Projected Potential Piggyback Energy Savings Through the Year 2000

KENNETH M. BERTRAM

Recent research concerning the energy advantage of using piggyback traffic (trailer-on-flatcar/container-on-flatcar) versus trucks is described and evaluated, and the potential energy savings that may result from capitalizing on this advantage are projected to the year 2000. Projections are based on an approximation of this energy advantage and scenarios of low, medium, and high levels of growth in piggyback traffic developed at the Center for Transportation Research, Argonne National Laboratory.

This paper surveys the results of six recent studies related to the energy-saving potential of piggyback traffic [trailer-on-flatcar/container-on-flatcar (TOFC/COFC)]. It begins by cautioning intermodal advocates to be conservative in their expectations concerning this potential. Although conventional rail traffic has an overall average energy consumption of about 700 Btu/ton mile versus about 2500 Btu/ton mile for trucks, the 3.5:1 energy-use advantage implied by these figures is not applicable to most present and potential piggyback traffic.

A major reason for this is that average rail energy use is heavily influenced by shipments of commodities that are far more dense than piggyback shipments. For instance, about 20 percent of rail ton miles consists of coal traffic that moves in shipments of 100 tons/car, whereas average TOFC/COFC cargo weights are about 30 tons/car. As a result, when the resistance effects of these relative weights are used to compute fuel use, unit coal trains have energy intensities of less than 500 Btu/ton mile, whereas piggyback cars on conventional mixed trains have energy intensities of more than 1500 Btu/ton mile. However, piggyback energy intensities vary considerably depending on whether piggyback cars are part of conventional mixed trains, conventional dedicated trains, or dedicated trains with new, innovative equipment. This paper, therefore, discusses each of these piggyback systems in terms of operational energy use. Then alternative scenarios of TOFC/COFC traffic growth are set forth, and potential energy savings are estimated. Operational improvements that can increase piggyback energy efficiencies are also mentioned. The relative amounts of indirect energy consumption involved in the construction and operation of the various types of equipment are not discussed.

TYPES OF PIGGYBACK OPERATION

Piggyback Cars in Conventional Trains

The approximate energy intensity of TOFC/COFC traffic moving in conventional mixed trains can be derived by using a recently developed algorithm that compares cargo-specific carload weights and resistances with average carload weight and energy intensity for the overall railroad system (1). Because the typical piggyback car has two trailers that carry 16 tons of cargo each and 6 tons of tare weight each (2), versus a rail system average carload cargo weight of about 50 tons each (3), the piggyback car on a mixed train has an average energy intensity of about 1700 Btu/ton mile. It is not known what portion of total TOFC/COFC ton mileage is traveled in conventional trains. However, since a recent Federal Railroad Administration (FRA) study indicates that about 80 percent of all 1976 piggyback tonnage traveled more than 500 miles (4, p. III-25) and that in 1977 there were 67 dedicated piggyback train routes (4, pp. III-15 and III-16), mostly between long-distance city pairs, this portion is relatively small.

Dedicated Piggyback Trains

Two recent studies have estimated the line-haul energy uses of dedicated piggyback trains. Although, as will be shown later, neither of these studies is conclusive or extensive enough to yield definitive, universally applicable results, their findings are similar. One of the studies compiled actual fuel-use data for dedicated piggyback trains versus trucks, whereas the other estimated fuel use by dedicated piggyback trains on six different routes by using a computer model and highly detailed data on route characteristics. The U.S. Department of Energy (DOE) sponsored the first study, which was done in conjunction with the FRA Intermodal Freight Program (of which the second study was a part) and the Federal Highway Administration.

The DOE study began in late 1978 and involved a six-month comparison of the "Sprint" piggyback operations of the Milwaukee Road with those of 45-ft highway trailers of C. W. Transportation, Inc. The objective of the project was to determine the relative, operational energy use of the two modes under the specific conditions existing in the Chicago-Twin Cities corridor.

It was not possible to control all pertinent parameters, although both a truck tractor and a locomotive were equipped with fuel flow meters. The highway and railroad trailers did not operate with the same cargo weights because of weighing complications in the railroad's operations, which resulted in rail trailer weights not being available in time to make possible equivalent loadings of the truck trailers. Other problems that hindered the project and prevented its findings from being conclusive were

1. Increases in locomotive fuel temperature due to use in cooling fuel injectors, which expanded fuel volumes by about 3-4 percent and caused slight inaccuracies in locomotive fuel-use readings;
2. An extremely severe winter and a truck strike that reduced the 26 planned simultaneous rail and truck runs to 12;
3. Determinations of railroad-trailer weight on only half of the simultaneous runs; and
4. Use of estimated rather than actual energy use for rail-terminal loading and unloading.

