI's.

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*Results presented in this chapter closely parallel those given in ref. 6. However, in ref. 6, EI for each mode was assumed constant over the 20-year period considered, while in this report the actual variation in modal EI (as derived in the preceding chapter) is included.

**Figures 1 and 3 show smoothed curves of EI trends. Actually, annual variations in computed EI values show seemingly random variations; see ref. 7.

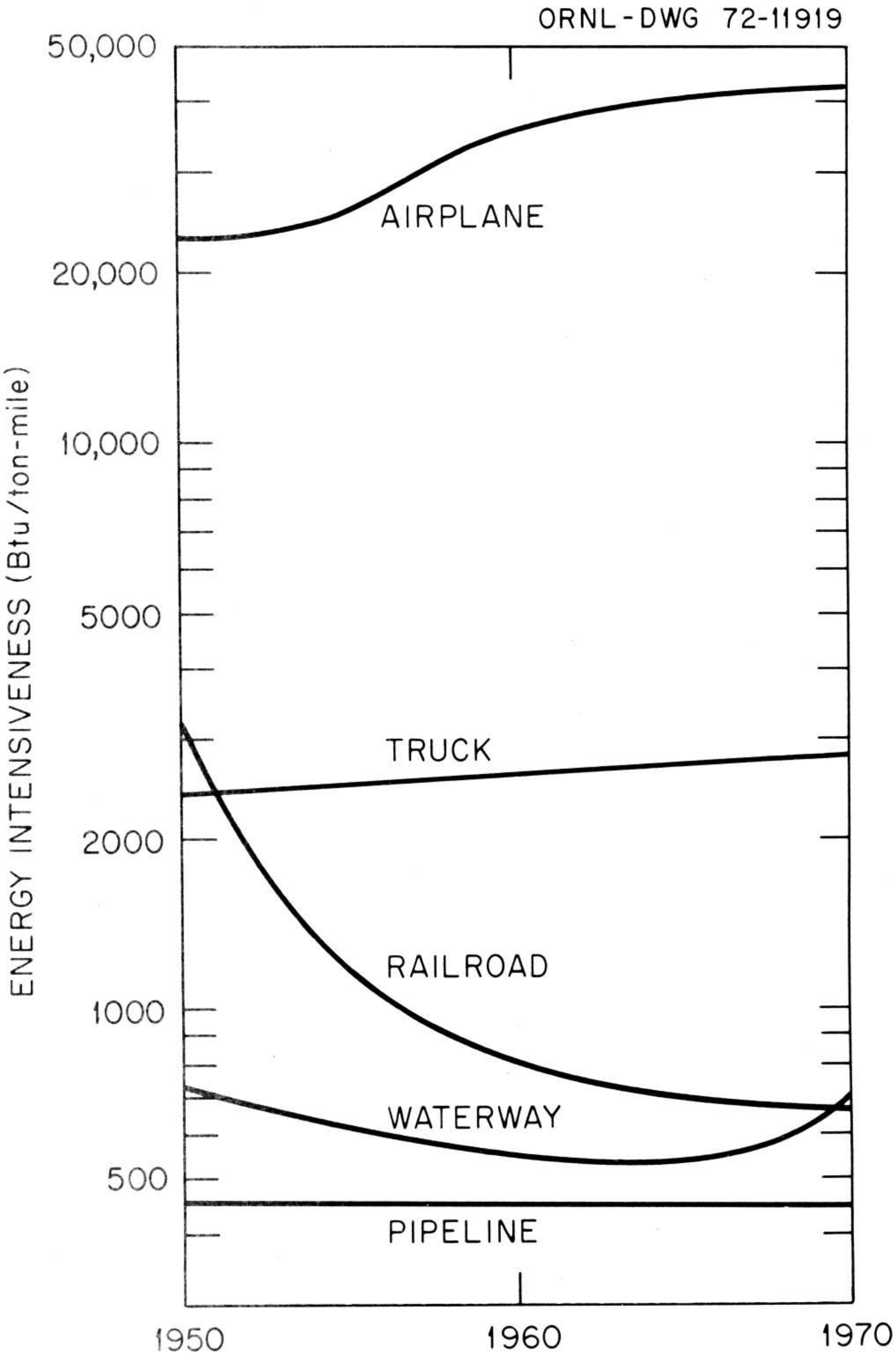

Fig. 1. Historical Variation in Energy Intensiveness for Inter-City Freight Modes, Plotted Semi-logarithmically.

