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Motor-Vehicle Fuel Economy: Estimated Cost and Benefits from 1980 to 2020

R.K. WHITFORD AND M.J. DOHERTY

Results of an analysis of motor-vehicle fuel economy performed by Purdue University as part of an ongoing analysis of the costs, benefits, and effects of various energy options are discussed. The analysis is presented in three sections: (a) automobiles, (b) light trucks, and (c) combined results and sensitivities. Three scenarios are studied in the automobile and light-truck sections. In the third section, automobile and light-truck scenarios are combined.

About 70 percent of the petroleum consumed in transportation is used by passenger automobiles and light trucks. Obviously, improvements in these vehicles or in their use could pay large dividends in reduced fuel consumption. However, unless domestic automobile makers can meet the demand for fuel-efficient automobiles, the United States may be simply substituting one import, automobiles, for another, oil. Congress passed legislation in 1975 that required a corporate average fuel economy for new cars of 27.5 miles/gal by 1985. Should more be done beyond 1985? If so, how much?

Purdue University is performing an analysis for the U.S. Department of Transportation (DOT) to determine the benefits, costs, institutional and environmental impacts, distributional equity effects, and technology mobilization for various energy options, including oil from shale, coal liquefaction, biomass liquids, freight movement, and automobile fuel economy. This analysis is called transition path analysis. This paper reports the work done to date, primarily in the development of nationwide costs and benefits for the passenger car and light-duty truck. All benefits are measured in terms of oil saved.

The discussion of the results is divided into three parts: automobiles, light trucks, and combined results and sensitivity.

AUTOMOBILES

Sales Forecast

The sales forecast was based on a relatively mature market. The forecast is based on an average increase in sales of about 0.33 percent each year, which would cause the total fleet to grow from 106 million cars in 1980 to 122 million in 2020 (1). Past sales cycles seem to correlate with gross national product, and the length of the cycles reflects the average life span of cars. If this average age stays relatively fixed, we can expect six-year cycles in the future. Figure 1 shows the Purdue sales estimate and also indicates the reference low and high sales estimates from DOT (2) and the Mellon Institute (3) for comparison.

Baseline

Whereas other studies have used a baseline of 27.5 miles/gal for new cars in 1985 and later, this study instead assumes that no investments are made solely to improve fuel efficiency after 1985 and that some improvement will occur with normal replacement of worn-out plants and obsolete tools. More specifically, it is assumed that the industry will spend no more than $2 billion/year (after 1982) and that consumers will continue to demand improved fuel efficiency. The timing of line changeover will slow from the present replacement schedule of every 10-12 years to every 15-17 years. New models will be introduced much less frequently than at present.

This baseline is very different from that used by other studies, since fuel economy continues to improve over time. This means that future investments over the baseline achieve lower fuel savings with the moving baseline used here than would be achieved with a static baseline.

Scenarios

Meeting the 1985 standards will not be a severe technological problem. The standards will be met by the implementation of downsizing, front-wheel drive, limited material substitution, and less powerful engines. Although the scenarios predict large increases in fuel economy, this is not unrealistic in light of existing technological developments. According to a June 1980 news release, General Motors is predicting a corporate average fuel economy of more than 32 miles/gal in 1985.

The scenarios for this study are as follows:

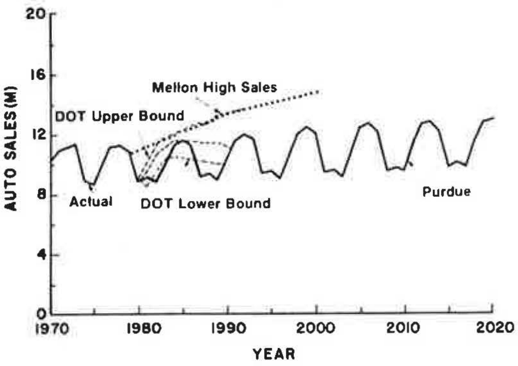
1. Scenario A--Production line changeovers will occur every 10-12 years and one new model will be introduced by the industry each year. Diesels will achieve 25 percent of the market. New-car fuel economy will reach 32.4 miles/gal in 1985, about 40 miles/gal in 2000, and 43.3 miles/gal in 2020.
2. Scenario B--Weight will be reduced significantly after 1990, and diesel penetration will be 50 percent by the year 2000. Fuel economy will reach about 32.5 miles/gal in 1985, 50 miles/gal in 2000, and 55 miles/gal in 2020.
3. Scenario C--Weight will be reduced even further and an 80-mile/gal sub-subcompact (commuter car) will account for 15 percent of the market by 2020. Diesels will penetrate 100 percent of the intermediate and large-car markets. Fuel economy will reach almost 59 miles/gal in 2000 and 64 miles/gal in 2020.

These scenarios, though not perfect, are illustrative of likely happenings under the definitions. The composite new-car fuel economy for the various scenarios is shown in Figure 2.

Technology Improvements

The primary areas of effort are downsizing, redesign for front-wheel drive, material substitution, and change to higher percentage of diesels. Other technology improvements incorporated include such items as aerodynamic design, improvements in accessory efficiency, improved transmission, turbochargers, and engine design parameters. However, no allowance has been made to incorporate either a Stirling or Brayton cycle engine.

Figure 1. Automobile sales forecast.



Downsizing to 1985

The 1985 fleet will be composed of four sizes of automobiles: subcompact, compact, intermediate, and large. The principal way in which the weight reduction will be realized is through downsizing and front-wheel drive on many models. Only limited changes in materials are anticipated, mostly to higher-strength steel and some aluminum castings.

After 1985

The improvements proposed in the fleets after 1985 are assumed to occur in five principal areas:

1. Materials substitution will account for a decrease in weight of about 750 lb for the large car and 450 lb for the subcompact.
2. A sub-subcompact will be introduced in the highest-rate scenario in about the year 2000 for two-passenger commuting.
3. Continued improvements in drive train, aerodynamics, and rolling resistance will account for about a 2.5- to 4-mile/gal improvement over this period.
4. Improvements in engine control coupled with an overall reduction in acceleration performance will provide an improvement of about 3-4 miles/gal.
5. Increased penetration of diesel in the year 2000, from 25 percent in scenario A to more than 75 percent in scenario C, represents a significant opportunity to improve fuel economy.

Investment Costs

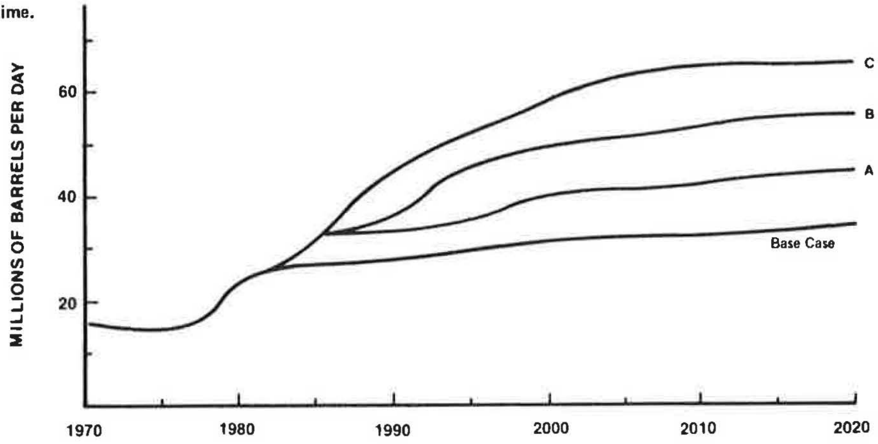
Data on investments were drawn from the report by Shackson and Leach (3) as well as assembly-line and production-facility changes outlined in the 1981 report by DOT (2).

