Based on these rankings and the judgment that less fuel use and more mobility are desirable, the mandatory fuel economy standards of the Energy Policy and Conservation Act offer an effective approach to resource conservation but one that appears open to improvement by an increase in the severity of the penalties and a decrease in the stringency of the standards. These modifications would tend to reduce the civil penalties that automobile companies and consumers must pay while increasing the marginal incentive to produce and consume fuel-efficient automobiles.

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Energy-Saving Potential of Transit

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In a study initiated by the Federal Energy Administration in response to growing national concern over the rapidly expanding rate of energy use and possible fuel shortages, an analysis was done of the energy efficiencies of various urban passenger transportation modes, including automobile and bus, rail rapid and commuter rail transit, and dial-a-ride. The study was primarily concerned with the potential impacts and energy efficiencies of short-term policies designed to induce automobile drivers to shift to transit. Policies to induce such mode shifts were grouped as scenarios for evaluation. Possible transportation energy savings for urbanized areas as well as reductions in vehicle kilometers of travel were first estimated for individual representative cities and then expanded to provide a national estimate for each of four tested scenarios.

Two major study tasks were undertaken in the Federal Energy Administration's evaluation of policies to enhance public transportation (1):

1. Determine the energy consumption and efficiency of transportation modes in urbanized areas and
2. Evaluate scenarios designed to achieve shifts from the automobile mode to public transportation, estimate the possible energy savings, and recommend scenarios to be implemented.

Major emphasis was placed on obtaining more definitive national estimates of urban transportation energy efficiency than had previously been available and on determining quantitatively which strategies for shifting travel from the automobile to transit could achieve significant energy savings. The amount of energy that could be conserved through individual actions and groups of actions was specifically estimated.

It should be pointed out, however, that this study was designed to provide only a macroscale estimate of the possible energy savings in individual cities and in the nation. Moreover, all data were derived from currently available material; compilation of new data was not possible. For these reasons, the energy savings determined in this study should be considered estimates and should not be taken as detailed forecasts.

NATIONAL ENERGY-USE CHARACTERISTICS FOR URBANIZED AREAS

Any analysis of energy conservation potential must be based on a description of existing energy use and efficiency. Person-travel energy consumption and efficiencies in urbanized areas are a function of the amount of person travel involved, average passenger loadings, and the applicable vehicular fuel consumption rates. National estimates of these and related characteristics, which were developed particularly for use in this study, were derived from data originally collected by the U.S. Department of Transportation (2, p. 52), the American Public Transit Association (3), and others.

Average urban energy consumption rates for individual vehicle types were estimated as follows (1 MJ/km = 1525 Btu/mile):

Vehicle Type	Energy Consumption Rate (MJ/km)
Automobile	7.2
Bus	
Gasoline-minibus	17
Diesel	22.8
Propane	30
Rail car	
Rapid	40.6
Commuter	74.1

Data describing national travel characteristics and energy consumption by mode for urbanized areas allowed calculation of energy per passenger kilometer traveled and total energy required by conventional modes. The total energy required was calculated on the basis of energy consumption per vehicle kilometer by mode and total vehicle kilometers. As expected, the automobile was found to dominate passenger travel in urbanized areas; it accounted for 98.1 percent of the 151 million m^3 (952 million bbl) of gasoline used in 1971 and 92.4 percent of the 1232 billion passenger·km (766 billion passenger-miles) traveled. The graph shown in Figure 1 provides a summary of passenger transportation efficiencies in urbanized areas.

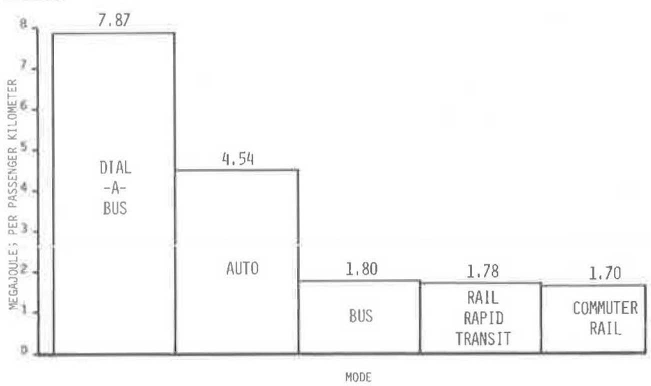
All conventional transit modes require about the same amount of energy per passenger kilometer: 1.7 to 1.8 MJ/passenger·km (2590 to 2740 Btu/passenger-mile). In contrast, automobile travel requires more than 2½ times the energy per passenger kilometer required by conventional transit or about 4.5 MJ/passenger·km (6930 Btu/passenger-mile). Less conventional modes of transit such as dial-a-ride systems require about 7.9 MJ/passenger·km (12 000 Btu/passenger-mile), almost twice as much as the automobile and 5 times as much as conventional transit modes.