In addition, care must be taken in applying the study's results to other corridors because of requirements of the Chicago truckers' union that even full truckloads be returned from the shipper to the trucking company terminal before going over the road. This created a situation in which measurements could not be made of the pickup-and-delivery energy-use advantages that truckers enjoy in many other cities.

Nevertheless, the project's findings, which are summarized in Table 1 (5), are a useful addition to the data on route-specific comparisons of piggyback and truck. In addition, as shown later, levels of rail energy use are similar to those found during computer simulations conducted as part of the FRA Intermodal Freight Program.

The estimated energy advantage of piggyback in Table 1 is used, in conjunction with the scenarios of projected increases in TOFC/COFC traffic set forth later, to calculate the preliminary potential piggyback energy savings presented in this paper. Although energy intensity for rail is 802 Btu/ton mile, or about half that for truck, it should be noted that the advantage is not definitive for a number of reasons. One reason is that truck-trailer cargo weights were 42 percent higher than piggyback-trailer cargo weights (17 versus 12 tons). This strongly biases the calculations of energy intensity in favor of trucks in these comparisons and tends to understate the advantage of piggyback. On the other hand, the absence of any truck movements involving twin 27-ft trailers, which are more energy efficient than single 45-ft-trailer truck movements, tends to overstate the energy advantage of piggyback. So does the absence of calculations of pickup-and-delivery energy use. Finally, there were the aforementioned problems during the project, which could easily have affected data accuracy.

Table 1. Comparison of piggyback and truck energy use for 12 one-way trips between Chicago and St. Paul.

Item	Truck	Piggyback
Distance (miles)	420	412
Line-haul speed (miles/h)	42.6	38.2
Fuel consumed (gal)	82.3	1283.2[a]
Trailer data		
Number loaded	1	42
Number empty		3
Miles per gallon	5.1	13.5
Gross weight[b] (tons)	23.1	18.1[c]
Gross ton miles per gallon	117.1	257.8[c]
Revenue weight (tons)	17.1	12.1[c]
Revenue ton route miles per gallon	86.9	172.9[c]
Energy intensity (Btu/revenue ton mile)	1596	802

[a] Includes line-haul and terminal fuel use (estimated).
[b] For 45-ft highway trailers and 40-ft railroad trailers.
[c] Includes only the six runs when trailers were actually weighed.

Table 2. Input data common to all simulations in FRA Intermodal Freight Program.

Train Unit	Value	Amount
Locomotive (SD40-2)	Nominal horsepower	3000
	Gear ratio	62:15
	Number of axles	6
	Unit weight (tons)	184
	Fuel consumption	
	Traction (gal/rail hp-h)	0.067
	Idle (gal/h)	5.5
Railcar (flatcar)	Number of axles	4
	Tare weight (tons)	35
	Payload (tons)	52
	Gross weight (tons)	87
	Loaded trailers per car	2
	Height[a] (ft)	16.96
Trailer (40-ft)	Volume (ft^3)	2713
	Tare weight (tons)	5.75
	Payload (tons)	20.25
	Gross weight (tons)	26
Caboose[b]	Weight (tons)	23.25
	Number of axles	2
	Height from top of rail (ft)	16.96

Note: Maximum trial operating speed = 69 miles/h.
[a] Top of rail to top of trailer.
[b] Caboose used in all train simulations except between Chicago and St. Louis.

There are, however, other factors that favor using this piggyback advantage. Another, independent effort (by the General Motors Transportation Systems Center) under the FRA Intermodal Freight Program obtained similar results by using track profiles on six routes and detailed data on grades and curvatures to perform simulations of dedicated piggyback movements. The piggyback cargo and train data given in Table 2 were used with the track data and a modified version of the Davis formula in the simulations. [The Davis formula was empirically derived in 1926 and is used by energy researchers to calculate railroad energy intensities. Current researchers modify its coefficients based on the relevant characteristics of modern equipment. Additional information is given by Hammitt (6).] The results given in Table 3 (based on the General Motors data) indicate that the effects of a wide range of distances, topographical conditions, and train operating characteristics were simulated.

Note that the Milwaukee Road's Chicago-St. Paul route is one of those simulated and that Table 3 indicates roughly equivalent trailer miles per gallon for the FRA study (14.2) in comparison with the DOE tests (13.5). In addition, although the FRA tests show a lower energy intensity for piggyback than the DOE test, this difference is due largely to the greater cargo weight assumed in Table 2 (no empty trailers and 20.25 tons/trailer versus three empties per train and 12.1 tons/trailer) and the absence in the simulations of terminal energy spent for loading and unloading operations. When the actual line-haul energy uses of two of the DOE test trips were compared with simulations that used the

Table 3. Summary of baseline-condition train simulations performed by General Motors as part of FRA Intermodal Freight Program.