The number and timing of the engine, transmission, and assembly lines that would be changed over were approximated based on a 10- to 12-year life for an engine plant and a slightly longer life for an assembly plant. Each engine plant turnover cost $300 million, and an assembly plant change for a major redesign like front-wheel drive or major material substitution was $1 billion. Only costs that involve a change for fuel economy are included. Table 1 indicates the total differential investment in 1980 dollars between the baseline and the various scenarios.

Variable Costs

The variable cost per car in 2020 ranges from an

Figure 2. New-car fuel economy over time.



additional $580 for the base case to $980 for scenario A, $1445 for scenario B, and $1750 for scenario C. Table 1 gives the variable cost for each scenario expressed in costs over the baseline car for that year. The major costs result from the switch to diesels ($400/car), turbocharger, transmission, and other improvements ($80-$170/car) and the substitution of materials, as given in Table 2. Substitution with more costly plastics occurs as the car gets lighter and plastic parts more complex (4).

Fuel Savings

Fuel consumption for the scenarios, in millions of barrels per day, is shown in Figure 3. It is interesting to note that for all scenarios, including the baseline, there is an overall drop over the long term. Since only a very minor increase in automobile use and fleet size is predicted, the curves do not bend upward near the end of the period. It is also worthy to note that even scenario A shows a reduction from the 1980 use of 4.8 million bbl/day to 1.9 million bbl/day.

This is much less than the 3 million to 3.5 million bbl/day postulated by several studies (3,5,6). The differences appear to be attributable to three major factors:

1. Others assumed that the baseline fleet would reach 27.5 miles/gal in 1985 and stay at that level. Our baseline shows an improving fleet fuel economy; this represents about a third of the difference.
2. This section is for automobiles alone. About one-third of the difference is due to truck fuel economy alone.
3. The conservative sales forecast means that there are fewer automobiles in the scenarios. Others contemplate a fleet of 160 million cars in 2000. This accounts for the remainder of the difference.

Economic Efficiency

By using a fuel escalation of 3 percent/year, the results of the efficiency model presented in Table 3 show that scenario A is by far the best scenario for the passenger car. The internal rate of return is more than 20 percent, and the resource cost is substantially less than the cost of oil on the market today.

Table 1. Investment and variable costs for automobile scenarios.

	Differential Investment by Scenario ($000 000 000s)			Differential Variable Cost Above Baseline by Scenario ($/car)		
Year	A	B	C	A	B	C
1985	9.5	12.3	12.5	190	240	250
1990	9.2	26.8	34.4	250	450	680
1995	7.3	34.5	55	250	550	930
2000	5	41	70	250	535	1170
2010	13	44	77	345	774	1200
2020	16	43	66	400	865	1170

Note: Amounts in 1980 dollars.

LIGHT TRUCKS

The approach to determining fleet mix and future capability for light trucks is somewhat different than that for automobiles. Whereas automobiles are purchased primarily for personal transportation, light trucks usually serve more than one transportation need. Most light trucks (roughly 60 percent) are purchased for personal use. However, this use frequently includes such duties as hauling, recreation, and outdoor activities as well as personal transportation.

Sales Forecast

The sales forecast for light trucks uses the same assumptions as that for automobiles. Thus, it is assumed that truck sales will vary with automobile sales and will be about 20 percent of total vehicle sales for all scenarios. This results in an annual growth rate of 1.5 percent/year in the light-truck fleet to the year 2000 and approximately 0.4 percent thereafter. Truck sales are projected to vary from 2.2 million in 1980 to a high of 3.2 million in 2020.

Baseline

The baseline for the light-truck model is much like the baseline in the automobile model. Thus, it shows some fuel-economy improvement over time. The major technological thrust is a program of gradual weight reduction to occur at the time of production line rollover. This results in an average weight reduction of 800 lb by 2020. Diesels will account for 10 percent of the market in 2020. A slight shift in fleet mix is also expected to improve fuel economy as existing minitrucks are substituted for conventional pickups. The baseline investment is held to a maximum of $0.5 billion after 1987, when a

Figure 3. Fuel use for various scenarios: automobiles.