Estimates of energy efficiency for person travel were also independently prepared for four individual urbanized areas: Albuquerque, San Diego, Baltimore, and Chicago. Automobile energy efficiency was computed based on vehicle kilometers traveled and the average automobile occupancy for each urbanized area. In all four areas this efficiency was calculated to be approximately 4.9 MJ/passenger·km (7500 Btu/passenger-mile).

Estimated energy efficiencies for transit in the four representative cities are given in Table 1. Energy efficiencies for bus systems ranged from 1.3 to 3.1 MJ/passenger·km (1950 to 4800 Btu/passenger-mile), compared with a national average of 1.8 MJ/passenger·km (2750 Btu/passenger-mile). The commuter rail (electric) operation in Chicago requires 1.3 MJ/passenger·km (2000 Btu/passenger-mile), considerably less than the national average of 1.8 MJ/passenger·km (2700 Btu/passenger-mile). This difference is not a function of fuel consumption per car kilometer (which was not specifically investigated except to distinguish between diesel and electric operation) but is instead attributable to the comparatively high average passenger loadings in Chicago. Chicago's rail rapid transit (diesel) system has an energy efficiency of 1.5 MJ/passenger·km (2300 Btu/passenger-mile), which is closer to the national average of 1.7 MJ/passenger·km (2600 Btu/passenger-mile).

In short, the automobile proved to be more energy intensive than transit in urbanized areas, both on a national basis and in the individual cities studied. Transit is not, however, 17 times more efficient than the automobile, as some sources suggest; its energy efficiency is between 1½ and 5 times that of the automobile. The efficiency of transit is also highly dependent on the type of service offered and the city involved.

Figure 1. Relative energy efficiency of urbanized-area transportation modes.



NOTE: 1 MEGAJOULE/PASSENGER KILOMETER = 1,525 BTU/PASSENGER MILE

PROCEDURES FOR ESTIMATING ENERGY SAVINGS

The central objective of the study was to quantify the nationwide mode shifts and energy savings that would be caused by implementation of alternative transit-oriented strategies. To provide the required estimates, an analysis procedure was chosen that addressed itself to site-specific conditions. For this purpose the four cities—Albuquerque, San Diego, Baltimore, and Chicago—were selected as being representative in certain ways of national urbanized areas. Data derived for these four cities were used to estimate national energy savings and impacts.

The four cities were chosen in the following way:

1. The more than 240 urbanized areas in the United States were categorized into four groups according to the reported percentage of transit use for travel to and from work and the presence or absence of an extensive rail transit system.
2. A representative city was chosen from each of these groups.

Different transportation policies and actions necessarily lead to different shifts in mode use. A mode-use sensitivity model was developed to evaluate potential mode shifts in the representative cities. In the model,

Table 1. 1974 energy efficiencies of public transportation in representative cities.

City	Mode	Annual Passengers (000s)	Average Trip Length (km)	Annual Passenger Kilometers (000s)	Annual Vehicle Kilometers (000s)	Passenger Kilometers per Vehicle Kilometer	Annual Terajoules	Megajoules per Passenger Kilometer
Albuquerque	Bus	3 537	5.8[a]	20 487	4 220	4.9	64.6	3.1
San Diego	Bus	32 032	6.7	213 889	18 315	11.7	350.5	1.6
Baltimore	Bus	113 396	7.0[b]	790 025	41 346	19.11	1068	1.3
Chicago	Bus	511 667	5.8[c]	2 963 780	141 890	20.9	3787.1	1.3
	Elevated and subway	171 415	10.9[c]	1 861 695	78 490	23.7	2835.4	1.5
	Electric commuter	15 478	30.1	465 707	7 384	63	594	1.3
	Diesel commuter	25 348	33.8	857 332	18 236	47	1231.7[d]	1.5

Note: 1 km = 0.62 mile; 1 J = 9.48×10^{-4} Btu.

[a] No data were given by Albuquerque that would allow the calculation of average bus trip length; an estimate of 5.8 km was used based on data from the U.S. Department of Transportation National Transportation Study for urbanized areas with populations between 100 000 and 250 000.
[b] From average transit running time at 16.1 km/h (10 mph) as simulated by the BMATS program.
[c] Derived from Chicago Area Transportation Study origin-destination survey data.
[d] Includes electric standby energy at terminals, which comprises an additional 15 percent above diesel energy used.

a set of mathematical relations was used to describe the sensitivity of transit ridership to changes in the transportation system, expressed as averages for urban sectors or entire urbanized areas. These relations were based on the transit ridership sensitivities displayed by travel mode-choice models of logit formulation calibrated for Denver; Minneapolis-St. Paul; Washington, D.C.; and San Diego (4).

