Survey and Analysis of Energy Intensity Estimates for Urban Transportation Modes

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Current interest in energy conservation has resulted in a spate of divergent estimates of the energy intensiveness of urban transit modes. This paper critically reviews the methodologies and data sources employed by these estimates. It is shown that a very small repertory of sources and methodologies underlie the energy intensity estimates and that variance among them is primarily attributable to contradictory load-factor assumptions. Energy intensity estimates for bus and rail transit are developed, and the inadequacies of automobile data are discussed. Bus transit is shown to be more efficient than rail transit, and it is shown that the energy advantage of light rail over heavy rail lies in construction, not operation.

During the past few years, researchers have devoted considerable effort to the estimation of the energy intensiveness of various transportation modes. As a result, a plethora of energy-intensity (EI) values, which are often widely divergent, have been published. This report focuses on principal modes of urban passenger transportation and reviews some of the standard methodologies and data sources employed by EI researchers in an attempt to reconcile, or at least explain, the varying results. Emphasis is on aggregate statistical measures of EI rather than on disaggregate engineering analyses. In some cases where new or expanded data have become available, this paper presents new EI estimates.

PROBLEMS OF DEFINITION

EI may be ambiguously defined as energy input per transportation output. Ambiguity results unless the boundaries of the energy supply and the transportation system are delineated precisely. Different boundaries may be chosen to serve different analytic purposes. A recent Senate report (28) presents an excellent hierarchical framework of EI definition. A modification of that schema is given below.

Components of Energy Input	Measures of Transportation Output
Vehicle propulsion—revenue operation	Vehicle kilometers or seat kilometers offered
Auxiliary power—revenue operation (e.g., heating and lighting)	
Vehicle operation—nonrevenue service	Passenger route kilometers
Vehicle operation—inactive service	
Power to stations, shops, and other fixed facilities	Passenger straight-line kilometers
Energy used to construct vehicles, guideways, and stations	
Energy used by subsidiary modes (e.g., feeders or distributors)	Passenger straight-line kilometers, door-to-door

Energy consumption is outlined in the left-hand column. At the top of the column is vehicle propulsion energy, which is the most narrowly construed boundary of energy input possible. Going down the column, other components of energy use are added successively, incrementally widening the scope of the energy input. The right-hand column works in the opposite direction. Starting with the broadest interpretation of transportation output, vehicle kilometers offered, scope is increasingly narrowed down to door-to-door straight-line passenger kilometers. Thus, to unambiguously specify EI, it is necessary to pick a specific level in the right-hand column and a cutoff point in the left.

The hierarchical EI scheme enforces consistency and has the attractive feature of distinguishing between fixed and variable energy costs. Too often an average EI value is employed in policy analysis where a marginal EI value would be more applicable and vice versa. For instance, it is inappropriate to consider sunk energy costs (such as guideway construction) in the evaluation of potential mode shifts between existing transportation systems. However, such costs become relevant in the evaluation of new transit systems.

Thus, a hierarchical scheme of EI definition allows the energy analyst a great degree of flexibility. Unfortunately there is a paucity of information about station, maintenance, and construction energy costs, and about trip circuity. Therefore, this report concentrates on vehicle operating energy—energy used to propel, heat, and light vehicles in active and inactive operation.

AUTOMOBILES

Automotive EI is determined by both vehicle fuel economy and average occupancy (load factor). Methodologically, these two aspects of EI are distinct and will, therefore, be treated separately.

Fuel Economy

Attempts to estimate nationwide average automobile fuel economy fall into three categories, each of which has severe drawbacks:

1. Those based on Federal Highway Administration (FHWA) compilations of aggregate gasoline consumption and vehicle kilometers traveled,
2. Those employing weighted averages of U.S. Environmental Protection Agency (EPA) fuel-economy ratings for individual models, and
3. Those based on the selection of a representative automobile.

FHWA Statistics

Highway Statistics, an annual FHWA publication (32), presents data on gasoline consumption and vehicle kilometers traveled. The fuel-consumption data, based on state reports on fuel-tax revenue, cover all domestic nonmilitary consumption for highway purposes. These data appear to be reliable.

Calculation of total U.S. vehicle kilometers traveled is a formidable task. FHWA's procedures for estimating nationwide vehicle kilometers traveled were the subject of a recent study by Transportation and Economic Research Associates (26). The report found that

1. The FHWA's role is limited to reporting estimates of vehicle kilometers traveled that are prepared by the individual state highway departments and
2. There is no uniformity of methodology among the states.

