able limits can be easily simulated by the model to determine the optimal purchase limits for vehicles of various size classes.

REFERENCES

1. V. Prins, R.A. Wolfe, and S.R. Lerman. Simple Analytical Model for Understanding Gasoline Station Lines. TRB, Transportation Research Record 764, 1980, pp. 43-49.
2. Y. Sheffi and V. Prins. Dual Price System for Management of Gasoline Lines. TRB, Transportation Research Record 801, 1981, pp. 60-67.
3. N.S. Dorfman and I.E. Harrington. Evaluating the Costs and Benefits of Plans to Reduce Gasoline Queues. TRB, Transportation Research Record 764, 1980, pp. 26-32.
4. M.S. Daskin, S.E. Shladover, and K.L. Sobel. An Analysis of Service Station Queues Under Gasoline Shortage Conditions. Computers and Operations Research, Vol. 3, 1976.
5. H. Muhmassani and Y. Sheffi. Queueing and Search Delays Due to Gasoline Station Closings: A Simple Equilibrium Framework. TRB, Transportation Research Record 764, 1980, pp. 32-38.
6. W.B. Tye. Review of Analytical Models of Gasoline Demand During an Energy Emergency. TRB, Transportation Research Record 764, 1980, pp. 49-53.
7. A.G. Hobeika, S.H. Young, and D. Seeman. Simulation for Evaluating the Impact of Supply Restriction Policies on Gasoline Consumption. TRB, Transportation Research Record 870, 1981, pp. 55-60.
8. J.N. Hooker. Effect of a Sudden Fuel Shortage on Freight Transport in the United States: An Overview. TRB, Special Rept. 191, 1980, pp. 71-81.
9. R. Gorman. Household Characteristics and Determinants of Travel Behavior. TRB, Special Rept. 181, 1980, pp. 135-138.
10. 1977 Nationwide Personal Transportation Study, Rept. 3: Purpose of Vehicle Trips and Travel. FHWA, Dec. 1980.
11. NPN Fact Book Issue. National Petroleum News, Hightstown, N.J., 1981.
12. Newsletter Spring-Summer 1978. Virginia State Data Center, Tayloe Murphy Institute, Charlottesville, Va., 1978.
13. S.H. Young. An Analytical Model for Contingency Management of Gasoline Lines Under Motor Fuel Supply Interruptions: A Simulation Approach. Department of Civil Engineering, Virginia Polytechnic Institute and State Univ., Blacksburg, Ph.D. dissertation, Aug. 1982.
14. D.T. Hartgen and A.J. Neveu. The 1979 Energy Crisis: Who Conserved How Much. New York State Department of Transportation, Albany, April 1980.
15. R. Archibald and R. Gillingham. An Analysis of the Short-Run Consumer Demand for Gasoline Using Household Survey Data. Review of Economics and Statistics, Vol. 62, No. 4, Nov. 1980.
16. Price Elasticities of Demand for Transportation Fuels. Office of Transportation Research, Federal Energy Administration, May 1976.
17. O. Schueftan and R.H. Ellis. Federal, State, and Local Responses to 1976 Fuel Shortages: Summary Report. Office of the Secretary, U.S. Department of Transportation, Feb. 1981.

Analysis of Total Energy Use of Urban Transportation Energy Conservation Strategies

MARGARET K. SINGH AND SARAH J. LaBELLE

As part of a technology assessment project sponsored by the U.S. Department of Energy, an evaluation was made of total energy consumption by fuel type resulting from local travel (by urban households) for 1980, 1990, and 2000 in two scenarios and under three alternative policies. Energy consumed in vehicle operation, fuel production, vehicle production, and infrastructure construction was projected, and the relative impact of each policy was also evaluated. A substantial decline in total energy use in national urban passenger travel from 1980 to 2000 was projected for both scenarios and all three policies. However, the analysis also indicated that indirect energy use required to support the policies can offset some of their direct energy savings. Further, the scenario that resulted in the greatest total energy savings did not save the greatest amount of petroleum.

In a project sponsored by the U.S. Department of Energy, Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT) (1), several alternative strategies promoting energy conservation in urban transportation were assessed to determine their energy, environmental, and economic impacts. The alternative strategies were tested in three cities for 1980, 1990, and 2000. They represented policies and technology developments designed to conserve urban transportation energy while maintaining a productive economy. They were set within two socioeconomic scenarios that differed in terms of growth rate of gross national product (GNP), social organization, retail fuel price, total metropolitan population, average household income, environmental regulations, and types of fuel available for transportation. The expected energy impacts, both direct and total, of these alternative strategies are related here.

PROJECT STRUCTURE

To evaluate the energy impacts of the alternative strategies properly, the strategies themselves, scenarios, vehicle characteristics, and fuel supply and prices assumed in this study need to be briefly described. The three conservation strategies analyzed were termed the in-place policy, group travel policy, and individual policy. As a baseline, the in-place policy was established as the extension to the year 2000 of all programs and plans in place in 1980 that affected urban transportation. For the three case-study cities used in this analysis, the in-place policy was defined in terms of existing state, regional, and local plans. By contrast, the group travel policy promoted mass transit and ride-sharing with no improvements to automobile technology relative to the in-place policy. In general, the group travel policy involved large-scale changes in level of service for transit, as measured by service frequency, line-haul travel time, and system coverage in each case-study region. The individual policy focuses on automobile technology improvements as the means to decrease transportation energy use while maintaining mobility. Research and development on engines, vehicles, and fuels was increased, and new-car fuel economy improved even more than expected under the in-place policy.

These policies varied by the scenario in which they were expected to have the greatest effect. For example, scenario 1, which projected a wealthy economy with high technological success, was assumed to be capable of supporting rail transit service expansion under the group travel policy. Scenario 3, on the other hand, a relatively poor economy with low technological success, emphasized reduced transit fares and express bus service, including busway construction, under this policy. No analysis was conducted for scenario 2.