The transit ridership sensitivities inherent in the mode-choice models for the various regions were similar and yet showed sufficient variation to preclude use of a single formula. Instead, a set of equations describing high, medium, and low transit-use response were developed and used to prepare high, medium, and low estimates. The model was validated by using data from three urban areas in which major policy changes had already been implemented.

The mode-use sensitivity model was applied to each of the four representative cities to estimate the effectiveness of different actions (strategies) and groups of actions (scenarios) in saving energy. The actions investigated for energy savings can be broken down into those actions that affect

1. Transit excess time,
2. Transit running time,
3. The cost to the rider of using transit, and
4. The cost of operating an automobile.

Each of the above categories is equivalent to one of the explanatory variables addressed in the model.

The so-called transit excess time experienced by transit riders is the sum of the time spent walking to and from the transit service plus the time spent waiting for a bus or a train. An increase in transit-service frequency or an increase in the density of routes (coverage) or both will reduce excess time.

Each strategy and scenario first had to be translated into changes in the explanatory variables for analysis with the mode-use sensitivity model. The expected change in transit use was then calculated. This provided an estimate of the number of new transit trips that would result from application of a strategy or a scenario.

Not all new trips attracted by transit improvements would be made by persons who had previously been automobile drivers. Some would previously have been automobile passengers or pedestrians or would have made no trip at all. An estimate was made of the proportion of new transit trips that represented prior automobile trips, and fuel savings were attributed only in the case of prior automobile drivers.

A survey undertaken after fare and service changes were made to the Atlanta Transit System (5) was the primary source of information on the mode used by new riders before the transit service enhancement. The proportions derived from this survey were validated by comparing them with those derived from other available surveys. Separate automobile-driver proportions were developed for work and nonwork trips as well as for three basic types of changes to the transportation system.

The Atlanta data revealed that 50 percent of new transit riders who are using transit for work trips and 25 percent of those using it for nonwork trips were previously automobile drivers. These percentages were applied by the study to the new transit riders attracted by bus transit improvements. Because rail service improvements typically affect longer distance travel, there is little likelihood of attracting bicycle users, pedestrians, or those using other transportation modes best suited for shorter distances. The percentages for rail system improvements were therefore adjusted to reflect a correspondingly higher proportional attraction of transit trips from the automobile driver mode. The values used for rail improvements were 59 percent for work trips and 33 percent for nonwork trips. The percentages of prior automobile drivers shifted to transit by means of highway disincentive strategies were estimated to be 71 percent for work trips and 55 percent for nonwork trips. The high percentage of prior automobile drivers in this case reflects the lack of induced travel when disincentives are applied.

Trips diverted from the automobile to transit were multiplied by an appropriate trip length to determine the vehicle kilometers of automobile travel eliminated. Energy savings were calculated on the basis of vehicle kilometers saved. Fuel consumption varies among different automobile trips within a city; thus, to select the appropriate energy intensities, speed, stops per kilometer, and trip length were estimated and then applied to derive the energy savings.

The additional vehicle kilometers of transit service that would be required to accommodate all new riders were then determined on the basis of the 2-h p.m. peak capacity of each system, current capacity utilization, and the additional riders attracted during that period. Transit vehicles were added to accommodate new riders only if the appropriate maximum load ratio of passengers to seats was exceeded. The additional daily bus kilometers that would be required were calculated by assuming a constant ratio between peak service requirements and daily transit vehicle kilometers.

In the case of bus transit, when additional vehicle kilometers are added, the service frequency increases and the passenger wait time decreases. Therefore, when additional buses were required to accommodate the new passengers gained as a result of the various actions in a scenario, an additional decrease in wait time was taken into account and the concomitant number of new passengers attracted by the additional service improvement was estimated. The amount of energy required for the additional transit vehicle kilometers was calculated on the basis of the existing fuel economy of each transit system. The net energy savings for each strategy and scenario were determined by subtracting the additional energy required by the transit system from that saved by the reduction in vehicle kilometers of automobile travel.

Some of the more important limitations that should be considered when the results of the analysis are reviewed are

1. Data voids, which often required estimating the necessary values based on available information and judgment;
2. Model limitations, such as the inability to predict changes in attitude and other intangibles; and
3. The means employed by new riders to gain access to transit service, which was not analyzed but could add to the new total energy use if an automobile were used.

ANALYSIS OF INDIVIDUAL STRATEGIES

The actual evaluation of the energy savings made possible through actions to induce mode shifts began with an analysis of individual transportation strategies. This analysis weighed the effects of each individual strategy, identified the strategies that exhibited significant energy-saving potential, and then grouped these strategies in suitable alternative scenarios. Estimates of the potential energy savings of individual strategies were made only for San Diego and Chicago and were based on a less

detailed analysis than the subsequent scenario evaluations.