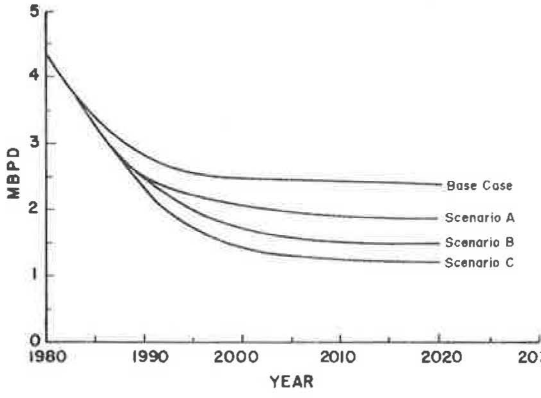


Table 2. Weight-reduction data by time period for scenario C.

	Weight Removal (lb)						
Year	Subcompact	Compact	Intermediate	Large Car	Cost per Replacement Pound ($)	Steel Weight to Weight of Substitute Material	Cost of Substitute Material to Steel Cost
1985-1990	200	200	200	300	1	2:1	2:1
1991-1995	200	200	200	200	1.50	2.25:1	3.4:1
1996-2000	50	200	300	250	2	2.5:1	5:1

Table 3. Economic results of fuel-economy scenarios for passenger cars.

Scenario	Item	Total Dollars	Ten Percent Discount Rate	Internal Rate of Return (%)
A	Benefits ($ billion)	495	58	22.3
	Costs ($ billion)	135	26	
	B/C ratio	3.7	2.0	
		3.7	2.0	
	Resource cost ($/bbl)	22.4	32.7	
B	Benefits ($ billion)	864	80	16.6
	Costs ($ billion)	301	55	
	B/C ratio	2.9	1.45	
	Resource cost ($/bbl)	29.1	45.4	
C	Benefits ($ billion)	1122	107	15.4
	Costs ($ billion)	479	83	
	B/C ratio	2.3	1.3	
	Resource cost ($/bbl)	35.3	51.1	

Table 4. Investment and variable costs for light-truck scenarios.

	Total Investment for Fuel Economy over Baseline ($)			Differential Variable Cost ($/truck)		
Year	A	B	C	A	B	C
1985	3.8	4.2	4.2	142	142	142
1990	4.6	11.2	12.1	165	500	645
1995	6.0	14.8	19.5	256	709	1363
2000	6.4	17.1	18.8	355	1026	1332
2010	7.9	15.6	16.1	570	1021	1169
2020	11.7	14.3	14.3	797	1027	1027

Note: Amounts in 1980 dollars.

20-mile/gal fleet average is attained. The baseline will reach the suggested 1985 light-truck fuel efficiency of 21 miles/gal in 1990.

Scenarios

All scenarios and the baseline begin in 1980 with an average inertia weight of 3775 lb, 17.9-mile/gal new-truck fuel economy, and 2 percent diesel penetration.

1. Scenario A--Lighter components and a mix shift result in a 1165-lb reduction from the current average weight, which will be spread over the entire 40 years of the model. A 50 percent diesel penetration will be achieved by the year 2020.
2. Scenario B--The weight reduction is the same as in scenario A but will be achieved by the year 2000 with 65 percent diesel penetration. The fleet will be 100 percent dieselized by 2020.
3. Scenario C--The same average weight and percentage of diesel penetration will be achieved as in scenario B except that the goals will be met on a vastly accelerated schedule. In this scenario, all technological changes will be complete by 1995.

Investment Costs

The same investment cost models as in the automobile fuel economy were used. Each engine plant turnover was estimated to cost $300 million, and the estimated incremental downsizing and material substitution cost was $340 million/line. Major redesign, such as the van redesign to accommodate a turbocharged diesel, was estimated at $600 million. The difference among the scenarios in total investment is due to differences in the time required for change. These results are presented in Table 4.