City Pair	Route Length (miles)	Avg Grade Equivalent of Curvature (%)	Avg Gradient (%)	One-Way Dwell Time (h)	No. of Locomotives	No. of Flatcars[a]	Total Trip Time[b] (h)	Trip Fuel[c] (gal)	Avg Travel Speed (miles/h)	Trailer Miles per Gallon	Net Ton Miles per Gallon	Btu per Net Ton Mile
Chicago-St. Paul	403	0.0149	−0.0022	2	3	45	9.86	2 513	40.9	14.43	292	475
St. Paul-Chicago	403	0.0149	0.0022	2	3	45	10.07	2 580	40.0	14.06	285	487
Chicago-St. Louis	268	0.0010	−0.0192	1	1	15	7.02	489	38.1	16.43	333	416
St. Louis-Chicago	268	0.0010	0.0192	1	1	15	7.61	540	35.2	14.86	301	460
San Francisco-Los Angeles	586	0.0239	−0.0004	2	4	45	14.03	5 413	42.1	9.78	198	700
Los Angeles-San Francisco	586	0.0239	0.0004	2	4	45	13.95	5 397	41.8	9.75	197	704
Chicago-Detroit	279	0.0046	−0.0014	1	2	30	6.22	1 267	44.8	13.19	267	519
Detroit-Chicago	279	0.0046	0.0014	1	2	30	6.22	1 282	44.8	13.03	264	525
Chicago-Houston	1350	0.0122	−0.0032	3	2	30	29.59	6 496	45.6	12.47	253	548
Houston-Chicago	1350	0.0122	0.0032	3	2	30	29.51	6 644	45.7	12.19	247	562
Chicago-Los Angeles	2204	0.0150	0.0028	7	5	60	47.40	24 429	46.5	10.83	219	633
Los Angeles-Chicago	2204	0.0150	−0.0028	7	5	60	47.87	23 545	46.1	11.23	227	611

[a] Number of loaded trailers = 2 x number of railcars (two loaded trailers per car).
[b] Includes dwell time.
[c] Includes dwell-time fuel consumption.

same train consists, the simulation estimates of fuel used were about 4 percent lower than the DOE tests both times. This indicates that, if one adds the real conditions experienced on the trips in the DOE tests, it raises the energy intensity for that route in Table 3 to near the value of 802 Btu/net ton mile found in the DOE tests.

In addition, it should be noted that net ton miles per gallon for the Chicago-St. Paul route are only 12 percent higher than the average of 257 net ton miles per gallon for all the routes simulated and that none of the routes varied by more than 23 percent from this average. This information, combined with the fact that the truck fuel-consumption rate of 5.1 miles/gal in the DOE tests falls comfortably within the 4.5-5.5 range generally experienced in the trucking industry, tends to support 800 Btu/ton mile as a reasonable approximation of the energy advantage of dedicated piggyback.

Finally, an important practical reason for using this approximation is that it is impossible to state a definitive TOFC/COFC energy-use relation to trucks without a very large sample of route-specific comparisons. This is because the energy uses of each of these alternatives vary significantly on different routes due to major differences in route characteristics. For example, relative circuity is important and varies greatly between routes. In addition, the grades on the same routes of each mode may be quite different and significantly affect their relative energy uses. Therefore, in the absence of the extensive research a large sample would require, the approximate energy advantage developed here, used with appropriate caveats, is currently the most practical approach to estimating overall potential piggyback energy savings.

The above approximation does not include the expected energy savings of the recent equipment innovations discussed in the next section of this paper. Nor does it include the new energy-saving operating techniques developed under the FRA Intermodal Freight Program. Instead, as will be shown later in the energy-savings calculations and sensitivity analysis, the incremental energy saving of these measures tends to be offset by TOFC/COFC traffic in less efficient mixed trains and improvements in truck energy efficiencies.

Innovative Piggyback Equipment and Improved Operating Procedures

Recent FRA wind-tunnel tests have confirmed that certain types of innovative piggyback equipment can reduce aerodynamic drag. This new equipment also has lower tare weights so that it reduces other resistance forces and the inertia of TOFC/COFC trains and thus energy consumption. Dedicated piggyback trains that use this new equipment can achieve significantly better energy intensities than those that use conventional TOFC/COFC equipment. These new types of equipment included the following (7,8):