In this analysis, automobile and transit vehicles were characterized by size class, engine type, fuel economy, emissions profile, purchase price, operating costs, materials composition, and (for personal vehicles) performance. Three different sets of vehicles were used: set C, the expected technologies, was used for the in-place policy and group travel policy in both scenarios; set A, designed as the the best technology for both conservation and performance, was tested for the individual policy in scenario 1; the third set, a modification of set C, was tested in scenario 3 under the individual policy.

Fuel supply varied across scenario and price across scenario and policy. In particular, synthetic fuels were expected to play an important role in scenario 1 and no role in scenario 3. Base average market crude prices were higher in scenario 3 than in 1 [$61/barrel (1975$) versus $46 in 2000]. The retail fuel prices derived from these base fuel prices were varied among the policies; imposition of stiff automobile fuel taxes under the group travel policy was the key variable. The retail gasoline price was $1.89/gallon under the in-place policy and $3.78 under group travel in scenario 1 in 2000, whereas in scenario 3 it jumped to $3.82 under group travel from $2.55 under the in-place policy.

NATIONAL PROJECTIONS OF DIRECT ENERGY USE IN URBAN VEHICLE OPERATION

Method Overview

The travel demand analysis conducted for TAPCUT resulted in estimates and projections of total daily direct energy consumption by fuel and vehicle type for home-based local passenger travel in automobiles and vans in three case-study cities. For the energy analysis these projections were expanded to national annual totals for urban passenger transportation, including non-home-based travel in automobiles and vans. The expansion was based on TAPCUT expansion factors for the three case-study cities and on regional surveys indicating the relationship of non-home-based to home-based travel and of average weekday to weekend travel. The description of the method developed for this analysis may be found in a technical memorandum by Singh (2).

Energy consumption by fuel type in mass transit operation was estimated separately for TAPCUT and was not included in the summaries of direct energy use in this section. Currently only about 2 percent of all urban travel is made on mass transit. Even under the group travel policies in the two scenarios, national energy consumption by mass transit rose to 0.2 quad annually compared with 0.1 quad now. The highest value forecast for 2000 represented 8 percent of the direct energy consumption of automobiles and vans in urban passenger travel in that year.

Direct Energy Use

Purchased Fuels

The forecast annual automobile travel in metropolitan areas is shown in Table 1. Under the group travel policy in both scenarios, total urban passenger vehicle miles of travel (VMT) by 1990 drops below that of 1980 and continues to drop slightly by 2000. Under the in-place and individual policies in scenario 3, urban passenger VMT in 1990 and that in 2000 are almost equal to that of 1980. Under the in-place and individual policies in scenario 1, urban passenger VMT in 1990 is approximately 9 percent above that of 1980 and in 2000 approximately 17 percent above the 1980 level. In scenario 1, the VMT increase is slightly greater than the 16 percent increase in metropolitan area population. Population growth in scenario 3 is only 4.6 percent over the 20 years; VMT growth lags population, probably because of a slight rise in the cost of travel.

Table 1 presents direct energy consumption by purchased fuel type in addition to VMT on each fuel in national urban passenger travel. The fuels include gasoline, diesel fuel, electricity, gasohol, methanol, and a combination of diesel fuel and methanol (diesel-methanol). Electricity is measured in this analysis as the input energy required at the power plant to meet the electricity requirements for charging and operation of an electric vehicle (EV). Gasohol, which is projected to be available only in scenario 1, is an approximately 90-10 blend (87-13 was used in this analysis) of gasoline and coal-derived methanol (actually methyl fuel).

The diesel-methanol combination occurs only in scenario 1 in 2000. No specifications currently exist for a blend of diesel fuel and methanol or for an engine to burn it, but it was assumed that in scenario 1 this fuel type might become available for use in diesel-powered vehicles. These may operate on a variety of blend ratios or alternate between 100 percent methanol and 100 percent diesel fuel. In aggregate, the fuel distribution assumed for the diesel-methanol combination is 70 percent diesel fuel and 30 percent methanol.

From Table 1 and Figure 1 it can be observed that all policies result in a decline from 1980 to 2000 in direct energy consumed in urban passenger travel. (Although information is provided on direct energy consumption in 1975, the base year for purposes of this analysis is 1980.) As might be expected, the greatest absolute declines occur under the group travel policy in both scenarios. The amounts of energy consumed in scenarios 1 and 3 under the group travel policy are virtually the same by 2000 and represent about 47 percent of the 1980 energy consumed in urban passenger travel. The smallest absolute decline by 2000 occurs in scenario 1 under the in-place policy; the 3.2 quads consumed under this policy represent about 63 percent of the 1980 levels.

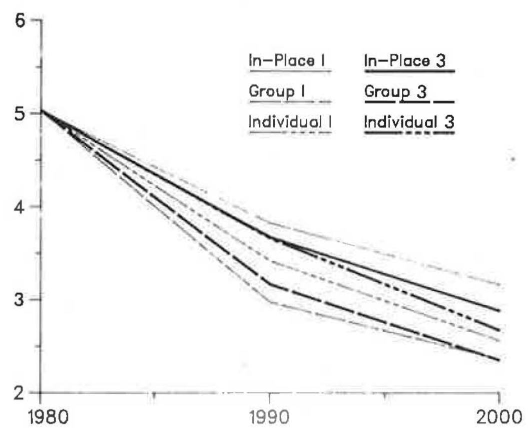
Gasoline energy consumption is still predominant in 2000 among the fuels used. However, energy consumption in the form of other fuels grows through 2000. In scenario 1 by 2000, energy consumed in the form of gasohol represents approximately 25 percent of total energy consumption under all policies. Under the individual travel policy of scenarios 1

Table 1. Total direct energy consumed by purchased fuel type and total VMT for each fuel in national urban passenger travel.