Two principal approaches are used by the states:

1. Traffic count—By monitoring the highway system with manual or automatic counters, it is theoretically possible to establish a rate of traffic flow that, integrated over a year's time, yields annual vehicle kilometers traveled. Since the U.S. highway system is more than 6 million km (3.7 million miles) long, the monitoring effort is diffuse and sporadic. Typically states rely on a mixture of continuous monitoring of a few primary routes, statistical sampling, and slowly rotating coverage of all road sections over a cycle of up to a decade. The states pursue traffic-count programs with varying degrees of enthusiasm.
2. Fuel-consumption method—Many states lack the resources to undertake comprehensive traffic counts, so they rely on the fuel-consumption method, which consists simply of multiplying an assumed average fuel economy (kilometers per liter) figure by fuel consumed. In many cases, the fuel-economy figure was generated by dividing FHWA-reported vehicle kilometers traveled by highway fuel consumption.

Evidently the FHWA vehicle-kilometers-traveled figures are of dubious usefulness in the estimation of average fuel economy, since the vehicle-kilometers-traveled estimates merely reproduce state assumptions about fuel economy, nor is there much reason to trust the breakdown of driving between urban and rural highways. A predominantly rural state, by using the fuel-consumption method of estimating vehicle kilometers traveled, will, for instance, err in its estimate of rural vehicle kilometers traveled by nearly as large a percentage as its assumed kilometers-per-liter figure differs from the actual value.

Method of Weighted Averages

Given a profile of the U.S. automobile fleet and the EPA fuel-economy ratings for each automobile model, it is tempting to try to compute a weighted average of automobile fuel economy. This approach is attractive because it seems to offer the possibility of easy annual updating with new registration and fuel-economy statistics. In practice, however, there are complications.

A general formulation of the weighted average is as follows:

$$\text{Average fuel economy} = \sum_{i,y} n_{iy} m_{iy} [r_{iy} R_{iy} + (1 - r_{iy}) U_{iy}] \div \sum_{i,y} n_{iy} m_{iy} \qquad (1)$$

where

i = the index of automobile model (or, for a less disaggregate approach, automobile size or weight class);
y = the index of model year or age of automobile;
n_{iy} = the number of registered automobiles of model (class) i, vintage y;
m_{iy} = the corresponding average annual kilometers traveled;
r_{iy} = the proportion of kilometers driven on rural highways;
R_{iy} = the average rural (highway) fuel economy (km/L); and
U_{iy} = the average urban fuel economy (km/L).

The computation requires five data values for each automobile type. Of these five values, the first is known or can be established, the last two are known with modest reliability for recent vintages, and the other two are not known at all. The following data are all that is actually available:

$$m_y = \sum_i n_{iy} m_{iy} / \sum_i n_{iy} \qquad (2)$$

as estimated by the Nationwide Personal Transportation Study of 1969-1970 (31). R_{iy}, U_{iy} is as estimated by EPA dynamometer tests, which are subject to correction.

Obviously there are severe problems in using these data. First, the applicability of the EPA tests can be questioned. Some understanding now exists of the relation between dynamometer measurements and actual road tests that use a particular driving cycle, but the extent to which the EPA driving cycles are typical of urban and rural driving is unknown. For this reason empirical data on automobile use would be preferable. Second, it is not known how much covariance exists between vehicle weight and kilometers traveled, or proportion of rural driving. Do city dwellers tend to buy smaller automobiles? Are larger automobiles driven further, on the average? Data from the Nationwide Personal Transportation Survey (31) might be used to answer these questions.

Method of the Representative Automobile

Given the lack of aggregate data on vehicle kilometers traveled, it is reasonable to change strategy and merely choose a typical automobile model as a point of comparison. The method of the representative automobile seeks to go a step further and choose the automobile whose fuel economy approximates the national average. Selection of this representative automobile is equivalent to computing the weighted average detailed in the previous section, which is impossible, given existing data. Some authors have made the mistake of equating the national average fuel economy with the fuel economy of the national median-sized automobile.

Load Factor

Load factor, or average occupancy, is the other determinant of automotive EI. Load factor varies with trip purpose and length, geographic area, size of automobile, and a host of other variables.