1. Santa Fe Ten-Pack cars are 10-unit articulated-frame cars, each capable of carrying one 45- or 40-ft trailer. Construction is lightweight: 42 700-lb tare weight per pair of trailers versus 68 000 lb for equivalent conventional two-trailer flatcar.
2. Trailer Train Prototype cars are two-unit short-frame cars, each capable of handling one 45-ft, or shorter, trailer. Construction is lightweight: estimated 50 000-lb tare weight per two-unit car.
3. Paton Low-Profile cars are six-unit, articulated, low-profile frame cars capable of handling 45- or 40-ft trailers as well as 20-, 35-, and 45-ft containers. Construction is lightweight: approximately 50 000-lb tare weight per pair of trailers.
4. Bi-Modal Corporation Roadrailers are highway trailers, each equipped with one pair of steel flanged wheels and couplers for assembly into a train. Tare weight is 17 200 lb/unit but eliminates the need for a railcar.
5. Southern Pacific Double-Stack cars are three-unit depressed-center cars capable of handling six 40-ft containers. Construction is lightweight: estimated 40 000-lb tare weight per pair of containers.

One example of the implementation of these equipment innovations is the "Ten-Packer". Because of tests that indicate fuel savings of 6000 gal/round trip for 100-trailer Ten-Packer trains between Los Angeles and Chicago, the Atchison, Topeka, and Santa Fe (AT&SF) Railroad has increased its commitment to this new equipment. Ten-Packer cars are currently being constructed for four additional trains to ply this Santa Fe route. The improved energy efficiency of this equipment has been further verified by the FRA wind-tunnel tests, which indicate an 11 percent decrease in wind resistance over conventional piggyback operations (7,9). In addition, the Ten-Packer cars are 35 percent lighter than conventional piggyback flatcars and require one less locomotive per 100-trailer train. Use of the Davis formula with modifications based on the FRA wind-tunnel tests indicates that this equipment has a fuel advantage of about 15 percent, which closely corresponds to the AT&SF stated fuel savings (9).

Even greater savings have been claimed for the Bi-Modal Corporation Roadrailers, which combine lower aerodynamic resistance verified by FRA wind-tunnel tests (7) with much lower tare weights to produce an estimated 50 percent fuel-consumption savings over conventional TOFC/COFC operations. An FRA study due by the end of 1981 will estimate the energy intensities of this and other piggyback equipment innovations. However, there has been an analysis of the relative energy uses of these types of equipment by the manufacturer of the Roadrailer. That analysis used the Davis formula and was conducted prior to the FRA wind-tunnel tests by using estimates of bearing, mechanical, and aerodynamic resistance coefficients. The estimated coefficients, train consists, and operational energy intensities of the conventional and innovative dedicated piggyback train types at 60 miles/h with a 15-mile/h head wind on level terrain are given in Table 4 (8). All of the innovations except double-stack container cars show substantial energy improvements.

On the other hand, these equipment innovations have certain disadvantages that will tend to inhibit their acceptance and the realization of their potential energy savings. Another independent effort in the FRA Intermodal Freight Program identified the disadvantages of each of the innovative equipment types (10). Space does not permit delineation of these disadvantages here.

Improved operating procedures can also decrease piggyback energy use. A number of measures for saving energy in TOFC/COFC line-haul operations were developed during the FRA program and presented at the Intermodal Technology Conference in Chicago in late 1979. Some of these measures that could be applied to all rail operations include decreasing train speed and increasing acceleration rates in order to travel at a constant speed for the longest possible time. The measures specific to piggyback operations were having all trailers in the train consist facing forward and reducing gaps between trailers to as close to zero as possible to reduce

Table 4. Dedicated piggyback train consists, resistance coefficients, and Davis formula energy intensities.

	Type of Equipment					
Train Characteristic	Conventional	Santa Fe Ten Pack	Trailer Train Prototype	Paton Low Profile	Southern Pacific Double-Stack	Bi-Modal Corporation Roadrailer
Piggyback cars						
Number	22	40	40	40	22	0
Weight (lb)	68 000	21 350	25 000	25 000	40 000	-
Number of locomotives	2	2	2	2	2	1
45-ft trailers[a]						
Number	38	36	36	36	40[a]	36
Empty weight (lb)	11 500	12 000	12 000	12 000	6 500[a]	16 500
Avg loading						
Number	38	34	34	34	38	34
Weight (lb)	36 000	40 235	40 235	40 235	36 000	40 235
Resistance coefficients						
Bearing (lb/ton)	3.06	3.06	3.06	3.06	3.06	3.0
Mechanical [lb/ton/(mile/h)]	0.032	0.031	0.031	0.031	0.029	0.021
Aerodynamic [lb/(mile/h^2)]	0.081	0.040	0.045	0.040	0.210	0.030
Energy intensity[b,c] (Btu/ton mile)	814	723	770	733	1358	456

[a] 40-ft containers.

[b] At 60 miles/h and 15-mile/h head wind on level, straight grade.