Year, Scenario, and Policy	Gasoline 10^{15} Btu	Gasoline 10^{11} VMT[a]	Gasohol 10^{14} Btu	Gasohol 10^{10} VMT	Methanol 10^{14} Btu	Methanol 10^{10} VMT	Diesel 10^{14} Btu	Diesel 10^{10} VMT	Diesel-Methanol 10^{13} Btu	Diesel-Methanol 10^{9} VMT	Electricity 10^{13} Btu[b]	Electricity 10^{9} VMT	Total 10^{15} Btu	Total 10^{11} VMT
1975	5.996	5.269	–	–	–	–	–	–	–	–	–	–	5.996	5.269
1980	5.014	5.142	–	–	–	–	0.185	0.291	–	–	–	–	5.032	5.171
1990, scenario 1														
In place	3.183	4.548	3.336	5.050	–	–	3.065	5.564	–	–	0.065	0.114	3.824	5.611
Group	2.510	3.899	2.633	4.332	–	–	1.996	3.457	–	–	0.127	0.221	2.975	4.680
Individual	2.923	4.852	3.066	5.391	–	–	1.849	2.721	–	–	0.238	0.464	3.417	5.668
2000, scenario 1														
In place	1.886	3.447	8.478	16.41	1.745	3.830	1.985	4.308	5.554	14.82	0.417	0.863	3.164	6.059
Group	1.405	2.652	6.318	12.63	1.301	2.947	1.261	2.789	3.968	10.51	2.654	5.498	2.360	4.649
Individual	1.306	2.910	5.872	13.86	1.209	3.233	4.287	11.079	9.292	28.73	2.399	5.590	2.560	6.070
1990, scenario 3														
In place	3.456	4.971	–	–	–	–	2.134	3.827	–	–	0.090	0.158	3.671	5.346
Group	2.985	4.301	–	–	–	–	1.802	3.099	–	–	0.202	0.349	3.167	4.614
Individual	3.471	4.971	–	–	–	–	1.881	3.287	–	–	0.123	0.212	3.660	5.302
2000, scenario 3														
In place	2.613	4.789	–	–	–	–	2.666	5.592	–	–	0.244	0.504	2.882	5.353
Group	2.147	3.899	–	–	–	–	1.735	3.720	–	–	2.811	5.799	2.349	4.329
Individual	2.348	4.532	–	–	–	–	2.991	6.986	–	–	2.455	5.109	2.672	5.282

[a]Excluding mass transit vehicles. [b]Converted at 10,400 Btu/kW·hr.

Figure 1. Direct energy consumed in national urban passenger travel by scenario and policy, 1980-2000.



and 3, diesel-fuel energy consumption is more than 10 percent of total energy consumption by 2000. In scenario 1 under all policies in 2000, approximately 5 percent of the total energy consumption is in the form of neat methanol. Energy consumption in the form of electricity for EVs, however, is at most only 1 percent of total energy consumption. This level occurs in both scenarios in 2000 under the group travel and individual policies.

Table 2 is derived from the results presented in Table 1. It illustrates the generally steady increase in the on-the-road fuel economy of urban passenger vehicles operating on various fuels under all policies in each scenario. Further, it illustrates that by 2000 in both scenarios the group travel policy results in fuel economy similar to that under the in-place policy. Concurrently, the individual policy in both scenarios results in greater fuel economy, the highest levels of which are achieved in scenario 1. The average (over all fuel types) on-road fuel economy and that for gasoline vehicles only are plotted in Figure 2 for scenario 1.

Resource Fuels

For the comparison of total energy use it is necessary to further disaggregate the energy consumption by fuel-type totals shown in Table 1. The amount of (a) gasoline used in gasohol, diesel fuel in the diesel-methanol combination, and methanol in both gasohol and the diesel-methanol combination; (b) resource fuels for the gasoline and diesel fuel (petroleum, oil shale, and coal); (c) resource fuels for methanol; and (d) resource fuels used to generate electricity is specified in order to allow analysis of the total energy required to produce these fuels.

Table 3 presents the results of this disaggregation: total energy consumed in urban transportation by primary fuel type and resource fuel. As defined here, the primary fuel types are gasoline and diesel fuel combined, methanol, and electricity. The resource fuels for gasoline and diesel fuel are assumed to be the same in this analysis rather than assign a particular input fuel (crude oil, coal, shale) to each of these refined products. Energy for production of these refined products is estimated for the average national refinery in each scenario and applied to diesel and gasoline Btu in the same manner. Thus these two fuels are aggregated here. The proportion of gasoline and diesel fuel produced from petroleum, shale oil, and coal in each scenario was assumed part of the TAPCUT scenarios; by applying these proportions to the gasoline and diesel totals, the absolute amounts of petroleum-derived, shale-oil-derived, and coal-derived gasoline and diesel fuel are determined. The resource fuels for electricity and methanol are similarly assumed in the TAPCUT scenarios.