Urban Load Factor

The literature on urban load factors includes a few studies of specific cities and two comprehensive studies. Specific city studies include Boyce and the Institute for Transportation Studies. Boyce and others (3) studied journey-to-work trips from three suburban New Jersey counties in 1970. Data from the 1970 census urban transportation planning package were used to compute a passenger kilometers-vehicle kilometers ratio of 1.14.

The Institute of Transportation Studies has for some years conducted surveys of San Francisco-bound commuter traffic that originates in the East Bay area. The surveys are disaggregate, based on screenlines at the

Caldecott Tunnel and the Bay Bridge. A fall 1977 survey (14, 15) yielded the following observations of vehicle occupancy:

Survey Area	6:30 a.m.-6:30 p.m. Westbound	6:30 a.m.-6:30 p.m. Eastbound	7:30 a.m.-8:00 a.m. (peak half-hour) Westbound	7:30 a.m.-8:00 a.m. (peak half-hour) Eastbound
Caldecott	1.26	1.28	1.22	1.20
Bay Bridge	1.51	1.40	1.73	1.23

The Nationwide Personal Transportation Study of 1969-1970 attempted to characterize the driving habits of the entire civilian (noninstitutional) population. Automobile load-factors data for households located in incorporated areas were reported as (31):

Item	To and From Work	All Purposes
Passenger kilometers-vehicle kilometers	1.5	2.2
Occupants per trip	1.4	1.9

The passenger kilometers-vehicle kilometers measure is simply occupants per trip weighted by trip length. The former is skewed upward by the high average occupancy of long trips—2.6 occupants per trip for trips of over 64 km (40 miles). Since many of these long-distance trips are undoubtedly vacation or other intercity journeys, the all-purpose urban load factor is more accurately estimated by the occupants-per-trip measure. A second Nationwide Personal Transportation Study is currently in the final stages of processing.

The National Transportation Study (30) suggests 1971 load factors of 1.3 (peak hour) and 1.5 (daily) averaged over all standard metropolitan statistical areas (SMSAs). These figures are based on compilations of local agency estimates.

In sum, adoption of an overall peak-hour estimate of 1.3 or 1.4 people per automobile would not be inconsistent with the specific city studies. It is not so easy to reconcile the disparate estimates of average daily occupancy. The NationwidePersonal Transportation Study estimate of 1.9 (31), although high, is the most authoritative.

TRANSIT BUSES

EI is codetermined by vehicle kilometers per liter and load factor. We examine each separately.

Fuel Economy

The standard statistical source for both vehicle kilometers traveled and fuel consumption is the American Public Transit Association (APTA). APTA surveys its members annually and publishes data for individual systems (2). APTA also published estimates of aggregate energy consumption statistics (1). The aggregate estimates are based on the responses of about 125 systems, which represent approximately 75 percent of total vehicle kilometers traveled. Fuel consumption for the missing systems is estimated on the basis of number of buses owned, adjusted differentially based on the service area population.

APTA data are not perfectly reliable. An Urban Mass Transportation Administration (UMTA) study reports (33)

> The data's main limitations lie in the basic structure of the reporting elements, a lack of conformity by data suppliers to the (APTA reporting) system with regard to data submissions. In other words, the APTA system does not provide the scope, uniformity, consistency, and accuracy that would be desirable for current and future requirements.

Project FARE, developed by UMTA in association with APTA, attempts to provide a consistent base of information about transit operations. Until FARE is fully implemented, the APTA data are the best available.

In scope, the APTA data are meant to cover all U.S. transit systems, both public and private. Excluded are school buses, jitneys, sightseeing buses, and intercity buses. Vehicle kilometers traveled includes all passenger vehicle kilometers, both revenue and nonrevenue (1). Fuel consumption is not precisely defined and has probably not been interpreted consistently.

Calculation of megajoules per vehicle kilometer is straightforward, given the APTA data (1 L = 0.26 gal; 1 km = 0.62 mile; 1 MJ/vehicle-km = 1525 Btu/vehicle mile) (1, pp. 30, 40):

Year	Fuel Use (000 000s L) Gasoline	Fuel Use (000 000s L) Diesel	Fuel Use (000 000s L) Propane	Vehicle Kilometers Traveled (000 000 000s)	Megajoule per Vehicle Kilometer
1971	111	972.0	100	2.213 2	19.9
1975	19.0	1 381.8	9.69	2.455 3	22.1

The energy content of the fuels in the above table is as follows: gasoline—34.84 MJ/L (125 000 Btu/gal); diesel—38.66 MJ/L (138 700 Btu/gal); and propane—25.53 MJ/L (91 600 Btu/gal).