Table 9. Historical Energy Consumption Patterns for Transportation

Year	Total Traffic	Percent of Total Traffic						Total Energy (10^{12} Btu)	Average EI
		Air	Truck	Rail	Waterway & Pipeline	Auto	Bus[a]		
				Inter-City Freight Traffic					
1950	1350[b]	0.02	13	47	41	—	—	2700	2000[d]
1960	1600	0.05	18	38	44	—	—	1800	1100
1970	2210	0.15	19	35	46	—	—	2400	1100
				Inter-City Passenger Traffic					
1950	500[c]	2	—	7	—	86	5	1700	3400[e]
1960	800	4	—	3	—	91	2	2700	3400
1970	1120	10	—	1	—	87	2	4300	3800
				Urban Passenger Traffic					
1950	310[c]	—	—	—	—	85	15	2100	7000[e]
1960	430	—	—	—	—	94	6	3300	7700
1970	710	—	—	—	—	97	3	5700	8000

[a]Inter-city bus or urban mass transit.

[b]Billion ton-miles.

[c]Billion passenger-miles.

[d]Btu/ton-mile.

[e]Btu/passenger-mile.

Figure 2 shows the 1970 IC freight traffic and energy distributions. Trains, ships, and pipelines consumed smaller fractions of the freight energy budget than their shares of traffic would indicate. On the other hand, trucks and airplanes consumed larger fractions of the energy budget, a reflection of their relatively high EI's.

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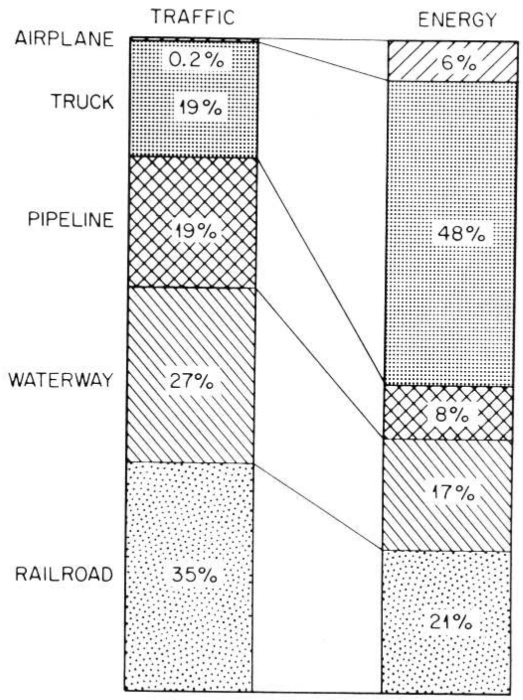

Fig. 2. 1970 Inter-City Freight Traffic and Energy Distributions.

Inter-City Passenger Traffic

IC passenger traffic is carried primarily by automobiles and, to a lesser extent, by airplanes, buses and railroads. Figure 3 shows EI trends for these modes.* Although the variation in EI is considerable, it is not as great as for freight transport. Buses and railroads are the most efficient modes, followed by autos and airplanes. In 1970, EI for airplanes was six times the value for buses.

Between 1950 and 1970, the fraction of IC passengers carried by airplane climbed rapidly at the expense of trains and buses (Table 9). The increase in total energy use for IC passenger traffic of 155% was

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*See second footnote, page 17.