From the results of Table 1, it is clear that the use of petroleum-derived fuels decreases substantially between 1980 and 2000. Table 3 shows that the use of petroleum-derived fuels is substantially less in scenario 1 than in scenario 3 in 1990 and 2000 under all three travel policies. By 2000 the use of petroleum-derived gasoline, diesel fuel, and electricity in scenario 1 represents about 70 percent of the total petroleum used in scenario 3. This occurs despite the 10 percent difference at most between total direct energy consumption in the two scenarios. The chief reason, of course, is the use

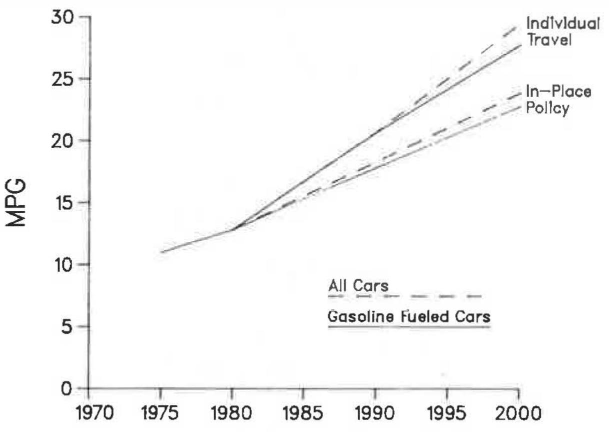


Figure 2. On-road fuel economy for urban vehicles in scenario 1 under in-place and individual policies.

of gasoline derived from oil shale and coal and diesel fuel in scenario 1 but not in scenario 3; to a lesser extent, the substitution of coal-derived methanol for gasoline in scenario 1 also accounts for some of the difference. The direct use of petroleum for urban travel is plotted in Figures 3 and 4 for each scenario.

TOTAL ENERGY REQUIRED TO SUPPORT TAPCUT SCENARIOS AND POLICIES

Total Energy and Petroleum Use

Total energy use for urban transportation is the sum of direct and indirect energy use. Indirect energy includes energy required to produce the fuels used in vehicle operation, to produce the automobiles and transit vehicles used by urban travelers, and to construct the infrastructure (highways, busways, and rail systems) necessary to support the transporta-

Table 2. Average on-the-road fuel economy of urban passenger vehicles by fuel type.

Year, Scenario, and Policy	Gasoline (mpg)	Gasohol (mpg)	Methanol (mpg)	Diesel (mpg)	Diesel-Methanol (mpg)	Electricity[a] (Btu)
1975	10.99	–	–		–	–
1980	12.82	–	–	21.92	–	–
1990, scenario 1						
In place	17.86	17.86	–	25.23	–	21.86
Group	19.41	19.41	–	24.07	–	21.73
Individual	20.75	20.75	–	20.46	–	24.40
2000, scenario 1						
In place	22.85	22.85	15.58	30.59	31.50	25.90
Group	23.59	23.59	16.09	30.73	31.25	25.89
Individual	27.84	27.84	18.99	35.92	36.48	29.13
1990, scenario 3						
In place	17.98	–	–	24.93	–	21.88
Group	18.01	–	–	23.91	–	21.56
Individual	17.90	–	–	24.30	–	21.63
2000, scenario 3						
In place	22.91	–	–	29.16	–	25.77
Group	22.70	–	–	29.81	–	25.79
Individual	24.13	–	–	32.47	–	26.02

[a]Converted at 10,400 Btu/kW-hr and at 125, 000 Btu/gal.

Table 3. Total direct energy consumed in national urban passenger travel by primary fuel type.

Year, Scenario, and Policy	Petroleum to Gasoline and Diesel (10^{15} Btu)	Shale Oil to Gasoline and Diesel (10^{15} Btu)	Coal to Gasoline and Diesel (10^{15} Btu)	Coal to Methanol (10^{15} Btu)	Coal to Electricity (10^{12} Btu)	Uranium to Electricity (10^{12} Btu)	Petroleum to Electricity (10^{12} Btu)	Natural Gas to Electricity (10^{12} Btu)	Other[a] to Electricity (10^{12} Btu)	Total[b] (10^{15} Btu)
1975	5.99562	–	–	–	–	–	–	–	–	5.9956
1980	5.03234	–	–	–	–	–	–	–	–	5.0323
1990, scenario 1										
In place	3.23948	0.36666	0.17388	0.04323	0.33	0.18	0.11	0.02	0.01	3.8239
Group	2.51877	0.28510	0.13520	0.03413	0.64	0.36	0.22	0.05	0.01	2.9746
Individual	2.89196	0.32733	0.15523	0.03973	1.19	0.67	0.41	0.09	0.02	3.4166
2000, scenario 1										
In place	2.16357	0.50588	0.18863	0.30155	1.80	1.67	0.55	0.12	0.02	3.1638
Group	1.59651	0.37329	0.13919	0.22421	11.44	10.67	3.50	0.77	0.16	2.3597
Individual	1.74899	0.40895	0.15249	0.22568	10.34	9.64	3.17	0.70	0.14	2.5601
1990, scenario 3										
In place	3.66972	–	–	–	0.45	0.26	0.16	0.03	0.01	3.6706
Group	3.16515	–	–	–	1.01	0.57	0.35	0.07	0.02	3.1672
Individual	3.65877	–	–	–	0.61	0.35	0.21	0.04	0.01	3.6600
2000, scenario 3										
In place	2.87988	–	–	–	1.05	0.98	0.32	0.07	0.01	2.8823
Group	2.32092	–	–	–	12.11	11.30	3.71	0.82	0.17	2.3490
Individual	2.64698	–	–	–	10.58	9.87	3.24	0.71	0.15	2.6715

[a]Hydroelectricity and pumped storage. [b]Rows do not always sum because of rounding.

Figure 3. Direct use of petroleum for urban transportation in scenario 1.

