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Energy Implications of Rail Transit

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Whether mass transit actually saves energy is not easy to answer; different studies show different results. This paper reviews the major studies, notably the Congressional Budget Office's 1977 report, "Urban Transportation and Energy: The Potential Savings of Different Modes," and several studies done in response that debate many of its findings. A possible petroleum conservation strategy that focuses on future urban and regional development is identified and discussed.

The U.S. energy crisis is essentially a transportation crisis. In recent years the transportation sector accounted for one-fourth of all the energy used nationally—some 19.8 quadrillion Btu in 1979—and half of the petroleum consumption. Ninety-seven percent of the transportation sector's energy needs were supplied by petroleum in 1979.[1] Highway vehicles used 80 percent of this petroleum and private autos 70 percent. Natural gas accounted for 2.6 percent, mostly in pipeline consumption, although interest is now being renewed in the use of compressed natural gas and propane for vehicles. The electricity used was less than 1 percent, and most of this was used by fixed rail transit systems, which in 1978 used 2223.0 million kWh of electricity—about 7.5 trillion Btu. Buses used diesel oil and a small amount of gasoline, equivalent to about 60 trillion Btu in 1978.[2]

Total and per capita consumption in the transportation sector rose steadily through 1978 and fell sharply in 1979 despite increases in other sectors (Table 1[2]). In the first 9 months of 1980, gasoline consumption was 7 percent lower and imports of petroleum and products were nearly 20 percent lower than in the same period in 1979. This trend reflects a number of developments: sharply higher world oil prices, gradual deregulation of United States oil prices, and mandated automobile fuel efficiency standards of 20 mpg fuel average in 1980.

Additional factors will eventually affect energy use in the transportation sector, including development and use of alternative vehicles (e.g., the electric car), engines (e.g., the Stirling engine), and fuels (e.g., hydrogen, natural gas, ethanol, and methanol). Implementing existing and proposed energy efficiency standards for new automobiles (corporate average fleet efficiency), mandated to reach 27.5 mpg in 1985, will also reduce gasoline consumption. However, even if a fleet average of 24 mpg for all existing autos is achieved by 1990, the daily petroleum consumption is estimated to rise to 2.8 million bbl/day compared with 2.6 million bbl/day in 1975 when the fleet average was only 14 mpg.[3]

Another energy-saving transportation option is rail transit. Its energy-saving implications caused considerable controversy in the past few years, particularly as increased investment in mass transit has come under mounting criticism.

TRANSIT TRENDS

Only 16 of the 1003 transit systems in the United States in 1978 included heavy and/or light rail. Three systems consisted only of heavy rail and 948 only of motor buses.

Table 1. Sectoral primary energy consumption.

	Residential/Commercial		Transportation		Industrial
Year	Total 10^{12} Btu	Per Capita 10^6 Btu	Total 10^{12} Btu	Per Capita 10^6 Btu	Total 10^{12} Btu
1970	24 574	120.0	16 077	78.47	26 170
1971	25 540	123.4	16 671	80.52	26 086
1972	26 807	128.4	17 675	84.63	27 145
1973	27 396	130.2	18 525	88.04	28 685
1974	26 699	126.0	18 057	85.20	27 998
1975	26 635	124.7	18 186	85.15	25 881
1976	27 831	129.3	19 071	88.62	27 603
1977	28 193	130.0	19 751	91.06	28 442
1978	28 807	131.8	20 626	94.35	28 716
1979	29 369	133.2	19 786	89.74	29 627

Notes: Excludes natural-gas transmission losses and unaccounted-for-natural gas. These data include distributed electricity end uses converted at rates corresponding to national average thermal power plant performance. Per capita values calculated by the author.

Heavy rail accounted for 27.5 percent of the 2.19 billion vehicle-miles covered and motor buses for 75 percent. Most heavy rail transit is located in 8 urban regions: New York, Chicago, Philadelphia, San Francisco, Boston, Cleveland, Atlanta, and Washington; 2 more cities, Baltimore and Miami, have systems under construction. The automobile still accounts for 97 percent of all passenger-miles traveled locally except in large cities where mass transit systems are available, but generally still ranges between 80 and 90 percent. An exception is New York City, where more than half the travel is on rapid rail transit or transit bus.[8]