Variable Costs

The variable cost per truck in the year 2020 ranges from an additional $679 for the baseline to $1472 for scenario A and $1702 for scenarios B and C (Table 4). The major costs result from the switch to diesels ($400/truck) and the material substitution costs (as explained in the previous discussion of automobiles). The cost schedule for the average 1165-lb weight reduction program in the three scenarios is $0.50/lb for the first 580 lb, $1.00 for the next 350 lb, $1.50 for the next 260 lb, and $2.00 for the final 60 lb.

Fuel Savings

Fuel consumption for light trucks in 1980 (see Figure 4) is approximately 1.35 million bbl/day. For the baseline, this consumption is reduced to 0.9 million in the year 2020. Fuel consumption for the scenarios ranges from 0.64 million bbl/day for scenario A to roughly 0.5 million for scenarios B and C. The bulk of the fuel savings results from the shift to diesel. For example, a 2600-lb minipickup in 1980 achieves 25.2 miles/gal and a 2700-lb achieves 31 miles/gal in 2020. The same truck as a diesel achieves 47 miles/gal.

Economic Efficiency

The internal rate of return for the three scenarios ranges from 24.17 to 21.72 percent; scenario A has a very slight edge over the others. It is interesting to note that, although scenarios B and C are virtually identical with respect to the type of light-truck fleet that will result in 2020, the investment schedule for scenario B seems to yield a slightly higher rate of return. These results are presented in Table 5.

COMBINED RESULTS AND SENSITIVITIES

All of the studies to date treat automobile fuel economy and light-truck fuel economy as a single package. For these results, passenger-car scenario A has been combined with light-truck scenario A, and so on.

Fleet Fuel Use and Savings

Fleet fuel use based on past vehicle miles of travel (VMT) performance is shown in Figure 5. The automobile/light-truck fleet will exhibit a decrease in fuel use from 6.3 million to 3.3 million bbl/day just due to the normal turnover of plant and equipment. The small investment of scenario A adds another 0.8 million bbl/day to that. Scenarios B and C get a lower return for a much higher investment.

Economic Results

As presented in Table 6, the net benefits are increased somewhat in the combined approach largely due to the higher benefits from the light-truck scenarios. The internal rate of return is likewise a small amount higher.

Sensitivity to Discount Rates

Each of the scenarios was evaluated at 5, 10, and 15 percent discount rates and at a 3 percent oil price increase. In Figure 6, B/C ratio is plotted versus discount rate for the three scenarios.

Different Base Data

The B/C ratio and the internal rate of return are

Figure 4. Fuel saved over baseline: light trucks.

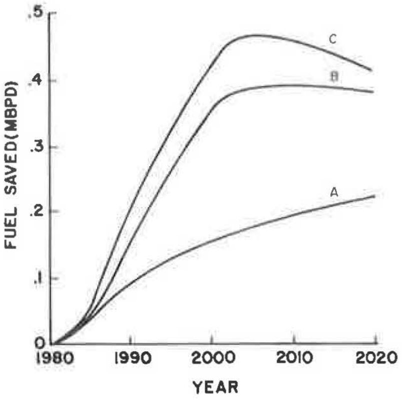
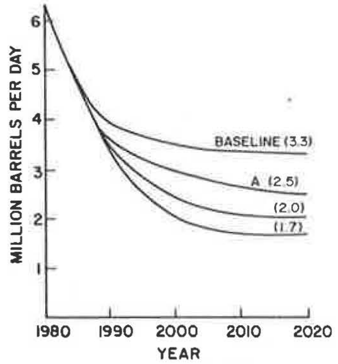


Table 5. Economic results of fuel-economy scenarios for light-trucks.