The effect of individually applied strategies may differ substantially from their combined effect in scenario groupings. For example, when excess (walk and wait) time is reduced, transit riders are attracted to the system, but there is little or no net impact on energy use because of the large corresponding increase in the number of transit vehicle kilometers required. When this action is combined with other actions, however, the additional transit vehicle kilometers may prove to serve the purpose of carrying passengers attracted to transit by other actions in the scenario. In such a case, a decrease in excess time contributes to the benefit of the total scenario.

In San Diego, the current excess capacity of the bus system was such that additional bus kilometers were not needed to handle peak loads unless the increase in peak-period riders caused by a mode-shift strategy exceeded 3100 persons. Few individual strategies were found to be so effective as to require additional bus kilometers except when an increase in service was inherent in the strategy. This is not to say that additional bus kilometers would not be required when two or more strategies are combined; many of the scenario evaluations showed a need for substantial additional service.

The key findings of the San Diego analysis of individual strategies were as follows:

1. It would be more effective to institute improvements to both radial and circumferential bus routes concurrently than to either configuration alone.
2. It would be more productive in terms of energy savings to decrease all bus running times by applying traffic engineering improvements and bus priority and other measures than to implement a comprehensive express bus system to serve longer trips. This finding is a function of the low density of the San Diego central business district (CBD), the fact that express bus service would not improve service to local riders, and the extra bus kilometers and energy that would be required to provide the total service.
3. Alternative fare structures established within the constraint of a single average fare show no significant potential for increased ridership nor for decreased energy use related to changes in the ridership mix. However, overall decreases in bus fares would be effective in inducing mode shifts.
4. Strategies whose effectiveness depends on penalizing automobile travel achieve about twice as much energy saving per transit passenger gained as do strategies designed to induce new ridership by enhancing transit because the only new transit riders obtained through disincentives are previous automobile drivers or automobile passengers.
5. The effect of percentage increases in existing parking fees would be less in San Diego than corresponding percentage increases in gasoline cost, probably because of the current low parking cost in the CBD and the lack of parking charges outside the CBD. However, a universal parking surcharge (or equivalent automobile toll) in the CBD and the central city would have strong potential for inducing mode shifts.

In the following table, representative, quantitative estimates of mode shifts and energy savings are given for the strategies that proved to be among the more productive in San Diego (1 m^3 of gasoline = 6.3 bbl).

Strategy	Increase in Transit Use (%)	Gasoline Equivalent of Net Energy Saved (m^3/d)
Decrease excess time		
By 5 percent	12.4	1.1
By 15 percent	42.6	3.5
Decrease bus running time		
By 5 percent	6.2	2.2
By 10 percent	12.9	4.8
Decrease transit fare		
By $0.05	5.2	1.7
By $0.10	10.6	3.5
Increase gasoline cost		
By 25 percent	5.6	3.7
By 100 percent	24.8	15.3
Central city-CBD parking surcharge		
$0.72	15.0	7.9
$1.44	38.8	21.6

The net energy savings should be compared with a total automobile energy use in the San Diego area of approximately 5247 m^3/d (33 000 bbl/d) of gasoline.

The energy savings attributed to the automobile disincentive strategies account only for the impact of traveler diversion from automobile to transit. Automobile disincentives will also cause curtailment of less essential trips and increased participation in car pools. No attempt was made in this study to quantify these additional energy-saving impacts.

The analysis of individual strategies in San Diego was of significant value in weeding out the less productive strategies. An investigation was also made of the effectiveness of individual strategies in Chicago, an urbanized area in which travel characteristics are quite different.

The one major difference between the evaluation results for individual strategies for San Diego and Chicago was that, when bus and rail service was increased to reduce excess time throughout the Chicago metropolitan area, there was a loss of transportation energy. This finding, which was not totally unexpected because of the already extensive transit service in the city of Chicago, demonstrates that there exists a point of diminishing returns if transit service is intensified under present conditions (if no other strategies are imposed).

In the analysis of bus-service increases in Chicago, estimated energy losses occurred mostly in the central city. A separate test of decreasing bus excess time was made only in the suburbs, and it was found that slight energy savings could be expected from this action.

The results for the Chicago central city do not necessarily eliminate the feasibility of changes in the level of bus service as a potential energy-saving action. It was pointed out earlier that, when combined with other strategies, service increases may meet a need for additional capacity. Nevertheless, in view of the Chicago results, the scenarios subsequently tested were adjusted to include differential application (to the city versus the suburbs) of any additional bus service required to meet capacity needs.

All of the remaining individual strategies examined for Chicago showed transit ridership increases and energy savings similar to those in the San Diego tests, although the absolute changes were greater and, for the most part, the percentage changes were less. In view of the greater reliance on transit in metropolitan Chicago, these results were expected.