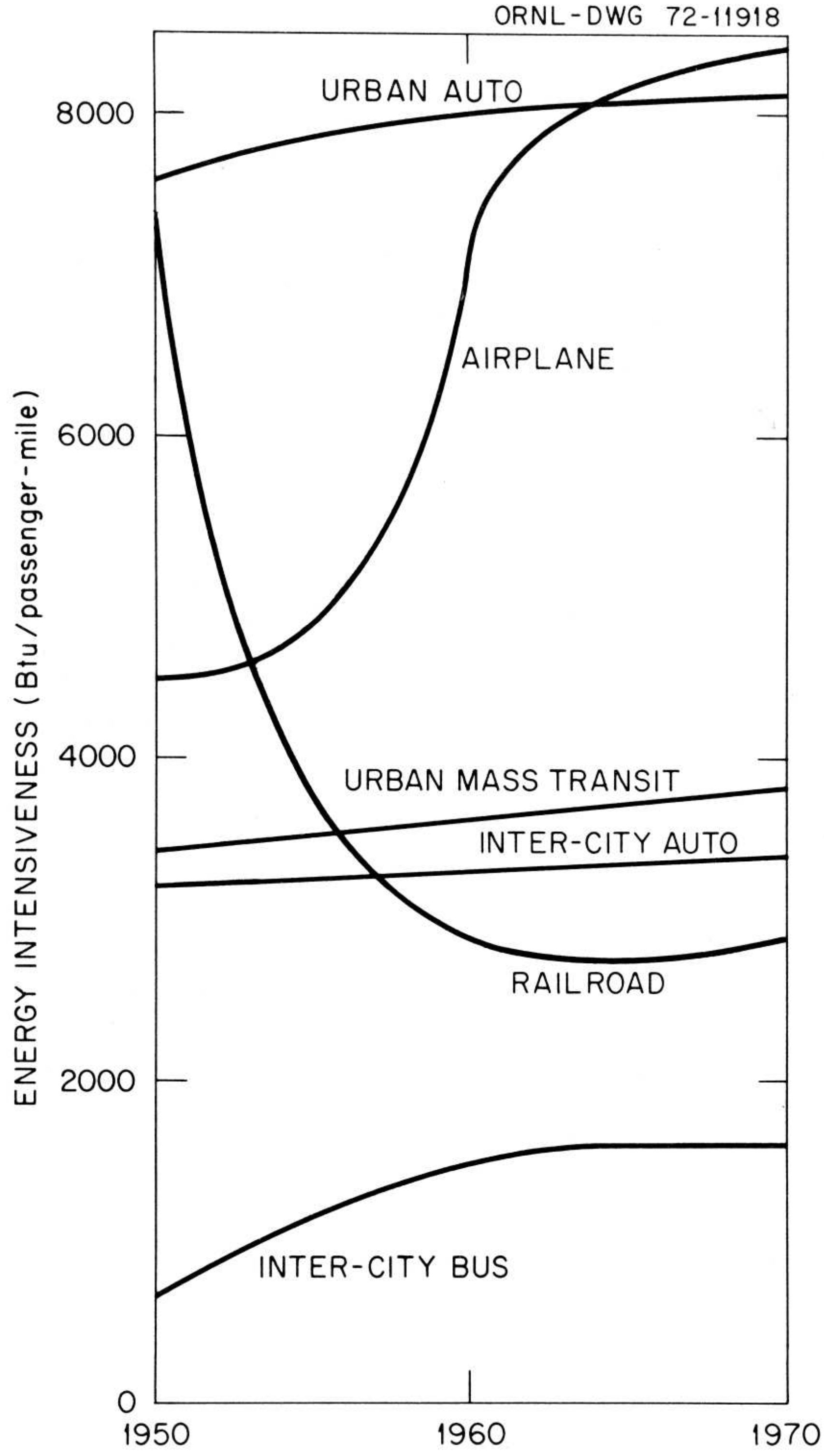

Fig. 3. Historical Variation in Energy Intensiveness for Passenger Modes.

caused by a 124% increase in traffic and a 14% rise in EI. Increased EI was due to increases in EI for individual modes and the shift from buses and trains to airplanes.

Figure 4 shows the 1970 IC traffic and energy distributions. Automobiles account for the largest fractions of both budgets. Airplanes, because of their high EI, account for a much larger share of the energy budget than of the traffic budget.

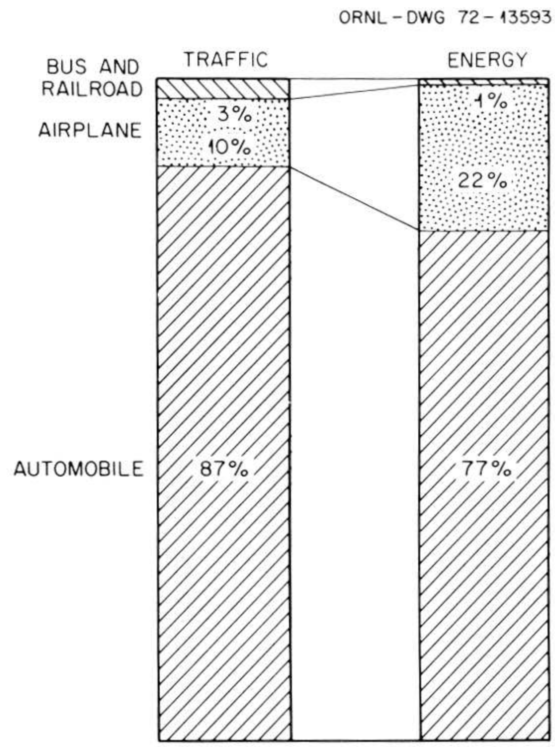

Fig. 4. 1970 Inter-City Passenger Traffic and Energy Distributions.

Urban Passenger Traffic

Urban passengers are carried almost exclusively by automobiles, with only a small and declining fraction carried by mass transit. Figure 3 shows EI for autos and mass transit. EI for mass transit is less than half that of automobiles. Urban values for passenger EI are more than double the comparable IC values because of poorer vehicle performance (fewer miles/gallon) and poorer utilization (fewer passengers/vehicle).

Between 1950 and 1970, the percentage of urban traffic moved by cars steadily increased (Table 9). The 165% rise in energy consumption for urban passenger traffic was caused by a 132% growth in traffic and a 14% increase in overall EI. Increased EI was due to increases in individual modal EI and the shift from mass transit to automobiles.

Figure 5 shows the 1970 urban passenger traffic and energy distributions. Autos account for the largest fractions of both budgets. Mass transit, because it is relatively efficient, accounts for a smaller share of the energy budget than of the traffic budget.