Heavy rail use has dropped significantly over the past 4 decades, as has mass transit ridership in general (Table 2[7]). Between 1940 and 1979, heavy rail vehicles in operation declined from 11 032 to 9567; light rail vehicles declined from 26 630 to 944; but motor buses increased from 35 000 to 52 866. The United States has lagged behind all other nations in urban rail construction. Between 1960 and 1980, rapid transit and light rail mileage doubled worldwide. Over two-fifths of the new construction was in developing countries, and over two-fifths was in Europe and Canada.[5] A reversal of this trend may be in progress, however. The American Public Transit Association reports that transit ridership in July 1980 was 30 percent higher than in July 1972.[7]

The decline in mass transit in the postwar period was a result of federal home financing and road building policies that fostered urban sprawl and suburbanization in America. Between 1960 and 1970, populations in central cities rose by only 7 percent, while those of suburban areas rose 26 percent. Many transit systems suffered financial difficulties, and in 1964 the Federal Urban Mass Transit Authority was created to provide capital assistance to systems. In the 1970s, the OPEC embargo and subsequent rise in crude oil prices created a new interest in energy conservation and energy efficiency and a consequent reexamination of mass transit. The Project Independence Study of 1974 included a rather superficial section on transportation conservation that alleged that public transit—identified exclusively with buses—was 2 to 4 times more energy-efficient than the automobile. The report called for legislation to double the size of the bus fleets and discourage the use of automobiles.

MODAL ENERGY EFFICIENCIES

Operating Efficiencies

A number of studies done in the 1970s dealt with the energy efficiency of various transportation modes, both passenger[9-14] and freight.[15] In 1977, the National Research Council's Transportation Research Board[8] published a survey of these studies and a summary of their conclusions. All these studies evaluate energy efficiency in terms of operating efficiency only. The report measures energy efficiency in several ways: (a) Btu (or gallons) per vehicle-mile, the average fuel consumed by a vehicle in its daily duty cycle; (b) Btu or gallons per seat-mile, the efficiency of a given transit mode as it transports people; and (c) Btu or gallons per passenger-mile. (This assumes an average passenger occupancy that represents actual or expected use. Average occupancy is the sum of the total annual passenger-miles, divided by the total annual vehicle-miles.)

Table 3[8] is an adaptation and summary of a table in the TRB report for passenger modes in urban areas. In all 3 estimates the automobile has a lower efficiency than rail, but the 2 rail estimates vary widely: 1646 and 4300 Btu per passenger-mile.

Congressional Budget Office Study

In September 1977, Senator Lloyd Bentsen, Chairman of the Senate Subcommittee on Transportation of the Committee on Environment and Public Works, asked the Congressional Budget Office to prepare a study on the potential of energy conservation in urban transportation. In contrast to most previous studies, this analysis considers not only the energy needed to actually propel vehicles, but

Table 2. Trend of passenger vehicle miles operated.

	Railway					
Calendar Year	Light Rail (Millions)	Heavy Rail (Millions)	Total Rail (Millions)	Trolley Coach (Millions)	Motor Bus (Millions)	Total Vehicle Miles Operated (Millions)
1940	844.7	470.8	1 315.5	86.0	1 194.5	2 596.0
1945	939.8	458.4	1 398.2	133.3	1 722.3	3 253.8
1950	463.1	443.4	906.5	205.7	1 895.4	3 007.6
1955	178.3	382.8	561.1	176.5	1 709.9	2 447.5
1960	74.8	390.9	465.7	100.7	1 576.4	2 142.8
1965	41.6	395.3	436.9	43.0	1 528.3	2 008.2
1966	42.9	378.9	421.8	40.1	1 521.7	1 983.6
1967	37.8	396.5	434.3	36.5	1 526.0	1 996.8
1968	37.5	406.8	444.3	36.2	1 508.2	1 988.7
1969	36.0	416.6	452.6	35.8	1 478.3	1 966.7
1970	33.7	407.1	440.8	33.0	1 409.3	1 883.1
1971	32.7	407.4	440.0	30.8	1 375.5	1 846.3
1972	31.6	386.2	417.8	29.8	1 308.0	1 755.6
1973	31.2	407.3	438.5	25.7	1 370.4	1 834.6
1974	26.9	431.9	458.8	17.6	1 431.0	1 907.4
1975	23.8	423.1	448.4[a]	15.3	1 526.0	1 989.7
1976	21.1	407.0	429.6[a]	15.3	1 581.4	2 026.3
1977	20.4	361.3	383.2[a]	14.8	1 623.3	2 021.3
P1978	19.5	363.5	384.5[a]	13.3	1 630.5	2 028.3

Notes: Table excludes automated guideway transit, commuter railroad, and urban ferry boat.
P = preliminary.

[a] Includes cable car and inclined plane.

Table 3. Energy efficiency for passenger transportation modes.