ANALYSIS OF SCENARIOS

The knowledge gained in the preliminary analysis of individual strategies was essential to the development of

Table 2. Policy scenarios and medium-estimate results for representative cities.

City and Scenario	Decrease in Transit Fare (¢)	Decrease in Transit Running Time (%)	Increase in Gasoline Cost (%)	Increase in Parking Cost ($) CBD	Increase in Parking Cost ($) Central City	Decrease in Transit Excess Time (%)	Decrease in Transit Wait Time (%)	Increase in Transit Use (%)	Daily Additional Passenger Trips (linked)	Daily Reduction in Automobile Travel (km)	Reduction in Kilometers of Automobile Travel (%)	Daily Gasoline Saved (m^3)	Total Automobile Energy Saved (%)
Albuquerque													
1	10	5	25	—	—	5	—	34	3 200	9 815	0.14	1.6	0.11
2	20	10	25	—	—	15	—	99	9 200	26 709	0.39	3.8	0.27
3	20	10	100	0.70	1.00	15	—	162	15 000	50 523	0.73	8.7	0.60
4	—	—	100	0.70	1.00	—	—	25	2 300	11 424	0.16	2.4	0.16
San Diego													
1	10	5	25	—	—	5	20	68	47 700	120 675	0.48	14.3	0.27
2	20	10	25	—	—	15	40	184	127 400	302 331	1.19	25.4	0.50
3	20	10	100	0.70	1.00	15	67.5	426	295 900	753 173	2.96	65.2	1.24
4	—	—	100	0.70	1.00	—	50	144	100 300	239 258	0.94	20.7	0.40
Baltimore													
1	10	5	25	—	—	5	30	66	165 300	493 157	2.37	41.3	1.35
2	20	10	25	1.00	—	15	35	128	319 400	946 575	4.55	106.5	2.58
3	20	10	100	2.00	1.00	15	55	256	639 600	2 067 565	9.95	259.1	6.25
4	—	—	100	2.00	1.00	—	50	121	302 500	1 043 276	5.02	139.9	3.34
Chicago													
1	10	5	25	—	—	5	5[a], 50[b]	26	437 200	1 948 338	3.05	120.8	0.92
2	20	10	25	1.00	—	15	—[a], 55[b]	58	963 600	4 335 451	6.79	265.5	2.02
3	20	10	100	2.00	1.00	15	25[a], 65[b]	106	1 763 100	8 319 656	13.03	699.4	5.31
4	—	—	100	2.00	1.00	—	35[a], 60[b]	64	1 077 600	6 089 100	9 53	602.5	4.53

Note: 1 km = 0.62 mile; 1 m^3 = 6.3 bbl.
[a]City. [b]Suburb.

the four scenarios examined in the course of this study. These scenarios were structured to include the entire range of possible actions—from those requiring minimal government intervention to those that would require significant federal and local government input as well as the imposition of substantial cost penalities on the average automobile driver. These scenarios included the following actions:

1. Decrease transit fare,
2. Decrease transit running time,
3. Increase gasoline cost,
4. Increase selected parking costs,
5. Decrease transit excess time, and
6. Decrease transit wait time.

Scenario 1 requires the least intervention and incorporates trends that to some extent are already evident. Scenario 2 requires that there be substantial modification and enhancement of transit service but can still be considered a strategy of "carrots" in that few disincentives are imposed on automobile travel. Scenario 3 requires the same carrots in terms of transit service enhancements as scenario 2 but adds bigger "sticks" in the form of substantial disincentives to automobile travel. Scenario 4 differs from the other three in that it includes no carrots other than the decrease in transit wait time that would be required to provide any necessary additional capacity; it relies entirely on disincentives to automobile travel identical to those included in scenario 3 to achieve mode shifts.

These four scenarios were applied in each of the representative urbanized areas. In general, each scenario is similar for all areas. However, the scenarios were not exactly the same for each area in the degree of their application. An explicit description of the scenarios evaluated in each representative area, as well as information on the corresponding reductions in automobile travel and energy savings, is given in Table 2.

Albuquerque

As shown by the estimates given in Table 2, the potential energy-saving effects of the four scenarios in the Albuquerque urbanized area were disappointingly slight. Even scenario 3, which would cause a projected increase of 162 percent in transit ridership, would achieve only a 0.6 percent decrease in energy use and a 0.7 percent reduction in automobile travel. The three less intensive scenarios would cause only a 0.1 to 0.3 percent decrease in energy use, a 0.1 to 0.4 percent decrease in automobile travel, and a 25 to 99 percent increase in transit ridership.

In this type of city, current transit ridership is so small that even an astronomical increase in transit ridership will have little effect on total automobile travel. It is difficult to provide good, convenient transit service to cities such as Albuquerque, which have low population densities. Because there is little congestion on Albuquerque's extensive road network, transit travel in that city cannot be highly competitive. Downtown areas are normally a major source of transit trips, but the Albuquerque CBD is neither strong nor extensively developed.