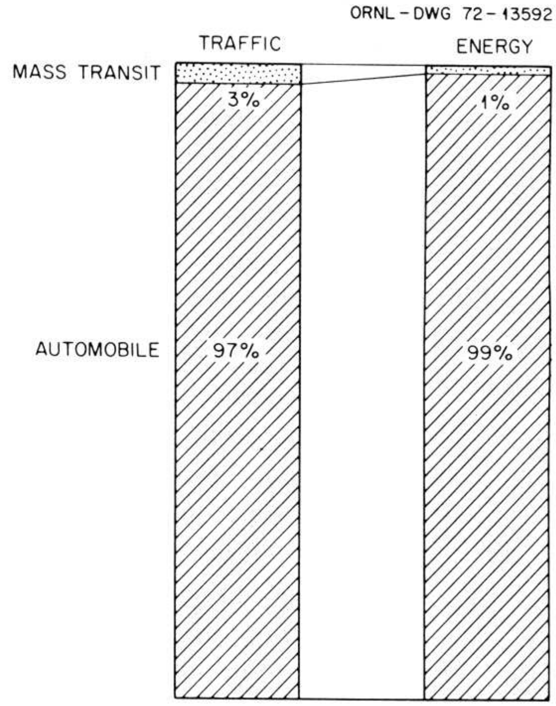

Fig. 5. 1970 Urban Passenger Traffic and Energy Distributions.

DISCUSSION

The preceding two chapters described basic traffic and energy consumption statistics for individual transport modes and for aggregated freight and passenger service. Here we collect these data to examine overall trends in transportation.

Between 1950 and 1970, total annual energy consumption for transportation (as reported by the Bureau of Mines[3]) grew by 89%, from 8,700 to 16,500 trillion Btu a year, averaging one-fourth of the total U.S. energy budget. During this period, U.S. population increased by 34%.[2] Thus, per-capita transportation energy use rose by 41%.

Table 10 and Fig. 6 show how the distribution of energy by mode changed between 1950 and 1970. The fractions of energy devoted to automobiles, trucks, and airplanes grew steadily, with airplanes showing

Table 10. Distribution of Energy Within the U.S. Transportation Sector

	Percent of Total Energy		
	1950	1960	1970
1. Automobiles	(38.0)	(51.4)	(54.2)
urban	22.3	29.2	34.2
inter-city	15.7	22.2	20.0
2. Trucks	(16.6)	(19.8)	(21.1)
inter-city freight	4.7	7.5	6.9
other	11.9	12.3	14.2
3. Railroads	(25.2)	(4.9)	(3.3)
freight	22.4	4.3	3.1
passenger	2.8	0.6	0.2
4. Airplanes	(1.7)	(7.5)	(10.8)
passenger	0.5	2.0	5.6
freight	0.1	0.3	0.8
general aviation	0.1	0.3	0.6
military	1.0	4.9	3.8
5. Buses	(1.1)	(1.0)	(0.8)
urban	0.8	0.5	0.3
inter-city	0.2	0.3	0.25
school	0.1	0.2	0.25
6. Non-bus urban mass transit	1.0	0.3	0.2
7. Waterways, freight	3.6	2.8	2.5
8. Pipelines	0.7	0.9	1.2
9. Other [a]	12.1	11.4	5.9
Total Transportation Energy Consumption[b] (10^{15} Btu)	8.7	10.9	16.5

[a]"Other" (the difference between Bureau of Mines totals and the sum of lines 1-8) includes passenger traffic by boat, pleasure boating, nonfuel uses of energy (lubricants, greases), nonaviation military fuel uses, and errors due to the use of approximations and assumptions.

[b]As reported by the Bureau of Mines.[3]

the greatest percentage growth. These increases were offset primarily by the sharp drop in the fraction of energy used by railroads (a reflection of both falling share of traffic and declining EI). The fractions of energy devoted to IC buses and mass transit also fell. Highway vehicles (autos, trucks, buses) accounted for about 75% of the energy budget in 1970, compared to less than 60% in 1950.

Figure 7 shows the distribution of energy by purpose of transportation (derived from Table 10). The fraction of energy used for passenger traffic increased steadily while the IC freight fraction fell. In 1970, about 60% of the energy budget was devoted to passengers, compared to about 40% in 1950. The decline in percentage of energy used for freight may reflect the shift from a goods-producing economy to a service economy and growth in affluence that allows people to buy and use more automobiles.

IC freight and passenger traffic and urban passenger traffic account for about 75% of the transportation energy budget.

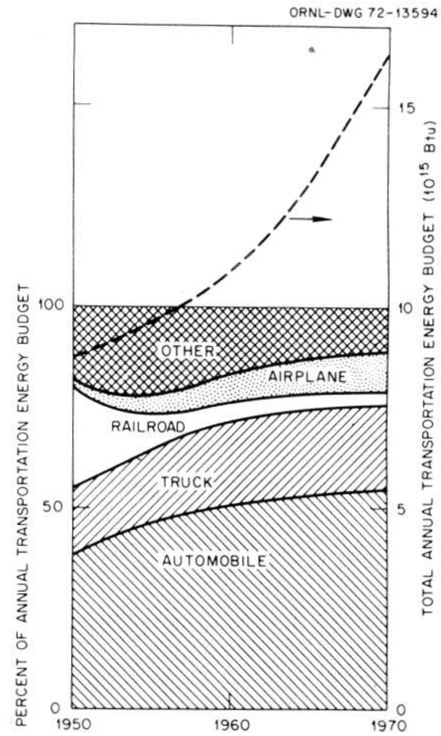

Fig. 6. Distribution of Transportation Energy by Mode.