It is of interest to compare these results with the engineering estimates presented elsewhere (19)—1.5-1.7 km/L (3.6-4.0 miles/gal), depending on load, for a 50-seat diesel bus. This corresponds to 22.6-25.2 MJ/vehicle-km (34 500-38 500 Btu/vehicle mile), which is somewhat higher than the estimates derived above. The disparity could be due to errors in the APTA data, or the engineering estimates may posit a bus with air conditioning.

APTA is unable to disaggregate vehicle kilometers and energy consumption by fuel type or bus size.

Load Factor and Passenger Kilometers

There are two methods of estimating passenger kilometers. One method assumes an average load factor and multiplies by vehicle kilometers traveled; the other assumes an average trip length and multiplies by the number of passengers. These methods can be applied at either an aggregate or disaggregate level. The only comprehensive set of disaggregate estimates available is contained in the National Transportation Study (NTranS) (30). This study, which was based on a survey of state transportation departments, presents estimates of passenger distances by mode for each SMSA. Despite its shortcomings, NTranS data contain the best available guesses about passenger kilometers, load factor, and average trip length. NTranS is consistent with APTA with regard to vehicle kilometers traveled and total passengers (1 km = 0.62 mile) (2, pp. 26, 30; 30, Tables SD-6, SD-15):

Study	Vehicle Kilometers (000 000 000s)	Passenger Trips (000 000s)
NTranS	2.202 4	4285
APTA	2.213 2	4699

Comparison of APTA fuel-consumption data and NTranS passenger-distance data to generate an EI estimate is therefore reasonable. For 1971 we find (30, Table 20-23):

Energy consumption = 44.016 PJ (41.721 × 10 trillion Btu).
Passenger kilometers traveled = 27.125 billion passenger-km (16 858 × 10 million passenger miles).
EI = 1.6 MJ/passenger-km (2500 Btu/passenger miles).

This estimate is consistent with an average load factor of 12.25 or an average trip length of 5.8-6.3 km (3.6-3.9 miles). Other assumptions about load factor or average trip length will yield proportionately different estimates of EI.

HEAVY RAIL

Aggregate Estimates

Several attempts have been made to estimate average EI of all 10 U.S. heavy rail systems combined. All are ultimately based on the energy-consumption statistics published by APTA (1). APTA statistics are comprehensive but flawed. APTA no longer separates light rail and trolley coach energy consumption because the combined heavy and light rail systems do not do a good job of this in their own internal accounting. Also, the systems have not interpreted "electricity used to operate vehicles" in a consistent fashion. Some systems have reported total energy consumption, including station heating and lighting; others have reported traction energy only. These inconsistencies become evident when data reported in another APTA report (2) are compared with other detailed analyses (3, 7, 23, 24). If these sources are used together, it is possible to separate traction energy from station and other energy for six systems, which together account for 95.2 percent of heavy rail vehicle kilometers traveled (1). These calculations are performed and documented in Table 1 (2, 3, 7, 23). In addition, Stanford Research Institute (SRI) (24) has made or obtained a best guess of average trip length on each system and derived passenger distance estimates, which are also presented in Table 1. As in the case of buses, the EI estimate will be very sensitive to assumptions about average trip length.

The left side of the equations below represents electric consumption as metered at the rail system; the right side includes energy used to generate the electricity and assumes a 30 percent efficiency in generation and transmission (i.e., 10 J at the power station yields 3 J of delivered electricity). The New York City Transit Authority is, however, supplied electricity at only 25 percent efficiency (24). Allowance for this would increase overall EI values by 15 percent (1 MJ = 947.8 Btu; 1 km = 0.62 mile).

Traction Energy Only

0.141 kW·h/passenger-km = 1.7 MJ/passenger-km
3.45 kW·h/vehicle-km = 41.4 MJ/vehicle-km

Total Operating Energy

0.173 kW·h/passenger-km = 2.0 MJ/passenger-km
4.22 kW·h/vehicle-km = 50.8 MJ/vehicle-km

The overall average EI values presented above are somewhat misleading and must be used cautiously. These averages reflect the efficient performance of the New York subways, which account for the bulk of heavy rail passenger kilometers traveled. Modern heavy rail systems tend to use more energy-intensive vehicles in less heavily populated regions, which results in much higher EIs. A disaggregate approach to heavy rail EI is therefore desirable.