[c] Space does not permit full presentation of the Davis formula variation used here to calculate energy intensities. However, it can be summarized by stating that total resistance equals the sums of weight- and velocity-dependent mechanical resistances plus aerodynamic resistances.

drag resistance. Both of these latter improvements to TOFC/COFC operations can also be used by conventional mixed and dedicated trains. In addition, truck operators are already striving to improve the energy efficiency of their operations, which will tend to counterbalance piggyback operational improvements and prevent increases in the energy advantage of piggyback.

Summary

This discussion has described three categories of piggyback traffic that represent three levels of energy efficiency. It illustrates why this paper uses a preliminary estimate of the energy advantage of current conventional dedicated TOFC/COFC operations without equipment innovations or operating improvements to develop projected piggyback energy savings. Two sets of forecasts of growth in piggyback traffic are presented below, followed by projections of energy savings.

PROJECTIONS OF GROWTH IN PIGGYBACK TRAFFIC

Transamerica Interway, Inc.

A recent study for Transamerica Interway, Inc., has projected growth in piggyback traffic through 1990 (2). Like the Argonne National Laboratory projections, which are also discussed in this paper, it uses scenarios. Based on a 1979 base volume of 3.2 million trailer loads, differing assumptions concerning intercity freight market growth and penetration, energy prices, reduced regulation, and TOFC/COFC service levels are used to form the scenarios given below (2):

Scenario (growth level)	Trailer Loads (000 000s) 1979	1990	1979-1990 Growth Rate (%)
Low	3.2	4.5	3
Medium	3.2	5.3-5.5	4.5-5.0
High	3.2	10-12	12

A key assumption is the estimate of the eligible market for piggyback. The estimate, based on an analysis of the 1972 Census of Transportation, is that TOFC/COFC is suitable for moving about 10 percent of total intercity freight and has only captured about 10 percent of that eligible market. This share is about the same today due to the 3 percent annual growth rate of piggyback during the 1970s, which roughly equaled overall intercity traffic growth. In determining the eligible or maximum piggyback market, which the study correctly cautions will be nearly impossible to capture, unsuitable items are excluded, such as high-valued air freight shipments, pipeline movements, average shipment sizes greater than 60 000 lb [which exceed maximum single-trailer loads (multiple-trailer loads are assumed to be minimal)], and movements over distances of less than 200 miles (2).

The conservative scenario assumes an annual growth rate of 3 percent to a level of 4.5 million trailer loads by 1990. An aggregate growth rate of 4 percent in industrial production was assumed. In this scenario, no major changes are forecast in piggyback pricing or service levels, nor is a recession forecast during the period. It was observed that a recession would lower even this conservative forecast because TOFC/COFC growth has historically been quite sensitive to recessions (2).

The medium-growth scenario, which assumed significant 300-400 percent increases in fuel prices but no significant increases in piggyback service, projects annual TOFC/COFC growth rates of nearly 5 percent for a 1990 volume of 5.3-5.5 million trailer loads. The most optimistic scenario projects annual growth rates of 11-13 percent and 1990 volumes of 10-12 million trailer loads. The study indicated that the main factor driving this high-growth scenario is improvement of currently slow and unreliable service levels, although 300-400 percent increases in fuel prices were also assumed. Specifically, shipper interviews and analysis indicated that the high growth rate would require improving piggyback service levels to approach those of trucks in longer-haul corridors (>500 miles). A survey in one such corridor indicated that current piggyback service averages 7 days for delivery with a 95 percent assurance of delivery within 12 days. Analysis of shipper responses indicated that reducing the average piggyback delivery time to 4 days with 95 percent assurance of delivery within 7 days would cause significant traffic shifts to piggyback from trucks, which have a 3-day average delivery time and a 95 percent assurance of delivery within 5 days (2).

It should be noted that the FRA Intermodal Freight Program has developed several techniques for improving service levels. They are presented here because they represent ways to achieve the service levels assumed in the high-growth scenario. Recommended improvements designed to save time in piggyback terminal operations, where most bottlenecks occur, include

1. Dedicated intermodal yards in which dedicated line-haul piggyback engines originate and terminate (where facility layouts allow);
2. Improved intermodal-yard switching service (dedicated switch engines, if possible);
3. Establishment of yard layouts with separate inbound and outbound traffic lanes to eliminate congestion;
4. Separate lots for parking inbound and outbound trailers and containers;
5. Organized, planned traffic flows in intermodal yards with proper traffic signs to minimize distances traveled by trailers and containers; and
6. Immediate notification to consignees of railcar arrivals, preferably before trailers are grounded, which could allow more pickups at trackside and also reduce congestion and handling costs at terminals (11).

These scenarios to 1990 are presented to provide data that can be compared with the Argonne National Laboratory forecasts discussed below.