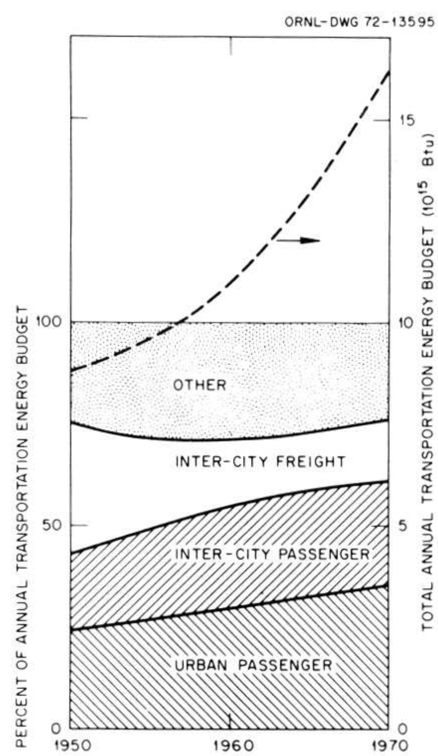

Fig. 7. Distribution of Transportation Energy by Purpose.

The remaining 25% is used for urban freight, military transportation, general aviation, pleasure boating, greases, lubricants, and so on.

Figure 8 shows the relative importance of changes in population, per-capita traffic, and overall EI to the growth in total transportation energy use from 1960 to 1970.* Growth in total traffic (freight plus passenger) accounted for over 80% of the decade's increased energy use. Per-capita traffic, especially passenger travel, accounted for 55% of the growth. Shifts in modal mix and changes in individual modal EI for passenger traffic accounted for 18% of the growth. There was almost no change in overall freight EI during this decade. Thus, transportation energy growth was due primarily to rising traffic levels and only secondarily to increases in EI.

Tables 11 and 12 summarize 1970 EI data presented earlier. Also shown are average prices (costs for autos), load factors, fatality rates, minimum EI, haul length, and speed for each mode. In general, the variation in prices closely parallels variation in EI. The increased price of high EI modes reflects their greater value (speed, comfort, flexibility, and reliability).

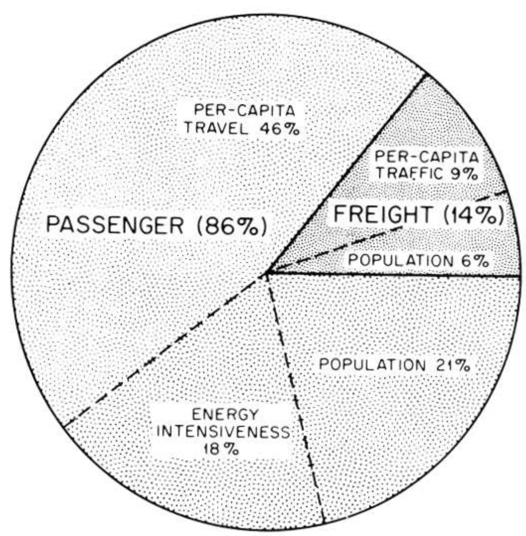

Fig. 8. Factors Accounting for the Increase in Transportation Energy Use Between 1960 and 1970.

*The period 1950-1960 is not discussed because freight energy use declined during that time due to improved railroad EI.

Table 11. Inter-City Freight Transport Data for 1970[a]

	EI Actual (Btu/TM)	Price (¢/TM)	Haul Length (miles)	Speed (mph)
Pipeline	450	0.27	300	5
Railroad	670	1.4	500	20
Waterway	680	0.30	1,000	—
Truck	2,800	7.5	300	∿40
Airplane	42,000	21.9	1,000	400

[a]Source: Price, ref. 1; Haul length, ref. 1; Speed, refs. 5, 14, 19, 22, and personal estimate for trucks based on data in ref. 2.

Table 12. Passenger Transport Data for 1970[a]

	EI (Btu/PM)		Load Factor (%)	Price (¢/PM)	Fatality Rate (deaths per 10^8 PM)	Haul Length (miles)	Speed (mph)
	Actual	100% LF					
			Inter-City				
Bus	1600	740	46	3.6	0.10	100	45
Railroad	2900	1100	37	4.0	0.09	80	40
Automobile	3400	1600	48	4.0	3.25	50	∿50
Airplane	8400	4100	49	6.0	0.13	700	400
			Urban				
Mass transit	3800	760	20	8.3	0.26	3	∿15
Automobile	8100	2300	28	9.6	2.11	6	∿20

[a]Source: Load factor, refs. 1, 9, 11, 12; Price, refs. 1, 8, 9; Fatality rate (1968-1970 averages) derived from refs. 1 and 24; Haul length, refs. 1 and 11; Speed, refs. 14, 19, 23, and personal estimates for autos and mass transit based in part on data in ref. 2.