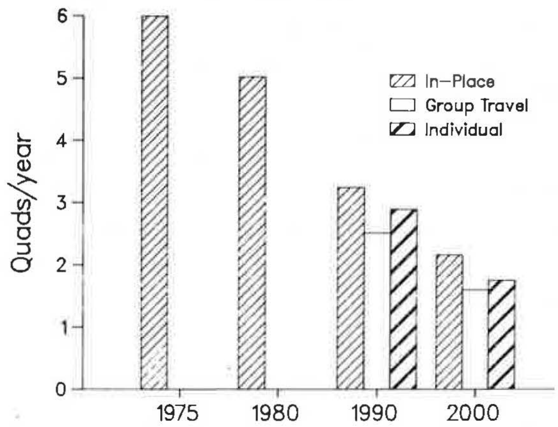
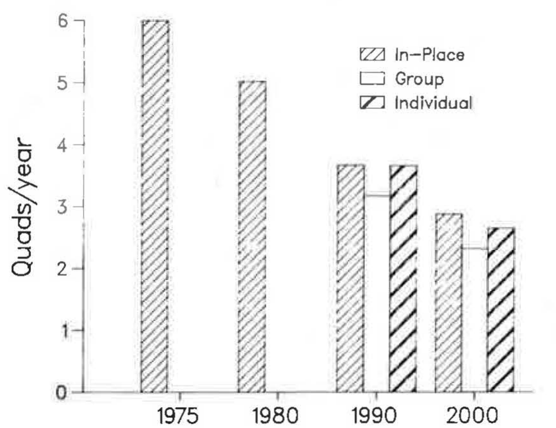


Figure 4. Direct use of petroleum for urban transportation in scenario 3.



tion level of service under each policy. These energy requirements were estimated with the methods developed for TAPCUT (2-7). The limits to the energy accounting have been described in a technical memorandum (2). The results of these analyses represent the indirect energy use under the TAPCUT policies and are combined with the results of the direct energy analyses in Table 4 to show the estimated total energy by fuel type for urban travel. Estimates for 1990 were also derived but are not presented in this table.

The results, which are further illustrated in Figures 5 and 6, show a substantial decline between 1980 and 2000 in energy use devoted to urban passenger transportation even when indirect energy (i.e., energy for fuel production, vehicle manufacture, and infrastructure construction) is included in the analysis. In scenario 1, the decline by 2000 in total energy use from the 6.6 quads estimated for 1980 ranges from 1.0 quad under the in-place policy to 2.4 quads under the group policy, or 16 to 36 percent. Most of this decline is achieved by 1990. In scenario 3, the decline in total energy use is even more dramatic. It is nearly halved by 2000 under the group travel policy; i.e., there is a 3.0-quad reduction in total energy use. This is much greater than the savings of 2.2 quads forecast under the in-place policy. The individual policy is identical to the in-place policy, also saving 35 percent relative to 1980. Much of the difference between scenarios is due to the greater amount of energy required for fuel production under scenario 1. In particular, more energy is required to produce gasoline and diesel fuel from the coal and oil shale used in scenario 1 than from petroleum, which in scenario 3 is the only resource fuel for gasoline and diesel fuel.

Although scenario 3 shows the greatest decline in total energy use, scenario 1 shows the greatest decline in petroleum use (see Figures 5 and 6). From the 1980 level of 5.6 quads of petroleum use in direct vehicle operation and associated indirect energy, petroleum use under the scenario 1 policies declines 3.2 to 3.8 quads, i.e., from 56 to 67 percent, by 2000. In scenario 3, petroleum use declines 2.4 to 3.0 quads, or 43 to 54 percent, by 2000. Petroleum consumption shown in Table 4 is not complete, however, because a portion of the unspecified external subsidies in fuel production is petroleum itself and these subsidies by 2000 represent 13 to 16 percent of the total energy requirement for urban passenger travel. However, any likely disaggregation of these subsidies should not alter the fact that scenario 1 leads to greater petroleum savings than does scenario 3.

The energy supply forecasts assumed in TAPCUT can be used as indicators of the changes in energy use under the alternative policies. The absolute levels of energy supply that are forecast in each scenario are not directly related to the demand analysis undertaken in TAPCUT. The forecast indicating that scenario 1 has a greater energy supply than does scenario 3, for example, does not support a conclusion regarding a lower need for conservation, nor are these forecast levels of supply equivalent to an official forecast of supply.

It is important, however, to look at urban transportation energy use in the context of the rest of the energy users in the economy. Thus the results of the direct and indirect energy analyses shown in Table 4 are compared here with the TAPCUT fuel supply assumptions. In 1980 the 6.6 quads of energy required directly and indirectly for urban passenger transportation represent approximately 8.3 percent of total national energy consumption of 80 quads. By 2000 in scenario 1 and depending on the policy, total energy consumption in urban passenger transportation represents 3.7 to 4.9 percent of the forecast national total of 114 quads. In scenario 3, total energy consumption in urban passenger transportation represents from 3.8 to 4.7 percent of the forecast national total of 94 quads.

In 1980 the 5.6 quads of petroleum required directly and indirectly for urban passenger transportation represent approximately 16.1 percent of the total national petroleum consumption of 35 quads. By 2000 in scenario 1, total petroleum consumption in urban passenger transportation represents 7.0 to 9.4 percent of the forecast national petroleum total of 26 quads. In scenario 3, total petroleum consumption in urban passenger transportation represents from 7.7 to 9.5 percent of the forecast national petroleum total of 34 quads.

Direct Versus Indirect Energy Use

The distribution of fuel types consumed in urban passenger transportation changes both directly and indirectly between 1980 and 2000, particularly in scenario 1. Excluding the external subsidies, in 1980 the total energy consumption is 90 percent petroleum, 5 percent coal, and 5 percent other fuels. By 2000 under scenario 3, the distribution changes modestly to 80 to 85 percent petroleum and 7 to 9 percent coal; the remainder is other fuels. By 2000 in scenario 1, however, petroleum consumption represents just 49 to 53 percent of the total energy consumption, coal jumps to 23 to 25 percent, and oil shale 13 to 15 percent; the remainder is other fuels. Obviously this change is largely because of the use of coal and oil shale as sources of gasoline and diesel fuel.