There is enough excess capacity in the present Albuquerque transit operation to accommodate all of the riders who would be attracted to the system by any of the four scenarios. Only those increases in service explicitly called for in scenario actions would be required. As the test results for scenario 4 show (Table 2), large increases in gasoline cost and parking surcharges are relatively ineffective in encouraging transit ridership. The structure of the city of Albuquerque and of its present transportation system does not allow transit service to provide a viable alternative to the automobile.

San Diego

San Diego represents U.S. cities that have moderate transit use. Of the four representative cities examined, San Diego exhibits the highest percentage increase in transit use attributable to the various mode-shift strategies. Implementation in San Diego of the substantial actions in scenario 3 would result in an estimated increase in transit ridership of over 400 percent, energy savings of 1.2 percent, and a reduction in automobile travel of nearly 3 percent. The more moderate actions in scenarios 1 and 2 would achieve between 68 and 184 percent ridership increases and between 0.3 and 0.5 percent reductions in energy use respectively.

Cities in this category tend to have enough of a transit-service base for transit improvements to show a high potential for attracting riders. At the same time, however, they retain a total ridership low enough for

transit improvements to have only a slight impact on energy conservation in urbanized areas. Like cities in the group represented by Albuquerque (although not to as extreme a degree), cities represented by San Diego have a relatively low population density, and the CBD is typically not a dominant focus of travel.

Major elements of the San Diego transit system currently operate well below capacity. A number of new riders could be added to the system before additional buses would be required. These new passengers, who would fully use the excess capacity available in the transit system, would produce larger energy savings than would any additional new riders who would make it necessary to operate additional vehicles.

Automobile disincentives, when tested alone in scenario 4, showed as much potential for saving transportation energy through inducing mode shifts as did the full package of transit enhancements included in scenario 2 without the automobile disincentives. Neither transit enhancements nor automobile disincentives showed much potential for reducing transportation fuel use in the San Diego area. In both scenarios 2 and 4, energy savings were estimated at less than 0.05 percent, which illustrates the limitations of transit as an alternative to the automobile in San Diego and similar cities.

Baltimore

Baltimore was used to represent cities that have relatively high patronage of an all-bus transit system. As in the analyses of other representative cities, scenario 3 exhibited the greatest energy-saving impacts, showing a potential ridership increase of approximately 250 percent, or some 640 000 riders/d. The shift to transit would result in a 6.2 percent reduction in automobile energy requirements and just short of a 10 percent reduction in automobile travel. Scenario 1, which has the least potential impact, would yield a 66 percent increase in transit use, or some 165 300 additional riders, and an energy reduction of 1.4 percent and a reduction of 2.4 percent in vehicle kilometers traveled.

Baltimore has many characteristics that cities like San Diego and Albuquerque lack, which serve to make it supportive of extensive transit travel. These include a strong and well-developed CBD, significant highway congestion, and other qualities common to older and more densely populated urbanized areas. In cities of this type, transit has a much better chance of competing with the automobile for discretionary ridership. Because of this, those actions that were shown to be relatively ineffective in Albuquerque or San Diego would have a much greater impact in the Baltimore metropolitan area. The current Baltimore transit system is also sufficiently effective that automobile disincentives alone (scenario 4) could work to save more energy than could be saved by the scenarios oriented primarily toward transit-service enhancements (scenarios 1 and 2).

Chicago

Chicago was used to represent the major urbanized areas in the United States that have relatively extensive rail rapid and commuter rail systems. In the Chicago area, scenario 3 would double transit ridership, or add some 1.8 million daily transit users. This shift in mode use is accompanied by savings of 5.3 percent for current transportation energy use and 13 percent for automobile travel. Of the scenarios that concentrate on transit service enhancements without major automobile disincentives, scenario 1 would save 0.9 and 3 percent and scenario 2 would save 2 and 6.8 percent in energy and vehicle kilometers of travel respectively.

Characteristics supportive of heavy transit use are quite pronounced in the city group represented by Chicago. The extensive existing transit use in these cities makes it difficult to achieve the large percentage increases in transit ridership demonstrated in the other representative cities. On the other hand, a mere 10 percent increase in ridership in Chicago would account for more transit trips than would a doubling of transit use in San Diego. Thus, the impact on automobile use would be more noticeable.

In the Chicago estimates of scenario impacts, the automobile disincentives of scenario 4 would produce nearly as much in estimated energy savings as would a combination of the strategies with the major transit enhancements of scenario 3. Thus, it appears that automobile disincentives work more efficiently toward decreasing energy use than do transit enhancements in cities that have preexisting, extensively developed transit systems. These cities can be contrasted with cities that have less extensive transit operations, in which both carrots and sticks are needed to promote mode shifts. On the other hand, when the medium scenario estimates were constructed to exclude the more onerous automobile-disincentive strategies, none of the representative cities exhibited energy savings in excess of 2.6 percent of transportation fuel consumption for the urbanized area. In the smaller cities, expected savings without major sticks were well under 1 percent.