The minimum EI values in Table 12 assume 100% load factor (LF) and no energy penalty for increased passenger weight per vehicle. The low load factor for passenger trains helps to explain its high EI. Similarly, EI values for urban travel (both autos and mass transit) would be lower if load factors were higher.*

CONCLUSIONS

This report examines data from a variety of sources to determine traffic carried, energy consumed, and EI for passenger and freight modes from 1950 to 1970. Several assumptions and approximations (described in the Appendix) are necessary for derivation of these numbers. Therefore, results presented here should be used cautiously.

This analysis shows the considerable variation in EI among freight and passenger modes. For freight (Fig. 1), airplanes are the most energy-intensive mode, followed by trucks, boats, trains, and pipelines. For IC passengers (Fig. 3), airplanes again have the highest EI, followed by autos, trains, and buses. For urban passenger travel, mass transit is much less energy intensive than are autos.

Between 1950 and 1970, overall freight EI declined because of the sharp decrease in railroad EI. During the past few years, however, IC freight EI increased as freight traffic continued to shift from trains to trucks and airplanes, and railroad EI remained nearly constant. Overall passenger EI increased because of shifts from low-EI to high-EI modes and because of increases in individual modal EI.

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*Shifts in modal mix from high-EI to low-EI modes would reduce energy use and might also reduce traffic deaths and user costs, as indicated in Tables 11 and 12. The magnitude of such savings in energy, lives, and dollars depends on the extent of modal shifts and the consequent load factors for each mode. Hypothetical scenarios for transportation energy savings are given in refs. 6, 25, and 26.

These trends suggest that overall transport EI (for both freight and passengers) is likely to increase in the future. These trends are probably a reflection of our growing affluence (e.g., desire for speed and comfort, suburban development, diffusion of employment locations).

However, overall transport EI can be decreased through a shift in modal mix and/or improved load factors. Whether or not transport EI decreases in the future depends, in part, on economic growth although changes in life styles and attitudes could reduce energy growth without reducing GNP growth, let alone "welfare." A number of emerging factors — fuel scarcities, rising fuel prices, growing dependence on petroleum imports, balance of payments deficits, urban congestion, noise, air pollution, and new federal policies — may combine to reverse the historic trend and lower overall transportation EI.

ACKNOWLEDGMENTS

I thank Robert Stark, American Transit Association; Kenneth Hurdle, Association of American Railroads; and W. J. Page, Federal Highway Administration, for providing data necessary to complete this study. I appreciate the careful reviews of an earlier draft performed by Roger Carlsmith and John Moyers of ORNL and Joel Darmstadter of Resources for the Future. I am particularly grateful to William Mooz, Rand Corporation, for his thorough and critical evaluation of this research.

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APPENDIX

Details of Energy Intensiveness Calculations

This Appendix describes the details, data, approximations, and assumptions used in developing the EI estimates given in the report.

Automobiles

Automobile VM data are given by the Federal Highway Administration (FHWA).[10] These VM estimates are made annually for both rural and urban driving. To convert from VM to PM, one must know vehicle occupancy.

The Interstate Commerce Commission (cited in ref. 2) estimates annual IC auto PM. Dividing these figures by the corresponding FHWA VM data yields an estimate of average IC auto occupancy. Between 1950 and 1970, this number averaged 2.4 PM/VM.

Surveys reported in refs. 11 and 12 suggest an average auto occupancy of about 1.9. Between 1950 and 1970, the fraction of total auto mileage on rural roads averaged 0.5. Thus, we assume the following occupancy values:

	Passenger-miles/vehicle-mile
urban	1.4
rural	2.4
average	1.9

Rural and urban VM data[10] are multiplied by the appropriate occupancy values to yield total traffic (in PM).

The FHWA[10] also reports auto fuel consumption for each year in gallons, converted here at 136,000 Btu/gallon. Average EI is then computed by dividing energy consumption by total PM.

Auto performance is poorer in cities than in rural areas because of slower speeds, shorter trips, and more stop-and-go driving. We assume that gas mileage is 40% greater in rural areas than in cities. Since occupancy is 2.4 in rural areas and 1.4 in cities, auto transport is 140% more energy-efficient in rural driving than in urban driving. This 140% difference is then used to estimate auto EI for urban and rural conditions from the average EI, as indicated in Table 1.

Trucks

Truck VM data are reported annually by the FHWA.[10] Data are given for "All trucks," "Combinations," and "Single-unit trucks."