The relative importance, in terms of energy, of the individual components of urban passenger transportation (vehicle operation, fuel production, vehicle manufacturer, and infrastructure construction) changes over time and with scenario. The distribution of energy use by these components under the in-place policy in scenario 1 is shown in Figure 7. In 1980 direct energy use for vehicle operation represents 76 percent of the total energy use associated with urban passenger travel. By 2000 in

Table 4. Total direct energy consumed in urban passenger travel by primary fuel type and resource fuel.

Energy Need	Fuel (10^{15} Btu) Petroleum	Shale Oil	Coal	Natural Gas	Uranium	Hydro-electricity	Other	External Subsidies[a]	Total	Percentage of Total Energy
1980										
Vehicle operation	5.0323	–	–	–	–	–	–	–	5.0323	76.2
Fuel production	0.4479	–	–	–	–	–	–	0.3598	0.8077	12.2
Vehicle manufacture	0.0862	–	0.2640	0.1999	0.219	0.0238	0.0032	–	0.5990	9.1
Infrastructure construction	0.0607	–	0.0588	0.0416	0.0020	0.0015	–	–	0.1646	2.5
Total	5.6271	–	0.3328	0.2415	0.0239	0.0253	0.0032	0.3598	6.6036	
Percentage of total energy without external subsidies	90.1	–	5.2	3.9	0.4	0.4	0.0	–		
2000, Scenario 1, In-Place Policy										
Vehicle operation	2.1641	0.5059	0.4920	0.0001	0.0017	–	–	–	3.1638	56.8
Fuel production	0.1926	0.2029	0.2949	–	0.0004	–	–	0.8861	1.5769	28.3
Vehicle manufacture	0.0769	–	0.2802	0.2584	0.0859	0.0365	0.0109	–	0.7488	13.4
Infrastructure construction	0.0286	–	0.0304	0.0198	0.0032	0.0005	0.0003	–	0.0828	1.5
Total	2.4622	0.7088	1.0975	0.2783	0.0912	0.0370	0.0112	0.8861	5.5723	
Percentage of total energy without external subsidies	52.6	15.1	23.4	5.9	2.0	0.8	0.2	–		
2000, Scenario 1, Group Policy										
Vehicle operation	1.6000	0.3733	0.3748	0.0008	0.0107	0.0001[b]	–	–	2.3597	55.7
Fuel production	0.1424	0.1497	0.2203	0.0002	0.0025	–	–	0.6567	1.1718	27.7
Vehicle manufacture	0.0608	–	0.2215	0.2049	0.0684	0.0290	0.0089	–	0.5935	14.0
Infrastructure construction	0.0352	–	0.0424	0.0262	0.0047	0.0007	0.0004	–	0.1096	2.6
Total	1.8384	0.523	0.859	0.2321	0.0863	0.0298	0.0093	0.6557	4.2346	
Percentage of total energy without external subsidies	51.4	14.6	24.0	6.5	2.4	0.8	0.3	–		
2000, Scenario 1, Individual Policy										
Vehicle operation	1.7522	0.4090	0.3885	0.0007	0.0096	0.0001	–	–	2.5601	50.7
Fuel production	0.1560	0.1640	0.2268	0.0001	0.0023	–	–	0.7004	1.2496	24.7
Vehicle manufacture	0.0748	–	0.2873	0.2839	0.1098	0.0338	0.0192	–	0.8088	16.0
Infrastructure construction	0.1335	–	0.1730	0.1088	0.0154	0.0024	0.0014	–	0.4345	8.6
Total	2.1165	0.5730	1.0756	0.3935	0.1371	0.0353	0.0206	0.7004	5.0530	
Percentage of total energy without external subsidies	48.6	13.2	24.7	9.0	3.2	0.8	0.5	–		
2000, Scenario 3, In-Place Policy										
Vehicle operation	2.8802	–	0.0010	0.0001	0.0010	–	–	–	2.8823	65.7
Fuel production	0.2563	–	0.0002	–	0.0002	–	–	0.5899	0.8466	19.3
Vehicle manufacture	0.0594	–	0.2313	0.1978	0.0463	0.0326	0.0102	–	0.5776	13.2
Infrastructure construction	0.0283	–	0.0304	0.0194	0.0022	0.0007	0.0004	–	0.0814	1.8
Total	3.2242	–	0.2629	0.2173	0.0497	0.0333	0.0106	0.5899	4.3879	
Percentage of total energy without external subsidies	84.9	–	6.9	5.7	1.3	0.9	0.3	–		
2000 Scenario 3, Group Policy										
Vehicle operation	2.3246	–	0.0121	0.0008	0.0113	0.0002	–	–	2.3490	65.4
Fuel production	0.2069	–	0.0018	–	0.0027	–	–	0.4767	0.6881	19.1
Vehicle manufacture	0.0479	–	0.1865	0.1595	0.0374	0.0263	0.0083	–	0.4659	13.0
Infrastructure construction	0.0305		0.0337	0.0211	0.0024	0.0008	0.0004	–	0.0889	2.5
Total	2.6099	–	0.2341	0.1814	0.0538	0.0273	0.0087	0.4767	3.5919	
Percentage of total energy without external subsidies	83.8	–	7.5	5.8	1.7	0.9	0.3	–		
2000, Scenario 3, Individual Policy										
Vehicle operation	2.6502	–	0.0106	0.0007	0.0099	0.0001	–	–	2.6715	61.7
Fuel production	0.2359	–	0.0016	–	0.0023	–	–	0.5434	0.7832	18.1
Vehicle manufacture	0.0710	–	0.2679	0.2412	0.0555	0.0409	0.0118	–	0.6883	15.9
Infrastructure construction	0.0658	–	0.0680	0.0443	0.0047	0.0015	0.0008	–	0.1851	4.3
Total	3.0229	–	0.3481	0.2862	0.0724	0.0425	0.0126	0.5434	4.381	
Percentage of total energy without external subsidies	79.9	–	9.2	7.6	1.9	1.1	0.3	–		

[a]Fuels, electricity, materials, and equipment required to operate and construct the fuel-production system. Resource fuels are not included.