Individual System Estimates

There is a great deal of diversity among heavy rail systems. Detailed energy profiles of three systems have been prepared by Fels (7), whose results are given below.

For Port Authority Transit Corporation of Pennsylvania and New Jersey (PATCO) and Port Authority TransHudson (PATH), almost all of the traction energy is used in active operation of the vehicles. By contrast, Bay Area Rapid Transit's (BART's) policy of keeping all cars hot (i.e., idling) at all times results in a substantial component of energy devoted to inactive operation. Fels estimated that BART cars consumed only 8.28 MJ electric/car-km (3.7 kW·h/car mile) in active operation but drew 26 kW during inactive hours of service, so that fully 46 percent of traction energy consumption is incurred by inactive operation. Table 2 gives the energy consumption of three heavy rail systems. As BART expands service hours and increases car utilization, the proportion of inactive operation will decrease, probably resulting in thriftier EIs.

Table 1. Heavy rail data aggregation.

System	Vehicle Kilometers (000 000s)	Passenger Kilometers (000 000s)	Electricity Consumption (TJ)		Notes
			Traction[a]	Total[b]	
Chicago	79.045	1 735	824.04	936.55	65.52 TJ lost in AC-DC conversion
New York	487.21	12 137	6 045.5	7 375.7	
PATH	17.147	296	201.38	228.87	SRI lists 27.47 TJ to auxiliaries (24); Fels and Smith (7, 23) make clear that this is actually fixed installation and is therefore excluded from traction energy
PATCO	6.747	152.1	122.54	145.89	Traction derived from total energy applying Boyce's ratio of 0.84 (3)
BART	34.523	751	559.76	788.4	
Southeastern Pennsylvania Transportation Authority (heavy rail)	23.427	674	257.062	402.682	Energy consumption derivation from SRI (24)
Total	639.10	15 745.1	8 010.282	9 878.092	

Note: 1 km = 0.62 mile; 1J = 0.000 9 Btu.

[a] Includes all energy drawn by cars—propulsion, heating, air-conditioning, and lighting, in active service or on standby. For the most part, available data do not specify whether the traction energy reported refers to DC or AC electricity use. Because of conversion losses, about 5 percent more current is purchased as AC than is actually used in DC form. It is assumed here that the systems have reported DC usage.

[b] Includes traction energy, energy used by stations shops and offices, energy used to heat rails and ventilate tunnels, and AC to DC conversion losses. This is electricity as metered by the rail system; transmission and generation losses are not included.

LIGHT RAIL VEHICLES

Operating data on light rail vehicles (LRVs) are scarce. APTA reported aggregate U.S. light rail energy consumption until 1973 but no longer does so because of problems with data reliability. The problem lies mainly with the Massachusetts Bay Transportation Authority's (MBTA's) inability to account separately for light and heavy rail components of energy use. The MBTA generates a large fraction of total U.S. LRV vehicle kilometers traveled, so no meaningful average can be made without it.

Lacking a useful aggregate average, there is no alternative but to use the operating statistics of individual systems or to rely on engineering estimates. Of the six remaining light rail systems, four are described below. Unfortunately it is not clear whether the energy consumption reported for these four systems was total energy or traction energy (1 km = 0.62 mile; 1 J = 0.0009 Btu) (2, 24).

System	Energy Consumption (TJ electric)	Car Kilometers (000 000s)	MJ Electric per Car, Derived
Cleveland RTA	16.2	1.67	9.69
Newark TNJ	10.22	0.93	11.10
Philadelphia, Red Arrow	50.4	2.49	20.20
Pittsburgh Port Authority of Allegheny County (PAT)	54.3	3.38	16.13

The high energy per car kilometer value for Philadelphia's Red Arrow line may be due to heavier than average cars. The Red Arrow cars range in weight from 9.5 to 27.2 Mg (21 000 to 60 000 lb), but Cleveland Regional Transit Authority's (RTA's) cars all fall within the 16.3- to 19.0-Mg (36 000- to 42 000-lb) range (24).