Reference 10 also presents fuel use data, converted here at 136,000 Btu/gallon. However, before 1963 only aggregate truck fuel use was reported. In 1963, the FHWA began to report fuel use for each truck category. During the period 1963 to 1970, fuel economy (miles/gallon) for single-unit trucks was consistently 2.1 times higher than for combination (tractor-trailer) trucks. This 2.1 factor was applied to the data for 1950, 1955, and 1960 to estimate combination truck fuel use for those years.

IC freight traffic carried by truck is reported annually in refs. 1 and 2 (based on ICC statistics). Dividing these TM figures into combination truck fuel use gives the EI figures shown in Table 2.

Unfortunately, sufficient data are not available to further disaggregate truck fuel usage and EI. However, data in refs. 10 and 13 shed some light on truck usage. In 1967, combination trucks accounted for 19% of total truck mileage and for 33% of truck fuel usage.[10] That year, personal transportation by truck accounted for 25% of truck mileage, and agriculture accounted for 16%. Much of the remaining truck mileage was devoted to wholesale and retail trade and delivery of services.[13]

Aircraft

Consumption of aviation gasoline (120,000 Btu/gallon), jet fuel (135,000 Btu/gallon), and oil (150,000 Btu/gallon) for domestic certificated route air carriers is reported by the CAB.[14] Conversion factors are from ref. 3.

Revenue traffic (passengers and freight) carried by commercial airlines is reported in refs. 1, 2, and 14. To compute EI for freight and passenger services separately, it is necessary to distribute total fuel consumption between these two services.*

All-cargo aircraft[14] operated in 1970 with an average load factor of 55% and consumed about 27,000 Btu/ton-mile. All domestic operations (passenger/cargo planes plus all-cargo planes) operated with a passenger load factor of 49% that year and a freight load factor of 28%; the overall load factor[14] (based on total traffic) was 43%.

The ratio of payload weight (passengers, baggage, and freight) to average total aircraft weight,[18] including fuel, ranges from about 30% to 40%. Using an average value** of 35%, the 1970 load factor, and EI values for all-cargo planes, one can show that EI for all air freight in 1970 (load factor of 28%) was 42,000 Btu/TM.

This derived EI value is then multiplied by the 1970 volume of air freight. The resultant energy use, subtracted from total commercial aircraft energy use, is the energy allocated to passenger air traffic —

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*Mooz[7] uses a different method for fuel distribution from the one used here. His results are quantitatively different, but qualitatively similar, to those given here.

**The computed value for air freight EI is quite insensitive to the assumed ratio of payload to total weight.

919 trillion Btu. Division by total passenger traffic[14] (110 billion PM) yields 8,400 Btu/PM. Thus, one passenger is equivalent, in terms of fuel consumption, to 400 pounds of cargo. The typical passenger plus baggage weighs 200 pounds; this suggests that the weight of the passenger's seat, and share of empty seats, stewardesses, kitchens, lavatories, etc., is another 200 pounds. This equivalence factor between passengers and cargo is applied to each year's data from 1950 through 1970.*

Fuel consumption for general aviation is reported by the FAA[15] for the years 1952 through 1969. Estimates of fuel use for 1950 and 1970 were made by extrapolating fuel use from the two adjacent years.

Domestic military use of aviation fuels was reported for 1960, 1965, and 1970 by the Bureau of Mines.[17] Reference 16 details annual U.S. military procurement of aviation fuels (both domestic and foreign purchases). Domestic military use of aviation fuels was estimated for 1950 and 1955 using the ratio of domestic military fuel use[17] to total military procurement[16] for 1959.

Railroads

Railroad consumption of diesel and fuel oil (138,700 Btu/gallon), coal (26.2 million Btu/ton), and electricity (converted at prevailing heat rates) is reported in refs. 2, 19, and 20. Conversion factors are from ref. 3.

Revenue freight and passenger traffic are reported in refs. 1, 2, 19, and 20. As with airplanes, one must distribute total fuel consumption between freight and passenger services.

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*The fuel use estimate for 1950 is obtained from 1951 EI values and 1950 freight and passenger traffic data.

The ICC[20] reports fuel consumption for railroads in terms of freight, passenger, yard-switching, and work-train uses. Since passenger trains carry mail and express as well as passengers, the ICC figures for passenger train fuel used are multiplied by the fraction of annual passenger train car-miles devoted to passenger service. In other words, only the fuel used to haul coaches, combination cars, parlors, lounges, sleeping cars, diners, etc. is actually charged to passenger service. In 1970, 70% of total passenger train car-mileage was devoted to passenger service.[20] Rail passenger EI is then computed as the ratio of this fuel usage to total passenger traffic; in 1970, the value was 2900 Btu/PM.

The remaining fuel consumption is charged to freight service, yielding 670 Btu/TM for 1970. These figures suggest that one railroad passenger is equivalent (in terms of fuel consumption) to more than 4 tons of freight (compared with 0.2 tons for aircraft).