Mode	Passenger-Miles Per Gallon	Seat-Miles Per Gallon	Btu Per Passenger-Mile	Load Factor Assumed	Source	Remarks
Auto						
	22	57	5 578	1.9	(10)	Urban (1972)
	15	54	8 100	1.4	(9)	Urban (1970)
Small						
Work and related business	21.67	70[a]	5 768	1.6	(16)	
Shop and family business	41.39	63	3 020	2.3	(16)	
Social and recreation	74.93	94	1 668	2.8	(16)	
Subtotal	47.74	76	2 618	2.2		
Standard						
Work and related business	15.68	59	7 972	1.6	(16)	
Shop and family business	20.70	54	6 039	2.3	(16)	
Social and recreation	42.15	90	2 966	2.8	(16)	
Subtotal	24.51	67	4 209	2.2		
Total	29.70	69	4 209	2.2		
Bus						
	51		2 681		(10)	Urban transit (1972)
	48		2 891	24%	(17)	Urban (1972)
			3 700	<20%	(9)	
Rail						
	84		1 646		(10)	Transit (1972)
	32	128	4 300	25%	(18)	Urban (1970)
Misc.				PM/VM		
Bicycle			1 300		(19)	Total energy use
			97		(20)	10 mph
			200		(21)	5 mph
Walking			500		(20)	2.5 mph
			300		(22)	2.5 mph
Taxi[b]	8.0		15 600	0.7	(23)	
Dial-A-Bus	15.6			3.0	(24)	Peak hour
Van-Pool	81	108	1 540	9.0	(25)	Peak hour
BART	88			40	(26)	Peak hour

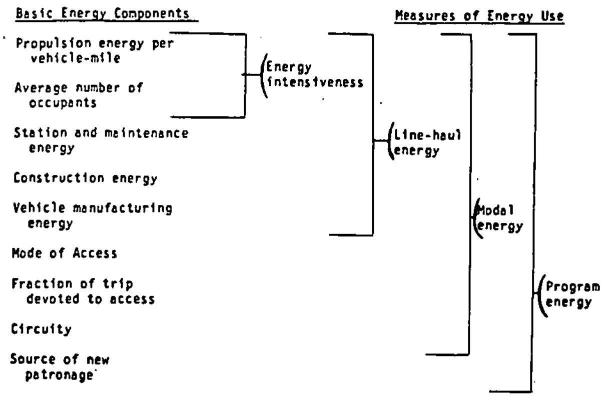
[a] Small cars are assumed to average 3.5 passenger-seats and other cars 6.0 passenger-seats.

[b] The driver is assumed not to be a passenger.

also indirect uses of energy such as energy used to manufacture vehicles, build rights-of-way (roads, rail, etc.), maintain systems, heat and light stations, and drive to railroad stations. It also examines the energy implications of adaptations to new systems. For instance, if improvements to one service draw passengers from another, energy-efficient mode—if vanpooling draws passengers from buses instead of autos—the effect on energy consumption is negative. Another problem the CBO study examines is that of "circuity." Many people who use public transit drive to stations, and combined automobile/transit trips are generally less direct than those made by auto alone, so a dual-mode trip may save little or no energy at all. The study does not analyze the long-term effect of changes in shopping, living, and working locations made because of changes in mode of transportation, and a serious deficiency of the report is that it does not recognize that such changes do occur. The various factors considered are shown in Figure 1.[4]

The CBO chose typical values for each component, based on what it called a comprehensive review of available literature, and then generated 3 sets of estimates—high, low, and middle—for each case. It examined automobiles, carpools, vanpools, dial-a-ride systems, old heavy

Figure 1. A framework for evaluating energy savings from urban transportation.



rail transit, new heavy rail transit, commuter rail, light rail transit, and buses. It emphasizes total energy consumption regardless of fuel used.

The conclusions based on the CBO study's middle estimates are shown in Table 4;[4] Table 5[4] shows some of the component estimates. The low and high estimates show little shift in the ranking of the modes: vanpools always appear to be the most energy-efficient and dial-a-ride the least. Other than dial-a-ride, new heavy rail transit is the only mode to show an energy loss. Although its operating energy requirements are relatively low on a per passenger basis, maintenance and station energy uses are high: 7300 to 10 000 Btu per vehicle-mile for old heavy rail and 13 990 to 14 700 Btu per vehicle-mile for new heavy rail compared to 1600 Btu per vehicle-mile for automobile maintenance. Guideway construction energy requirements for new heavy rail are high and have an extremely wide range—2400 to 22 000 Btu per vehicle-mile, compared to 100 to 130 for autos. However, CBO notes that estimates of guideway construction energy use vary from 85 billion to 775 billion Btu per mile of track, a variation that suggests "the estimation process needs more refinement," says the report. Vehicle manufacturing energy use estimates also show a wide range: for heavy rail transit manufacture, energy use is 1350 to 8100 Btu per vehicle-mile, versus 720 to 1330 for automobile manufacture.