[b]All energy listed as "other" in Table 3 is assumed to be hydroelectricity in this analysis.

Figure 5. Total energy required for urban passenger transportation versus total petroleum in scenario 1.

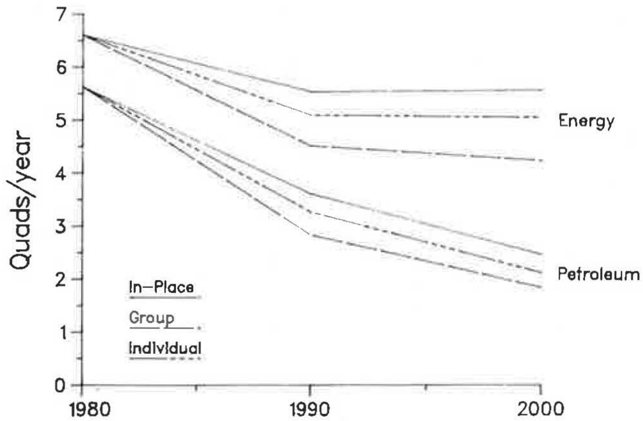
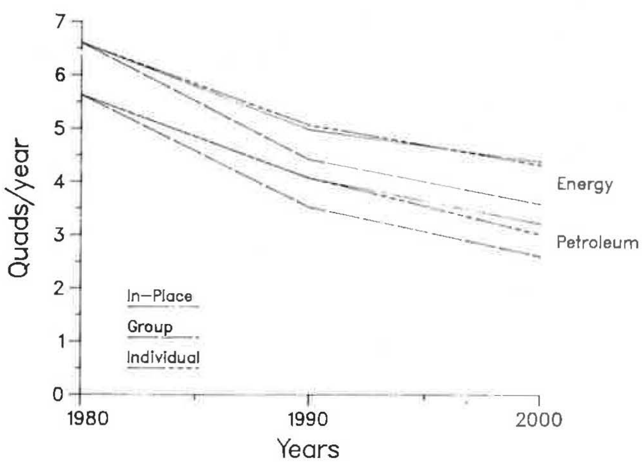


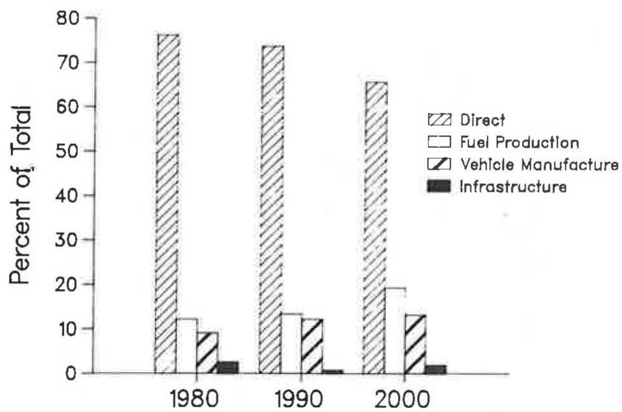
Figure 6. Total energy required for urban passenger transportation versus total petroleum in scenario 3.



scenario 1, vehicle energy use drops to 51 to 57 percent of the total, depending on the policy; in scenario 3 the decrease is to 62 to 66 percent of the total. Energy required for fuel production represents 12 percent of the total energy use in urban passenger transportation in 1980. By 2000 fuel production energy in scenario 1 increases to 25 to 28 percent of the total; in scenario 3 it increases to 18 to 19 percent of the total. Energy required for vehicle production is 9 percent of the total in 1980; by 2000 this increases to 13 to 16 percent of the total energy in both scenarios. This share increases because of the increased number of vehicles manufactured in the scenarios rather than because of an increase in the energy required to produce each vehicle, which declines from 1980 to 2000. Energy for infrastructure construction represents 2.5 percent of the total energy use in 1980. Only under the individual policy in both scenarios does it increase to 4.3 to 8.6 percent by 2000.

The scenario 1 totals for each phase of indirect energy under each policy are almost always higher than the scenario 3 totals for the equivalent policy in both 1990 and 2000. (The only exception is the energy required for vehicle manufacture in 1990 under the individual policy.) This higher indirect energy total generally explains why the scenario 1 total energy consumption is always higher than that of scenario 3 in spite of the similar effect on each

Figure 7. Urban travel energy use by type under in-place policy in scenario 1.



scenario, for direct energy consumption alone, of these policies. The major difference among the scenarios occurs in the energy required for fuel production. As indicated earlier, energy required to produce fuel under all policies for both scenarios is almost always the greatest proportion of the indirect energy in both 1990 and 2000. (In 1990 under the group travel and individual policies of scenario 3, energy for vehicle manufacture is slightly higher.) As stated previously, the totals for fuel production are much higher for scenario 1 than for scenario 3 because of the use of coal and oil shale in the derivation of gasoline and diesel fuel and because of the use of coal-derived methanol in scenario 1.