SRI also reports estimates of passenger kilometers. EIs derived from these estimates are given below. For the Transport of New Jersey (TNJ) system, the average trip length is 3.54 km (2.20 miles) and the average number of passengers is 2.408 million (1 MJ/km = 592 Btu/mile) (3,24).

System	Energy Consumption (TJ electric)	Passenger Kilometers (000 000s)	EI (MJ/passenger-km)
Cleveland	16.2	44.2	1.21
Red Arrow	50.4	44.4	3.77
TNJ	10.22	8.5	4.00

From the energy analyst's viewpoint, Cleveland is a showcase system. Its very success in achieving a high average load factor makes it inappropriate as a guideline for the typical EI of light rail operations. On the other hand, the poor showing of TNJ and Red Arrow (twice the EI of old heavy rail systems) are not necessarily representative either.

However, bear in mind that the above data refer almost exclusively to cars of 1940s vintages and older. The new generation of light rail vehicles, more sturdily constructed than their predecessors and equipped with air conditioning, are likely to be more energy intensive. Tests of the new Boeing LRV in Boston yield an average value at 21.3 MJ/car-km (9.52 kWh/car mile) for combined subway and surface runs (4).

Thus if the existing cars on the three systems mentioned above were replaced by the new Boeing LRV cars and the former load factors were continued, then the new EIs would be 2.65, 7.28, and 4.29 MJ/passenger-km, respectively.

The main point of interest here is that the new generation of light rail systems will have EIs in the range of 2.6-6.6 MJ/passenger-km (4000-10 000 Btu/passenger mile), which is higher than the comparable EI for new heavy rail systems of about 2.6 MJ/passenger-km (4000 Btu/passenger mile). Thus the energy savings associated with light rail lie in the lower construction energy, not in lower operating energy.

Table 2. Energy consumption of three heavy rail systems.

Measure	BART	PATCO	PATH
Car kilometers (000 000s)	37.6	6.8	17.7
Passenger kilometers (000 000s)	751	148	294
Total electricity consumed (TJ)	788	144	248
Traction (%)	71	85.5	89
Station (%)	24	12.5	5
Maintenance (%)	5	2	6
Total energy (MJ/car-km)	21.0	21.3	14.3
Traction (MJ/car)	14.8	18.1	12.5
Total EI[a] (MJ/passenger-km)	3.51	3.25	2.82
Traction EI[a] (MJ/passenger-km)	2.49	2.75	2.49

Notes: 1 km = 0.62 mile; 1J = 0.000 9 Btu.
These figures are based on the systems' billing records for energy and the systems' own estimates of car kilometers and passenger kilometers.
[a] Includes energy used to generate electricity, 30 percent efficiency assumed.

COMMUTER RAIL

APTA recognized 15 commuter railroads at the end of 1976 (1, p. 46). According to NTranS, the commuter rail system produced 206.9 million vehicle-km (128.6 million vehicle miles) of travel and 9311 million passenger-km (5787 million passenger miles) in 1971 (30, tables SD-6, SD-23).

Energy consumption by commuter railroads is not regularly published. The Interstate Commerce Com-

Table 3. Commuter rail EI.

Measure	Northwestern	Burlington Northern	Milwaukee Road
Fuel consumption (L diesel/train-km)	7.8	10.1	6.8
Total traction energy, including deadheading and electric standby (equivalent L diesel/train-km)	8.9	10.6	7.8
MJ per coach kilometer	72	85	98
Average seats per coach	159	134-146	152
Passenger kilometers per seat kilometer	0.29	0.42-0.46	0.41
EI (MJ/passenger-km)	1.6	1.4	1.6

Notes: 1 km = 0.62 mile; 1 L = 0.26 gal; 1 MJ = 947.8 Btu.
Walbridge's raw data are directly from the railroads. Walbridge uses an electric efficiency of 34 percent; reconversion to the 30 percent factor used in this report would not make a difference at the two-significant-figure level that Walbridge employs. These estimates do not include energy used for stations and maintenance.

mission (ICC) requires each railroad to report annually on fuel consumption by motive power units. SRI's energy analysis of commuter rail operations is largely based on these reports. It would be possible to aggregate these data and attempt an overall average EI figure. However, Walbridge (35) demonstrates that an important component of energy consumption is not reflected in locomotive fuel consumption alone. A substantial amount of electricity is used to keep coaches and locomotives hot during the winter. The results of Walbridge's detailed analysis of three Chicago commuter roads are worth reproducing (Table 3) as guideline examples of commuter-rail energy intensity.