Rail transit rates low when the energy use ratio per passenger-mile traveled as a result of new programs is considered. Several studies are cited to show that new rail transit system passengers formerly used buses (36 percent on Philadelphia's Lindenwold line, 54 percent on San Francisco's BART line, and 72 percent on Chicago's Dan Ryan line) or were making a new trip because of the system

Table 4. Middle estimates for various measures of energy required by urban transportation modes: all measures expressed in Btus per passenger mile.

Mode	Operating Energy[a]	Modal Energy[b]	Program Energy[c]
Single-occupant automobile	11 000	14 220	N/A
Average automobile	7 860	10 160	N/A
Carpool	3 670	5 450	4 890
Vanpool	1 560	2 420	7 720
Dial-a-ride	9 690	17 230	(12 350)
Heavy rail transit (old)	2 540	3 990	N/A
Heavy rail transit (new)	3 570	6 580	(980)
Commuter rail	2 625	5 020	970
Light rail transit	3 750	5 060	30
Bus	2 610	3 070	3 590[d]

Note: N/A = Not Applicable

[a] Propulsion only.

[b] All forms of energy, computed on a door-to-door basis, adjusted for roundabout journeys.

[c] Energy saved (lost) per passenger mile of travel induced by new programs.

[d] For new express bus service. Regular urban bus service would show smaller savings.

Table 5. Middle estimates of basic components of operating energy intensiveness and line-haul energy by urban transportation modes: in Btus per vehicle mile.

Mode	Propulsion Energy	Average Number of Occupants	Station and Maintenance Energy	Construction Energy	Vehicle Manufacturing Energy
Single occupant automobile	11 000	1.0	2 000	125	1 100
Average automobile	11 000	1.4	2 000	125	1 100
Carpool	11 000	3	2 000	125	1 100
Vanpool	14 000	9	2 000	200	2 000
Dial-a-Ride	15 500	1.6	2 000	200	2 000
Heavy rail transit (old)	61 000	24	9 000	3 000	1 500
Heavy rail transit (new)	75 000	21	15 000	4 000	1 500
Commuter rail	105 000	40	7 000	1 200	2 500
Light rail transit	75 000	20	7 000	1 700	2 000
Bus	30 000	11.5	900	370	1 200

(13 percent, 11 percent, and 16 percent for the 3 systems). Vanpoolers, by contrast, formerly drove cars.

On the basis of its findings, the CBO study concluded that "rail transit offers little aid to the nation's efforts to save fuel."

Responses to the CBO Study

Not surprisingly, the CBO report was criticized by city planners and academic transportation specialists as biased toward the auto and paratransit. The following is a summary of some of the major arguments against the CBO's findings:[5,27,28]

- It is misleading to base conclusions on average urban conditions and average mode efficiencies, when, as the CBO admits, no "average" city actually exists. Since conditions vary among cities, types of trips, etc., each mode is the most efficient for certain applications.
- The CBO focuses on energy use to the exclusion of other factors, especially performance; e.g., speed, reliability, passenger attraction. Any analysis that disregards these factors would conclude that bicycles and motorcycles are superior to all other modes.
- The modes considered do not serve the same travel demand: carpools and vanpools, for instance, are only for commuting to work, whereas regular transit serves all purposes at all hours and thus should not be compared directly. The report also includes empty miles of transit vehicles in its computations, but ignores them for automobile trips. Millions of auto trips are made each day for the purpose of dropping off or picking up a passenger (e.g., children at school). They should not be counted as if they had an average occupancy of 1.5 (2 persons in 1 direction, 1 in the other), but only 0.5, since the driver has no purpose in that trip. Doing this would lower the auto's estimated efficiency by 10 to 15 percent.
- While the energy consumed to build and maintain railway stations and related facilities is counted, corresponding items for other modes are ignored; e.g., the energy used to build and maintain private and commercial garages and parking lots, gasoline stations, body repair shops, street and highway maintenance, traffic controls, etc. The magnitude of this error is difficult to compute, but if corrected, it would result in a significant change in favor of rail.
- The report wrongly assumes that automobile energy efficiency will be greatly improved, while the energy efficiency of other transit modes will not change or will even deteriorate. Increased coasting (regenerative braking) alone could cut rail transit energy use by 16 to 30 percent. Energy-conscious station design can also effect significant savings for rail transit and is easier to implement than auto efficiency.
- The CBO report ignores the most important energy-related feature of rail transit: that it is driven by electricity, which can be produced from many energy sources, whereas automobile-based modes can, at present, be propelled only by liquid fuels. The use of nuclear and hydropower to generate electricity improves the gross efficiency of electricity production, while breeder reactors and, eventually, fusion reactors represent virtually renewable sources of energy.