There are at least three reasons for this high railroad passenger EI value. First, rail passenger service suffers from a low load factor, 37% in 1970 compared to 49% for airplanes.[1] Second, passenger trains are quite heavy. The average passenger train weight (exclusive of mail and baggage cars) per passenger* in 1970 was 4.4 tons.[19] For airplanes, IC buses and IC autos, average vehicle weight is less than 1 ton per passenger. Third, passenger trains travel at an average speed of 40 mph, double the speed of freight trains,[19] and energy requirements increase with speed.

*Even if passenger trains had a 50% load factor (rather than 37%), train weight would still exceed 3 tons/passenger.

Buses

PM data for IC buses are reported in refs. 1 and 2. Urban bus traffic is reported by the ATA.[9] The number of students transported by school bus is given in ref. 13. School bus PM are estimated assuming 200 school-days/year and a 10-mile round-trip for each student.

The FHWA[10] reports annual fuel use (converted at 136,000 Btu/gallon) for commercial and school buses. Urban bus fuel use is reported in ref. 9. Subtracting urban fuel use[9] from commercial bus fuel use,[10] yields fuel use for IC commercial buses. For 1950 and 1955, the derived IC fuel use figure is a "small" number obtained from the difference between two "large" numbers. Thus, small errors in either the FHWA figures[10] or the ATA figures[9] would have had an important effect on IC bus fuel use estimates. This may explain the low EI values for IC buses in 1950 and 1955 shown in Table 5.

Urban Mass Transit

The ATA reports annual PM figures[9] for urban buses, trolley coaches, and electric railways (subway, surface, elevated). Reference 9 also presents data on fuel use (converted at 136,000 Btu/gallon) for urban buses and electricity use (converted at prevailing heat rates[3]) for electric transit systems.

In practice, there is little difference in EI between electric and gasoline-powered mass transit (Table 6). However, because the load factor[9] for buses was 18% in 1970, compared with 26% for electric transit, buses have a much lower theoretical EI:

	Btu/seat-mile
Urban buses	650
Electric transit	1100

Waterways

Ships carry freight on the Great Lakes, in rivers and canals, and along the coastlines of the U.S. Data reported by the ICC (cited in ref. 2) and the U.S. Army Corps of Engineers contain duplications because of different data collection and reporting methods.[1] For the years since 1960, the TAA has recalculated these figures to exclude duplications.[1] Data presented in Table 7 are from ref. 1 and include all domestic waterborne freight traffic.

Distillate fuel oil (5.825 million Btu/bbl) and residual fuel oil (6.287 million Btu/bbl) use for waterborne traffic was obtained from ref. 7 (using data in refs. 16 and 17).*

Oil Pipelines

Total oil traffic is reported annually by the ICC (cited in refs. 1 and 2). Accurate data concerning energy consumption for oil pipelines are not available. Rice[5] estimates oil pipeline EI at 450 Btu/TM. His calculations (personal communication, April 1972) for the 48-in.-diam Alaskan oil pipeline yield an EI estimate of 220 Btu/TM. The "Big Inch" (24-in. diam) and "Little Big Inch" (20-in. diam) pipelines, constructed during World War II to transport crude and refined petroleum, operated with an EI[22] of about 400 Btu/TM.

Mooz,[7] using financial data reported by the ICC, estimates pipeline EI as 1200 to 2600 Btu/TM. These figures are substantially higher than those reported in refs. 5 and 22; possibly, this disparity reflects

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*The 1950 waterway traffic estimate is based on partial data for that year and complete data for 1949 from ref. 1. The 1970 fuel use estimate is based on 1968 and 1969 data in refs. 7 and 16.

differences in flow rate, pipeline diameter, fluid viscosity, and overall pumping efficiency.

The table below shows the wide range of pipeline EI possible with reasonable values for pipeline diameter, fluid velocity, and fluid viscosity. These EI values assume an overall pumping energy efficiency of 25% (equivalent to 29.5% efficiency in delivering energy in the form of electricity to the motor and 85% efficiency of the motor-pump set). Both the figure used in this report, 450 Btu/TM, and the values estimated by Mooz fall within the range of values shown in the table.

Pipeline Energy Intensiveness (Btu/ton-mile)

Pipeline Diameter (in.)	Kinematic Viscosity 0.000010 ft^2/sec[a]			Kinematic Viscosity 0.000075 ft^2/sec[b]			Kinematic Viscosity 0.00050 ft^2/sec[c]		
	Velocity (ft/sec)			Velocity (ft/sec)			Velocity (ft/sec)		
	3	6	9	3	6	9	3	6	9
8	180	590	1330	290	960	1850	460	1500	2870
20	60	220	450	90	310	660	140	490	980
32	30	130	260	50	170	360	80	270	540

[a]Kerosine at 80°F.

[b]California crude oil at 80°F.

[c]Light engine oil at 80°F.

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