Scenario	Item	Total Dollars	Ten Percent Discount Rate	Internal Rate of Return (%)
A	Benefits ($ billion)	202	19.1	24.17
	Costs ($ billion)	52	8.6	
	B/C ratio	3.87	2.22	
	Resource cost ($/bbl)	21.62	28.93	
B	Benefits ($ billion)	371	36.1	23.57
	Costs ($ billion)	99	18.1	
	B/C ratio	3.76	1.99	
	Resource cost ($/bbl)	21.89	32.8	
C	Benefits ($ billion)	426	41.3	21.72
	Costs ($ billion)	120	23.0	
	B/C ratio	3.54	1.79	
	Resource cost ($/bbl)	23.16	36.7	

Figure 5. Motor-vehicle fleet use over time.



based on the particular assumptions made concerning the stream of costs for the scenarios in comparison with the baseline. Concern for the adequacy of this baseline suggested that two other baselines be used to test sensitivity. These are the static baseline and the Environmental Policy and Control Act (EPCA) baseline.

The static baseline in effect freezes fuel economy at 1980 levels (22.5 miles/gal for automobiles and 17.9 miles/gal for trucks). Thus, there are no investment costs and no increase in variable cost per vehicle. This baseline is very similar in principle to the baseline used in the Mellon report (3).

In the EPCA, baseline investments and costs are included only until 1985, when the mandated fuel-economy standards are in effect. After 1985, the baseline becomes a straight line and effectively parallels the static baseline. Costs included through 1985 are $26.4 billion for investment and variable cost of $413/automobile [these figures are comparable to those reported in other studies (3,7)].

The effects of these baselines on economic efficiency in scenario B are given in Table 7. As noted in the table, in addition to the differing baselines, the results of the scenario are very similar to results presented in the Mellon report (3).

Surprisingly, the results seem to be very similar no matter what baseline is used. However, absolute

Table 6. Economic results of fuel-economy scenarios for combined motor-vehicle categories.

Scenario	Item	Total Dollars	Ten Percent Discount Rate	Internal Rate of Return (%)
A	Benefits ($ billion)	697	70	22.8
	Costs ($ billion)	187	35	
	B/C ratio	3.72	2.00	
	Resource cost ($/bbl)	22.3	31.7	
B	Benefits ($ billion)	1235	116	18.34
	Costs ($ billion)	400	73	
	B/C ratio	3.1	1.6	
	Resource cost ($/bbl)	26.9	41.5	
C	Benefits ($ billion)	1547	148	16.94
	Costs ($ billion)	599	106	
	B/C ratio	2.60	1.40	
	Resourre cost ($/bbl)	31.9	47.1	

Figure 6. B/C ratio versus discount rate at 3 percent increase in fuel price.

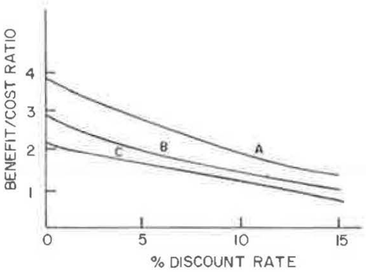


Table 7. Sensitivity of economic results to other data sources and differing baselines through year 2000.

Scenario	Item	Total Dollars	Ten Percent Discount Rate	Internal Rate of Return (%)
Mellon data[a] (5)	Benefits ($ billion)	413	113	16.88
	Costs ($ billion)	187	84	
	B/C ratio	2.20	1.35	
	Resource cost ($/bbl)	26.15	40.17	
Mellon data (5), our baseline	Benefits ($ billion)	145	38	18.20
	Costs ($ billion)	80	30	
	B/C ratio	1.81	1.29	
	Resource cost ($/bbl)	32.10	42.73	
Scenario B, static baseline	Benefits ($ billion)	522	139	16.58
	Costs ($ billion)	254	106	
	B/C ratio	2.05	1.31	
	Resource cost ($/bbl)	28.31	41.76	
Scenario B, EPCA baseline	Benefits ($ billion)	334	83	17.86
	Costs ($ billion)	168	61.9	
	B/C ratio	1.99	1.34	
	Resource cost ($/bbl)	29.73	41.98	

[a] Data similar to Mellon case of low sales and no mix shift: investment = $84.9 billion, automobile fuel economy = 45 miles/gal, light-truck fuel economy = 23 miles/gal.

cost values may be more meaningful when taken in conjunction with a "moving" baseline, which means assuming that some advances in motor-vehicle fuel economy will occur simply as a result of continuing demand for more efficient transportation.