An Alternative Model

Boris Pushkarev and Jeffrey Zupan of the Regional Plan Association analyzed the energy implications of rail transit as part of their comprehensive review of criteria to support implementation of a fixed guideway system in an American city.[5] They found that the average energy consumption for the 8 existing electric rapid transit systems cluster around the value 670 Btu/place mile (e.g., seat/mile), independent of speed. Buses are not necessarily more efficient than rail transit; at the speed at which most buses operate, 12 mph, gross energy use is about the same as for electric rail transit. It may be higher in downtown areas and lower at intercity free speeds. The energy efficiency of new advanced design buses is about 25 percent higher than in 1970. Pushkarev thus concludes that "both fixed guideway and free-wheeled mass transit vehicles have similar energy requirements for vehicle operation, regardless of diesel or electric propulsion. The greater efficiency of the electrical motor compared to the diesel engine is offset by greater losses in conversion from the primary energy source. Thus both bus and rail energy requirements are about one-third those of the traditional auto in local urban use."

If calculated per passenger-mile, the crucial factor is occupancy. Urban rail systems have a 23.3 percent occupancy rate compared to 19 percent for buses, equivalent to 1.4 persons in a 6-passenger auto. Yet, the auto uses 3 times as much energy as rail, so even if consumption was reduced by half, a car would still use 45 percent more energy than rail or bus. To compete with rail, the automobile would have to increase its occupancy to 2.0 or transit occupancy would have to decline to 16 percent.

The energy requirements for other transit operations are poorly documented and difficult to determine; Pushkarev and Zupan therefore developed their own estimates of the gross energy costs of autos, buses, and rail, including operation, maintenance, wayside and station requirements, vehicle manufacture, and guideway construction for different volumes of line miles.

An important factor is the phenomenon of nonownership of autos in the immediate vicinity of rail stations. This may be substantial and, according to one estimate, at service volumes in excess of 50 place miles/line miles, one-third or more of the energy cost of rail transit may be free, paid for by savings from reduced auto ownership.[5] Indeed, several studies have shown that a community with transit has different energy use patterns than one without transit. Housing is denser, employment and shopping sites are better organized, and car use differs. One result is that total gasoline sales in such regions are less than if transit were not available, and, in cities with rail transit, gasoline consumption per capita is lower than in those without transit.

In addition, it is axiomatic that the construction of a new transit line, either highway or rail, attracts development because of increased accessibility, and, where it is a rail line, the resulting development is generally of high density. A July 1980 study by the Federal City Council of the District of Columbia showed that nearly $1 billion worth of private development has taken place near Metro stations on the 43.5 miles then completed, with another $5 billion of development contemplated if the entire 101-mile system is completed. Major new downtown office development has occurred in Philadelphia, Pittsburgh, Chicago, Detroit, Milwaukee, and other cities with transit improvements either proposed or underway.[30] High-density land use results in energy conservation in ways other than reducing petroleum use by autos: building heating is more efficient—it is estimated that a multi-dwelling facility uses 45 percent less energy per person than a single dwelling—and providing services in general requires less energy.

CONCLUSION

Pushkarev and Zupan conclude that an analysis of United States cities identifies 4 cities as serious candidates for new heavy rail transit systems: Los Angeles, Seattle, Honolulu, and Houston. A tentative candidate is Dallas-Fort Worth. Candidates for light rail transit include St.

Louis, Milwaukee, Minneapolis, Indianapolis, Louisville, Cincinnati, Denver, Kansas City, and Columbus.

The American people are becoming increasingly sensitive to the cost and availability of the petroleum energy supply. There is general agreement that new energy and land use strategies must be developed to alter energy use patterns everywhere. Currently, 85 percent of rail mass transit's energy supply is nonpetroleum derived. Rail mass transit clearly has made and can continue to make a contribution to reducing petroleum consumption and energy consumption in general through applying appropriate land use strategies. The magnitude of these conservation efforts is becoming more apparent as more disaggregated data are produced and analyzed.

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