Argonne National Laboratory

The Argonne National Laboratory (ANL) projections of piggyback market potentials, market penetrations, and energy savings presented in this paper are an outgrowth of ongoing work for DOE. These forecasts are based on an analysis of intercity truck-market data instead of the 10 percent of the overall intercity market used to develop the Transamerica Interway scenarios. The truck market was used as the starting point for two reasons: (a) It was easier to focus on traffic that had packaging characteristics amenable to piggyback, and (b) bulk commodities were excluded more easily.

Definition of Two Potential Piggyback Markets

The ANL forecasts of the potential TOFC/COFC markets were developed by using projections of motor-carrier activity (i.e., ton miles) by commodity sector and truck size [taken from work in progress by Knorr and Millar to update their 1979 report (12)]. Two estimates were developed for use in the market-penetration scenarios. The pessimistic or constrained market estimate (market A) represents the core of traffic that piggyback might reasonably expect to penetrate given current service levels and moderate increases in fuel prices. The optimistic market estimate (market B) reflects the universe of traffic that TOFC/COFC could technically penetrate, given significantly improved service levels and large increases in fuel prices. However, the probability of achieving market level B is virtually zero. Only in an extreme case in which the gross national product, and thus freight traffic, were significantly greater than in the projected baseline could market level B be achieved.

Market A is based on the assumption that piggyback service is most feasible for commodities that tend to be transported in "dry vans" (i.e., conventional enclosed truck trailers). This market was projected by using data on dry-van shares of total shipments (in tons) by commodity sector from the 1967 and 1972 Commodity Transportation Surveys (13). Dry vans transport a significant share (20-70 percent or more) of total shipments of food, chemicals, stone, clay and glass, pulp and paper, and fabricated metals. These sectors do not represent the actual TOFC/COFC market because some shipments in these sectors are not applicable to piggyback service and some shipments in other sectors are applicable. However, they do represent a significant enough share of that market to be indicative of its current and future magnitude. Thus, market A should be viewed as an estimate of potential market size and not an estimate of market composition.

Market B is based on the assumption that piggyback service is applicable to all intercity heavy-heavy (i.e., class 7 and 8) truck traffic. By limiting this market estimate to intercity ton miles, market B excludes most short-haul, obviously inapplicable, traffic. Although it may include some shorter-haul traffic, this is assumed to be a relatively small portion of the total, since the market is defined in terms of ton miles, not tons. Similarly, it may include small amounts of some bulky, not easily containerized movements. For these reasons, market B is considered to be the high estimate of the potential TOFC/COFC market.

These conceptual market definitions were translated into trailer loads by using projections of truck ton miles developed by ANL, by commodity sector in the case of market A and by intercity heavy-heavy trucks in the case of market B. For market A, ANL projections of truck mode shares were also examined. With the exception of fabricated metals and one of the food sectors, truck shares of total ton miles in all sectors are less than 35 percent. This suggests relatively long average lengths of haul, which would tend to make piggyback an attractive alternative.

For both market projections, piggyback potential was estimated as

$$\mathrm{TRM} = \mathrm{TMT}/(\mathrm{LOH} \times \mathrm{LF}) \qquad (1)$$

where

TRM = trailer-load market;
TMT = total ton miles projected for the market;
LOH = average piggyback length of haul, assumed to remain constant at 1013 miles (2); and
LF = average load per piggyback trailer, assumed to remain constant at the 1979 level of 15.9 tons (4).

The following table displays the potential trailer-load markets calculated in this manner:

	Market A		Market B	
Year	Ton Miles (billions)	Potential Trailer Loads (millions)	Ton Miles (billions)	Potential Trailer Loads (millions)
1980	138.7	8.6	325.7	21.9
1990	176.7	11.0	507.7	31.5
2000	218.5	13.6	684.6	42.5

Although it may be argued that LOH will decline over time as TOFC/COFC penetrates shorter shipment segments, recent FRA research indicates that the overall LOH for piggyback traffic has increased from 921 miles in 1972 to 1013 miles in 1976. The research found that this increase was due largely to significant increases in traffic traveling over distances greater than 1500 and 2000 miles (4). Until piggyback completes its penetration of these long-distance segments, LOH may be expected to increase. Since a parametric analysis indicated that any net change in LOH over the forecast period is likely to be small, a constant value was assumed.