National Energy Savings

The analysis of potential energy savings for the representative cities, although noteworthy in itself, also provides the quantitative groundwork for an analysis of potential energy savings at the national level. Data derived for the representative cities were expanded and weighted to represent possible national annual energy savings for each scenario. The expected annual energy savings represent the national energy savings for passenger transportation in urbanized areas only.

Energy savings for the representative cities were calculated for an average weekday, and these figures were converted to annual estimates through multiplication by a series of annualization factors: 345 for overall kilometers of travel by automobile and energy used, 290 for additional transit ridership as well as kilometers of travel by automobile and energy saved, and 300 for additional annual kilometers of transit travel and the energy that would be required.

The procedure chosen in this study to estimate national energy savings is relatively simple. The population and total vehicle kilometers of travel for urbanized areas were determined for each city group by using data from the 1970 census and the 1974 National Transportation Study. The cubic meters of gasoline required for travel in urbanized areas by each group were determined at a rate of 0.0002 m^3/vehicle·km (0.0013 bbl/vehicle mile), which is equivalent to the previously derived average for urban areas of 7.2 MJ/vehicle·km (10 950 Btu/vehicle mile). The percentage reductions in annual vehicle kilometers and gasoline as determined for each scenario and representative city were applied to the vehicle kilometers traveled and gasoline used for the appropriate city group to obtain the nationwide energy savings. As before, high, medium, and low estimates were calculated.

Medium estimates of reductions in vehicle kilometers of travel and energy use for the four scenarios by city group are given in Tables 3 and 4. City groups 3 and 4, those in which the greatest transit use occurs, clearly

Table 3. Medium national estimates of impacts of four scenarios: vehicle kilometers saved per year.

	Vehicle Kilometers for Four Scenarios							
	1		2		3		4	
City Group	Number (000 000s)	Percent	Number (000 000s)	Percent	Number (000 000s)	Percent	Number (000 000s)	Percent
1	182	0.12	492	0.32	933	0.61	211	0.14
2	594	0.40	1 490	1.00	3 710	2.49	1 179	0.79
3	5 027	1.99	9 649	3.83	21 076	8.37	10 635	4.22
4	4 299	2.56	9 566	5.70	18 355	10.95	13 434	8.01
Total or average	10 102	1.40	21 197	2.94	44 074	6.12	25 459	3.53

Note: 1 km = 0.6 mile.

Table 4. Medium national estimates of impacts of four scenarios: energy saved per year.

	Energy for Four Scenarios							
	1		2		3		4	
City Group	Gasoline (m^3)	Percent	Gasoline (m^3)	Percent	Gasoline (m^3)	Percent	Gasoline (m^3)	Percent
1	29	0.09	69	0.22	160	0.51	44	0.14
2	69	0.22	119	0.39	305	0.99	97	0.31
3	563	1.08	1046	2.01	2564	4.94	1388	2.67
4	250	0.72	542	1.57	1465	4.24	484	3.70
Total or average	911	0.61	1777	1.20	4494	3.03	2013	1.89

Note: 1 m^3 = 6.3 bbl.

Table 5. Total national estimates of impacts of four scenarios: vehicle kilometers saved per year.

	Vehicle Kilometers for Four Scenarios							
	1		2		3		4	
Estimate	Number (000 000s)	Percent	Number (000 000s)	Percent	Number (000 000s)	Percent	Number (000 000s)	Percent
High	14 244	1.98	28 170	3.91	59 501	8.24	31 644	4.39
Medium	10 101	1.40	21 197	2.94	44 075	6.12	24 655	3.53
Low	6 792	0.94	14 355	2.01	33 061	4.59	20 135	2.80

Note: 1 km = 0.6 mile.

Table 6. Total national estimates of impacts of four scenarios: energy saved per year.

	Energy for Four Scenarios							
	1		2		3		4	
Estimate	Gasoline (m^3)	Percent	Gasoline (m^3)	Percent	Gasoline (m^3)	Percent	Gasoline (m^3)	Percent
High	1242	0.84	2397	1.61	5980	4.03	3488	2.35
Medium	911	0.61	1777	1.20	4494	3.03	2808	1.89
Low	628	0.43	1198	0.81	3470	2.34	2286	1.54

Note: 1 m^3 = 6.3 bbl.

show the highest potential for reducing vehicle kilometers of travel and saving energy. Although these two groups account for only 63 percent of the urban area population and 58 percent of automobile travel and gasoline use, they would contribute 89 to 94 percent of the expected reduction in automobile travel and 89 to 95 percent of the gasoline savings expected in all urbanized areas.