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Forecasts of Intercity Passenger Demand and Energy Use Through 2000

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The development of forecasts of national travel demand and energy use for automobile and common-carrier intercity travel through the year 2000 is reported. The forecasts are driven by the Passenger Oriented Intercity Network Travel Simulation (POINTS) model, a modified direct-demand model that accounts for competition among modes and destinations. Developed and used to model SMSA-to-SMSA business and nonbusiness travel, POINTS is an improvement over earlier direct-demand models because it includes an explicit representation of the relative accessibilities of cities and a utility-maximizing behavioral multimodal travel function. Within POINTS, path-building algorithms are used to determine city-pair travel times and costs by mode, including intramodal transfer times. Other input data include projections of SMSA population, public- and private-sector employment, and hotel and other retail receipts. Outputs include forecasts of SMSA-to-SMSA person trips and person miles of travel by mode. For the national forecasts, these are expanded to represent all intercity travel (trips longer than 100 miles one way) for two fuel price cases. In both cases, rising fuel prices, accompanied by substantial reductions in modal energy intensities, result in moderate growth in total intercity passenger travel. Total intercity passenger travel is predicted to grow at approximately 1 percent/year, slightly faster than population growth. Automobile travel is forecast to increase slightly more slowly than population and air travel to grow almost twice as fast as population. The net effect of moderate travel growth and substantial reduction in modal energy intensities is a reduction of approximately 50 percent in fuel consumption by the intercity passenger travel market.

This paper describes the methods used by Argonne National Laboratory (ANL) in projecting future intercity passenger travel and associated fuel consumption through the year 2000. These projections were developed for the Office of Vehicle and Engine Research and Development of the U.S. Department of Energy (DOE) and are documented in an Argonne National Laboratory report (1).

Intercity passenger travel accounts for approximately 16 percent of domestic passenger miles of travel and 13 percent of domestic passenger-related fuel consumption. Generally regarded as highly discretionary, this travel sector is perhaps best modeled via behavioral, policy-sensitive methods. The following steps provide an overview of the methods used by ANL:

1. Detailed city pair modeling to estimate person miles of travel (PMT) from standard metropolitan statistical area (SMSA) to SMSA by trip purpose and mode,
2. Computation of growth rates from a 1977 base year for SMSA-to-SMSA PMT by mode,
3. Application of the above growth rates to 1977 estimates of intercity PMT (intercity travel is defined as all trips of 100 miles or more one way) to estimate future-year intercity PMT by mode,
4. Application of vehicle load factors to convert automobile and light-truck PMT into vehicle miles of travel (VMT), and
5. Application of VMT- or PMT-based energy intensities to convert PMT and VMT to British thermal units by mode.

MODELING SMSA-TO-SMSA PMT

SMSA-to-SMSA travel for the base year and all future years was modeled by using the Passenger Oriented Intercity Network Travel Simulation (POINTS) model. POINTS estimates passenger demand for the four major modes (automobile/light truck, air, bus, and rail) that compete for this market. Like most recent approaches to intercity travel demand modeling, POINTS is a direct demand model. It simultaneously estimates (a) the total number of trips and the geographic distribution of their origins (trip generation), (b) the joint probability distribution of trip origins and destinations (trip distribution), and (c) the mode by which the travel occurs (mode split). All of these aspects of SMSA-to-SMSA travel are modeled as a function of (and are therefore sensitive to) the amount of activity (population, employment, sales, etc.) at the origin and destination cities and the transportation level of service that connects them. Although POINTS shares these attributes with other direct-demand models, two significant improvements have been incorporated into