Piggyback Market-Penetration Scenarios

Scenarios for low, medium, and high market penetration were developed by using the above-defined market estimates. The low and medium scenarios are based on market A. Since market A is a subset of market B, penetrations also occur in market B, although to a much more limited extent than in market A. The high scenario assumes penetration occurs in both market A and the non-A portion of market B. Trailer-load projections by scenario are given below:

Scenario (level of market penetration)	Projected Trailer Loads (billions)			1980-2000 Average Annual Growth (%)
	1980	1990	2000	
Low	3.4	4.4	5.4	2.3
Medium	3.4	5.5	8.1	4.4
High	3.4	8.1	13.8	7.3

In the low scenario, piggyback remains at the 1980 market share of market A--i.e., 40 percent. This assumption results in a piggyback projection of 4.4 million trailer loads in 1990, which grows to 5.4 million by the year 2000.

In the medium scenario, piggyback service is assumed to penetrate an increasing proportion of market A. Growing from 40 percent of market A in 1980 to 50 percent in 1990 and 60 percent in the year 2000, piggyback trailer loads increase to 5.5 million in 1990 and 8.1 million in the year 2000. On an annual basis, this growth rate is 4.4 percent, or slightly higher than the 3 percent growth rate of the 1970s. It is assumed to occur as a result of moderate increases in already high fuel costs and moderate service improvements, including some use of innovative equipment.

In the high scenario, significantly improved service levels, including a high level of use of innovative equipment, coupled with rapidly escalating fuel prices, results in much higher market-penetration rates. Penetration of 55 percent of market A plus 10 percent of the remainder of market B is assumed in 1990. In 2000, 70 percent penetration of market A plus 15 percent of the remainder of market B is assumed. (These penetration rates equate to 26 percent of all of market B in 1990 and 33 percent of it in 2000.) This results in high-scenario projections for piggyback of 8.1 million trailer loads in 1990 and 13.8 million trailer loads in 2000.

Table 5. Potential piggyback energy savings for 1981-2000 estimated by ANL.

Level-of-Growth Scenario	Potential Diesel Fuel Savings (millions of barrels)				
	1990	Cumulative 1981-1990	2000	Cumulative 1991-2000	Cumulative 1981-2000
Low	9.7	86.9	11.9	109.1	196.0
Medium	12.2	98.4	17.9	151.5	249.9
High	18.9	128.9	30.5	242.9	371.8

Piggyback Energy Savings by Scenario

Although these ANL projections give reasonable approximations of potential energy savings, it should be noted that they are preliminary for the reasons cited earlier. The cumulative estimates presented in Table 5 were developed for each scenario by determining annual piggyback energy savings and summing them over the two decades. Annual energy savings were estimated as

$$ES = TRM \times LOH \times LF \times EUA \quad (2)$$

where ES is annual energy savings and EUA is the 800-Btu/ton mile piggyback energy advantage over trucks.

Using this advantage over the 20 years assumes that overall rail and truck energy efficiencies will both improve over the period but that the difference between them will remain constant. Over the two decades, piggyback energy savings are estimated at about 200 million bbl of diesel fuel under the low scenario; this increases to 250 and 370 million bbl under the medium and high scenarios, respectively. Annual levels of savings range from about 10 million bbl in 1990 under the low scenario to 30 million bbl in the year 2000 under the high scenario.

Applying the nondefinitive 800-Btu/ton mile advantage of conventional dedicated piggyback trains to all TOFC/COFC traffic provides an expeditious method of approximating the energy savings that can be expected under different scenarios without implying false levels of accuracy. However, it does not relate energy savings to the level of service provided. Therefore, a sensitivity analysis was conducted in which two different service levels--high and low--were assumed (i.e., different traffic shares for piggyback movements in mixed consists, conventional dedicated consists, and dedicated consists using innovative equipment).

The low-service-level scenario involves little change from current service levels and only minor decreases in the share of traffic traveling in less energy-efficient mixed consists. It also assumes low penetration of more energy-efficient innovative equipment into the relatively static dedicated train share. The high-service-level scenario projects more significant decreases in mixed-consist piggyback movements and greater penetration of the growing dedicated train share by innovative equipment. It also assumes more modest improvements in service time than those postulated in the Transamerica Interway high-growth scenario. Table 6 presents these service scenarios.

Different energy advantages were assumed and applied to the different forms of piggyback trains. These were (a) zero mixed consists (see the discussion at the beginning of this paper on piggyback cars in conventional trains), (b) 800 Btu/ton mile for conventional dedicated trains, and (c) 880 Btu/ton mile for dedicated trains with innovative equipment (Table 4). These assumptions had the effect of projecting higher estimated energy savings as the level of service increased. They also offset

Table 6. Sensitivity assumptions of shares of piggyback traffic by type of train for two level-of-service scenarios.

Level-of-Service Scenario	Traffic Share by Type of Train (%)					
	1990			2000		
	Mixed	Conventional Dedicated	Innovative Dedicated	Mixed	Conventional Dedicated	Innovative Dedicated
Low	15	80	5	10	85	5
High	10	75	15	5	75	20

the higher energy savings of innovative equipment versus the lack of savings achieved by piggyback cars in mixed consists.