CONCLUSIONS

The best evidence available indicates that buses are substantially more energy efficient than is heavy rail transit; existing rail transit systems consume an average of 24 percent more operating energy/passenger km than do buses. Modern heavy rail systems consume approximately 100 percent more energy/passenger-km than do buses, not even taking into consideration the huge construction costs (16). Light rail systems, on limited evidence, seem to have no advantage over heavy rail in operating energy efficiency, but there may be some savings in construction costs. From the point of view of energy efficiency, bus is the preferred transit mode.

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Foreign Oil Dependence: State-Level Analysis

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This paper discusses the dependence of New York State on foreign sources of petroleum products. The paper defines dependence to include direct product imports and imported crude oil that is domestically refined into such products. By use of a generalized allocation procedure that is applicable to all states, the original foreign sources of petroleum products are traced back from major East Coast and Gulf Coast refineries to the particular countries that supplied the imported crude oil. Known imports of refined products are then added to these estimates to obtain estimates of total dependence. Four products are studied: residual oil, distillate, gasoline, and jet fuel. Results show that, overall in 1976, New York is 72 percent dependent on foreign oil, compared with 43 percent for the United States. For residual oil, New York is 96 percent foreign dependent; major suppliers are Caribbean and South American countries, particularly Venezuela, Virgin Islands, and the Netherlands Antilles. For distillate, gasoline, and jet fuel, New York is between 54 and 58 percent dependent on foreign sources; supplies come mainly from African and Middle Eastern countries, particularly Nigeria, Algeria, and Saudi Arabia. The United States' dependence pattern is similar but less severe and broader in base. Although New York, like many states, gets its oil from many countries, it relies primarily on a relatively small number of suppliers for most of its petroleum products, making it particularly vulnerable to supply curtailments. A number of actions are suggested to broaden New York's base of sources, to cut foreign dependence, and to reduce petroleum use.

The technology and lifestyle of America has been predicated on the availability of cheap, unlimited energy, particularly petroleum. In its various forms, petroleum powers our atuomobiles and airplanes, heats many of our homes, runs our factories, and generates our electricity. Its presence pervades our society. Recent shortages, however, have demonstrated the finiteness of this resource, its uncertain availability, and its volatile price. The overall problem may vary widely in individual states. New York has no indigenous petroleum supplies and gets all of its petroleum from other states and foreign countries. Refined petroleum products come to New York primarily from three sources (see Figure 1):

Flow	Description
A	Direct from foreign refineries
B	Direct from petroleum administration for defense district (PAD) 1 (U.S. East Coast) refineries
C	Direct from PAD 3 (U.S. Gulf Coast) refineries

Figures for 1975 (New York State energy plan) show that 40 percent of New York's refined petroleum products came from foreign sources (A), and that the remainder came from U.S. refineries (B and C).

However, the entire picture is not so simple, since crude oil flows must also be taken into account. For instance, crude (unrefined) oil is often imported to Gulf Coast (flow D) and to East Coast (flow E) refineries from foreign countries and then is refined into petroleum products and sent to New York. Domestic crude from PAD 3 is also sent to PAD 1, refined there, and sent to New York (flow F). [This assumes that no refined product arrives in New York from PAD 2, which understates by about 1 percent New York's domestic dependence (1).] Thus, the degree of total dependence of New York on foreign sources is likely to be much greater than 40 percent. Since not all countries or states produce all refined products, New York's foreign dependence for certain products (e.g., residual oil) may be greater than for others (e.g., gasoline). Detailed breakdowns by country can show exactly which nations or states New York depends on for what products.

This paper estimates and describes New York's dependence on both domestic and foreign sources for refined petroleum products. The following key questions are addressed:

1. To what extent is New York more or less dependent on foreign petroleum than is the United States?
2. On what countries and states is New York most dependent and for what petroleum products?
3. How is New York's profile of dependence different from that of the United States?
4. What are the implications of such dependence on New York's energy policies?

METHOD

The procedure for estimating New York's oil dependence is described in detail elsewhere (1). Basically, the total volume of petroleum products refined in the United States (e.g., gasoline refined in PAD 1) are allocated