Tables 5 and 6, which merge all city groups together for total national estimates, give high, medium, and low estimates of reductions in vehicle kilometers of travel and energy savings for each of the four scenarios. Scenario 3, which produces a 3.0 percent reduction in energy use for passenger transportation in urbanized areas, is seen to be more than half again as effective as scenario 4. Scenario 3 is almost twice as effective as scenario 2 in reducing vehicle kilometers of travel and energy use, and scenario 2 is in turn about twice as effective as scenario 1. Scenario 1 combined with elements of scenario 3 would be the most likely candidate for initial implementation.

CONCLUSIONS

The estimates presented here show that a reduction in the amount of energy used for personal transportation can be realized through actions designed to shift persons from the automobile to mass transit but that it is extremely difficult to conserve large quantities of energy in this way. The potential short-term fuel savings attainable from shifts to transit range from less than 1 percent up to a maximum of 3 or possibly 4 percent of national, urban area fuel consumption for person travel. The maximum reductions would involve twofold to threefold and greater transit ridership increases in individual cities, with corresponding transit subsidy increases.

Transit fare reductions, decreased running time, increased service coverage and frequency, and automobile disincentives all serve to increase transit ridership and, in most instances, to conserve energy. However, the energy savings that result from individually applied policy actions are less than those that result from appropriate joint applications of policy.

It should be noted that automobile-disincentive strategies will not only generate the energy savings esti-

mated in this study for mode shifts to transit at the least added cost to the transit agency but will also cause additional energy conservation attributable to increased car and van pooling, shortened trip lengths, and trip elimination.

Increased coverage and frequency of transit service are particularly effective in inducing mode shifts; this, however, is the one otherwise useful strategy that, when applied alone under the wrong circumstances, can increase net energy consumption. To conserve energy, increased coverage and frequency are best provided in connection with fare reductions, decreased running time, or automobile disincentives.

Of course, improvements to transit systems offer benefits in addition to the relatively small energy savings obtained. The potential for reducing vehicle kilometers of automobile travel in today's urban areas is twice as great as the total energy-saving potential; it ranges from 1 or 2 percent up to a maximum of 6 or possibly 8 percent for the highest impact group of mode-shift strategies examined.

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Rail Rapid Transit and Energy: The Adverse Effects

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Because it is generally believed that transportation energy can be saved by diverting people from automobiles to rail transit, the United States is now building or planning a number of multi-billion-dollar rail systems. These new-generation rail systems were examined and found to be a net user of energy. The two main points prompting this conclusion are that (a) the energy invested in building a rail system is enormous and thus difficult to repay and (b) the possible savings in operating energy are small, or even negative, because most rail passengers are diverted from buses and buses are more energy efficient than modern rail systems. The analysis was done for San Francisco's Bay Area Rapid Transit (BART) system, but evidence is cited to show that the results are typical for other modern rail systems as well. To the extent that BART is atypical, it appears to be atypically efficient. The analysis takes into account the reduced demand for automobiles and buses because their passengers are diverted to rail and then calculates the energy saved because these conventional vehicles are not built or driven and the roads on which they would travel are not constructed. It is concluded that even radical improvements in automobile diversion, rail patronage, and load factors would not significantly alter the results.

This paper examines the overall energy impact of modern rail transit systems and concludes that they are energy users. Although the analysis is done for a single example, the San Francisco Bay Area Rapid Transit (BART) system, it is shown that the conclusions are probably general. These conclusions are the result of two main points: (a) that the energy required to build a rail system is enormous and thus hard to repay and (b) that the possible savings in operating energy are small, or even negative, because most rail passengers are diverted from buses rather than from automobiles and buses are much more energy efficient than modern rail systems.

First, calculating the energy required to build BART and the amount of energy saved by building fewer kilometers of freeway as a result of the diversion of automobile and bus users to rail transit yields the net energy investment. This net figure would be essentially the same even if a doubling of the diversion figures were assumed. Next, energy figures are developed for automobile, bus, and rail operation that take into account the energy required to build the vehicle as well as to operate it. Finally, the length of time it would take to repay the net energy invested in constructing the system is calculated by using various assumptions about BART patronage. Under most of these assumptions the BART system can never repay the energy investment.

Had this analysis been done several years ago, it would have assessed the BART system in terms of the dollars of social cost rather than the units of energy expended. However, since the oil crisis focused attention on energy, many people have begun to discount financial analyses of alternative transportation systems by claiming that dollars do not matter—only energy matters.

Many economists may find the analysis that follows strange because it uses energy as the measure of all things. But, because a dispute over ways of measuring social cost would only compound the transportation issues, the joule—an energy measure—is used as a basis for assessing the effectiveness of BART.

The literature on energy use in transportation has