The sensitivity analysis resulted in slightly lower energy-savings estimates than those given in Table 5. For the low-service-level and low-growth scenario, the savings between 1980 and 2000 were 12 percent lower than those for the low-growth scenario given in Table 5. For the high-service-level and high-growth scenario, the energy savings over the two decades were 6 percent lower. However, these findings, like those in Table 5, are strongly dependent on nondefinitive (though reasonable) estimates of piggyback energy advantages. They should, therefore, be considered strictly as a sensitivity analysis and not a refinement of Table 5 estimates.

SUMMARY AND CONCLUSIONS

Based on the limited research results available, this paper has developed reasonable approximations of the energy advantages of piggyback traffic over trucks. It has also presented scenarios of projected TOFC/COFC growth that were developed independently by Transamerica Interway, Inc., and ANL. The ANL scenarios have been used to estimate potential piggyback energy savings through the year 2000.

The ANL energy-savings estimates are significant but not overwhelming, even in a high-growth scenario. For example, the highest annual savings are 30 million bbl in the year 2000 high-growth scenario. This amounts to less than two days' supply (less than 0.5 percent of annual needs) at the current U.S. oil-consumption rate of about 16 million bbl/day. Nevertheless, these savings are definitely worthwhile, especially since they are in petroleum, where U.S. energy scarcity problems are the most pressing.

In addition, it is important to realize that, although potential energy savings are generally smaller in freight than in passenger transportation, they do add up and should be pursued. Even at the current oil price of $35/bbl, which is likely to rise faster than inflation, the value in 1980 constant dollars of the cumulative energy savings projected here range from $7 billion in the low scenario to $13 billion in the high scenario. The main conclusion of this paper, therefore, is that shifting traffic from trucks to piggyback is definitely an attractive energy-conservation option worth considerable effort.

ACKNOWLEDGMENT

I am grateful to Marianne Millar and Rita E. Knorr for their development of the ANL total truck-market and potential piggyback-market projections used in this paper. Additional appreciation is extended to Ms. Millar for her help in both constructing the scenarios for piggyback market penetration and conducting the sensitivity analysis of level-of-service impacts on potential energy savings.

This effort was supported by E.W. Gregory II of the Office of Transportation Programs of DOE.

REFERENCES

1. A.B. Rose. Energy Intensity and Related Parameters of Selected Transportation Modes: Freight Movement. Oak Ridge National Laboratory, Oak Ridge, TN, Rept. ORNL-5554, June 1979.
2. Booz-Allen and Hamilton, Inc. Piggyback: The Efficient Alternative for the 80's. Transamerica Interway, Inc., New York, March 1980.
3. Carload Waybill Statistics Based on a Sample of Waybills for Terminations in the Year 1976: Territorial Distribution, Traffic, and Revenue by Commodity Classes. Federal Railroad Administration, 1977.
4. Peat, Marwick, Mitchell, and Company. Systems Engineering for Intermodal Freight Systems: Phase I--Exploratory Planning. Federal Railroad Administration, Vol. IV, July 1978.
5. Intermodal Fuel Consumption Comparisons. Office of Transportation Programs, U.S. Department of Energy, Memorandum, Jan. 9, 1980.
6. A.G. Hammitt. Forces on Freight Trains: Volume I--Wind Tunnel Tests of Containers and Trailers on Flatcars. Federal Railroad Administration, Dec. 1976, pp. 4-7.
7. Hammitt Associates. Aerodynamics Forces on Freight Trains: Volume IV--Wind Tunnel Tests of Freight Cars and New Trailer and Container Car Designs. Federal Railroad Administration, June 1979.
8. The Roadrailer: Opportunities. Bi-Modal Corp., Greenwich, CT, Nov. 1978.
9. Development of Train Resistance of Roadrailer Trains, Plus Brief Comparisons to Alternative TOFC/TOAC Trains. Bi-Modal Corp., Greenwich, CT, Nov. 1979, Appendix A, pp. 4-5.
10. R.H. Leilich. Economics of Improved TOFC/COFC Systems. TRB, Transportation Research Record 721, 1979, pp. 6-11.
11. A.T. Kearney, Inc. Presentation at Intermodal Technology Conference, Chicago, Oct. 8-9, 1979. Federal Railroad Administration, 1979, pp. 6-8.
12. R.E. Knorr and M. Millar. Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline. Argonne National Laboratory, Argonne, IL, ANL/CNSV-4, Aug. 1979.
13. A.D. Bourquard. Forecasting Rail Piggyback Traffic. Presented at 58th Annual Meeting, TRB, 1979.

Publication of this paper sponsored by Committee on Energy Conservation and Transportation Demand.