CONCLUSIONS

Some distinct changes are expected to occur in urban travel energy use to the end of this century. Energy conservation strategies can affect the forecast patterns of energy. These projected patterns have been examined here. Many assumptions are built into all phases of the analysis; changes in any of these assumptions would obviously affect the specific totals generated. However, the general results would probably not be greatly affected. The most important of these results are the following:

1. A substantial decline in direct energy consumed in national urban passenger travel is projected from 1980 to 2000. The 1980-2000 decline occurs in both scenarios under all energy-saving strategies.
2. Even when indirect energy (energy for fuel production, vehicle production, and infrastructure construction) is included, a substantial decline between 1980 and 2000 in energy use devoted to urban transportation occurs.
3. The scenario that results in the greatest savings of petroleum does not save the greatest amount of energy. This occurs in wealthy scenario 1 largely because more total energy is required to produce gasoline and diesel fuel from oil shale and coal (and to a lesser extent to produce coal-derived methanol, which substitutes for gasoline) than is required to produce gasoline and diesel fuel from petroleum. In other words, petroleum savings achieved through fuel substitution exact a price in the form of higher consumption of other fuels, particularly coal.
4. By contrast, petroleum savings achieved through improved vehicle efficiency are not balanced

against any increase in energy for vehicle production. This situation has come about because of the large decrease in vehicle weight that occurs by 2000, which compensates for the forecast increase in energy per pound of vehicle inherent in the new materials and production processes used in the more fuel-efficient cars.

5. The relative importance of individual components of urban transportation will change over time in either economic scenario. In particular, by 2000 indirect energy requirements are projected to account for at least 34 percent without synfuels and up to 49 percent with synfuels of the total energy required for urban passenger transportation as opposed to 24 percent in 1980. The opportunities for energy saving in fuel production in particular should be identified now to lessen the impact of the shift to alternative fuels.

6. Indirect energy use can offset some of the direct energy savings projected in urban transportation. Total indirect energy consumption increases between 1980 and 2000 under the in-place policy in one scenario and under the individual policy in both scenarios. Thus, when the implications of various transportation strategies on direct energy use in vehicle operation are examined, the energy consumed indirectly must be considered.

ACKNOWLEDGMENT

The effort reported in this paper would not have been possible without the help of other participants in the TAPCUT project, each lending his or her special expertise as needed. In particular, we would like to acknowledge the efforts of those who characterized the vehicle and fuel production technologies and infrastructure construction: Charles Hudson, now with EE&G, Santa Barbara, California; Evelyn Putnam, now with Priority Research, Santa Barbara; and Roy Hildestad, now with General Research Corporation, Santa Barbara. We would also like to acknowledge the efforts of those who provided the forecasts of population, travel demand, and automobile ownership: Bruce Peterson, Oak Ridge National Laboratory; Marc Kaplan, now with Bell Laboratories, in New Jersey; and Chris Saricks, Argonne National Laboratory. Last, but certainly not least, we owe our thanks to David O. Moses, U.S. Department of Energy, the sponsor of the TAPCUT project.

REFERENCES

1. S.J. LaBelle and D.O. Moses. Technology Assessment of Productive Conservation. Argonne National Laboratory, Argonne, Ill., Final Rept. ANL/ES-130, Nov. 1982.
2. M.K. Singh. Energy Consumption Due to Local Travel by Urban Households under Three Alternative Policies: 1980-2000. Center for Transportation Research, Argonne National Laboratory, Argonne, Ill., Rept. ANL/EES-TM-12, Nov. 1981.
3. A.J. Frabetti. Application of Net Energy Analysis to Consumer Technologies. Energy Research and Development Administration, U.S. Department of Energy, Feb. 1977.
4. A.J. Frabetti. A Study to Develop Energy Estimates of Merit for Selected Fuel Technologies. Office of Research and Development, U.S. Department of Interior, Sept. 1975.
5. A.G. Melcher. Net Energy Balance Study of Fossil Fuel Resources. Colorado Energy Research Institute, Golden, Colo., April 1978.
6. E.M. Dickson et al. Impacts of Synthetic Liquid Fuels Development: Assessment of Critical Factors, Volume II: Analysis, Energy Research and Development Administration, U.S. Department of Energy, and U.S. Environmental Protection Agency, Rept. ERDA 76-129/2, 1976.
7. T.O. Wagner et al. Diesel Fuel Ups Energy Efficiency. Oil and Gas Journal, Vol. 79, Jan. 4, 1981, p. 1.

The California Freight Energy Demand Model

HERBERT WEINBLATT

The freight model of the California Energy Commission transportation model system is designed to analyze rail and truck competition and to produce detailed projections through 2002 of activity and energy consumption within California of all trucks and of rail-freight operations. The model is also designed to analyze the potential effects of public policy on such transportation activity and energy consumption. A slightly simplified description of the entire model as it is now planned plus projections produced by the phase-1 model are presented. The phase-1 model consists of the truck-transportation components of the entire model plus a limited capability for projecting aggregate rail-freight energy consumption. Rail and truck competition and a more disaggregate rail-freight sector have been introduced in the phase-2 version of the model.

The California Energy Commission (CEC) transportation model system consists of a freight model (1), an automobile model (2), and a transit model (3). The freight model is designed to analyze rail and truck competition and to produce detailed projections through 2002 of activity and energy consumption within California of all trucks and of rail-freight operations. The model is also designed to analyze the potential effects of public policy on such transportation activity and energy consumption.

The freight model was implemented in two phases. The first was completed in August 1982, and the second was completed in June 1983.

A slightly simplified description of the entire model as it is now planned plus projections produced by the phase-1 model are presented. The phase-1 model consists of the truck-transportation components of the entire model plus a limited capability for projecting aggregate rail-freight energy consumption. Analyses of rail and truck competition and a more disaggregate rail-freight sector were implemented in early 1983.

In the first section of this paper various ways are described in which the basic variables of the model are disaggregated. In the second section the estimation of the base-year data used by the model is described. The operation of the model and a summary of the base-case projections produced by the phase-1 model are covered in the third and fourth sections, respectively.