Energy and the Environment: The Railroad Perspective

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The railroad industry is becoming increasingly more competitive, both among its members and with the trucking industry. The number of railroad industry revenue ton-miles has grown steadily during the past 6 years. This growth has been accomplished by reducing costs considerably and paying more attention to the needs of customers. Overall, the results have been improved profitability and increased shareholder return. Even so, the railroad industry still does not earn its cost of capital.

Railroad transportation, like other modes of transportation, consumes large amounts of diesel fuel and therefore generates nitrogen oxide emissions. On a ton-mile basis, however, railroads generate lower emissions of essentially all pollutants than do trucks. Railroads produce insignificant levels of pollutants, with the exception of nitrogen oxide.

Proposed U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) locomotive emission regulations will add substantial costs for the industry. Little information is available on how best to achieve compliance with the regulations now under consideration. Numerous options are available to reduce locomotive emissions, but each varies tremendously in potential costs. Diesel engine improvements now being developed may be sufficient to meet short-term emissions goals, but it is unclear how the industry will meet the long-term standards being considered. Locomotive changes under consideration include the use of such energy sources as natural gas, methanol, electrification, and hydrogen (fuel cells).

Considerably more research will be required before railroads and regulatory agencies decide on the appropriate long-term standards and the means to achieve compliance. The wide spectrum of research needs means that many diverse groups such as railroads and suppliers, as well as government agencies, national laboratories, and universities, have important research roles. National goals for both energy and environmental quality may be affected by the chosen solutions.

Energy, a Strategic Railroad Resource

Energy, a strategic interest for railroads today, has been a concern since the beginning of railroading. Route engineers were cognizant of the locomotive energy requirements when they surveyed the track locations of the developing railroads. In 1887, A. M. Wellington reviewed train resistance (*1*). Water-level grades, because they were minimal, were considered ideal, even though they often meant longer mileage. Procuring and distributing sufficient quantities of energy were real problems for early railroads. The use of coal in place of wood was an early breakthrough, but on the Santa Fe Railway, the shift to coal created an entirely new problem, which led to the development of the oil-burning locomotive. Former Santa Fe Railway Chairman of the Board John S. Reed discussed the problems in 1982 (*2*). As the Santa Fe Railway extended to California in the 1880s, the coal for use on the West Coast had to be hauled from the Midwest, approximately halfway across the United States, or shipped by sea around Cape Horn. To resolve this difficulty in obtaining coal, the Santa Fe Railway developed the idea in the 1890s of burning fuel oil in the locomotive boiler. This development may sound simple today, but it was a bold experiment at the time and actually took the lives of several men, who died from explosions and backfires in the locomotive firebox. The U.S. Navy continued to burn coal exclusively for many years thereafter. In addition, the Santa Fe Railway purchased extensive oil properties in California so that it would be self-sufficient for fuel.

Typical of other railroads' concern for energy through the years, the Santa Fe, at least three different times in its history, studied electrification as an alternative to on-board burning of petroleum fuels. The first was in the early 1900s, when petroleum products were thought to be soon depleted. The second time was in the 1940s, when the steam engine could not compete with electric motors and diesel engines or electrified lines for the power source. Finally, the energy cost and supply problems associated with large quantities of petroleum imports and the price requirements of the petroleum-producing cartels of the 1970s prompted a third study. In these cases, the large capital requirements and increases in some operating costs combined with long project life and highly uncertain savings doomed electrification as the preferred motive power. Because of the strategic interest and national energy independence issues, it should not be surprising that railroads and energy agencies continually reassess the energy needs for transportation.

Environmental Impacts From Energy Consumption: an Overview

Some of the environmental impacts from railroads were known relatively early. Much of the benefit from early electrification was to reduce the smoke and particulates associated with steam engines, especially in such urban areas as New York City. These projects occurred as early as 1895 in the United States (*3*). Railroads installed oil and water separators in the 1940s to remove oil and grease from shop wash waters and thereby protect the local water resources. The emphasis on environmental issues has increased to such a level that major railroads now have environmental departments. Remediation of property contaminated by more than 100 years of use, including the use of certain slag and cinder ballast; waste minimization; wastewater treatment; and reduction of railroad impacts on air quality remain important projects for railroad environmental engineers.

Energy and the environment have been interrelated for decades. The generation and consumption of energy have significant environmental impacts, and the reduction of these environmental impacts can change the energy efficiency of a process or piece of equipment. The dilemma posed by this relationship appeared to be either minimization of energy costs at the expense of the environment or protection of the environment at the expense of energy costs.

During the late 1940s and early 1950s, the relationship between air pollution and human health became particularly acute. In Donora, Pennsylvania, between October 27 and October 31, 1948, 20 deaths in an affected population of 13,300 were immediately attributed to the combination of industrial pollution and temperature inversions in the atmosphere. Approximately 40 percent of the residents had some physiological symptom, such as irritation of the respiratory tract. Oxides of sulfur were the most likely culprits (*4*). After similar circumstances occurred in London, England, between December 4 and 9, 1952, about 4,000 persons died within a 2-week period during and following the air pollution episode as a result of exposure to air pollutants mostly from domestic heating fires (*5*).

Many cities instituted vigorous campaigns to reduce air pollution. Industries installed devices to remove pollutants from the stacks. For example, in Pittsburgh, Pennsylvania, between 1946 and 1953, the amount of fly ash and other contaminants was reduced by 46 percent. Weather observations showed that periods of poor visibility caused by pollution were reduced from 1,000 hr/year to 300 hr/year. A major factor was the replacement of steam locomotives by diesel engines on the railroads (6).

Since then, the general role of transportation and energy consumption in creating air pollution has become more quantified. Table 1 presents data on the contribution of various sources (7).

Transportation is the main source of the five major pollutants, particularly carbon monoxide, in the United States. The railroad portion of nitrogen oxide emissions is only 2.8 percent nationwide and less than 0.2 percent each for particulates, carbon monoxide, and hydrocarbons. Although nationwide studies are important, the major impacts of locomotive emissions are manifest at the local level. This is especially true in nonattainment areas in the United States. Nonattainment areas are the areas in which the air quality does not meet health-based standards, and thus people are exposed to levels of air pollutants that can cause disease, injury, or death.

The authors of this paper will explore the current condition of the railroad industry and the role of energy and motive power in determining the health of the industry. The environmental effects arising from energy usage will be discussed in detail. In addition, the alternatives for reducing energy costs and the environmental impacts will be analyzed. Finally, the alternatives for safety and cost attributes will be reviewed briefly.

CURRENT BUSINESS CLIMATE

Characteristics of a Hostile Industry

In 1985, Windermere Associates began a research project to track the evolution of several "hostile" industries (i.e., industries that serve competitive markets). These industries included air express, automatic test equipment, beer, baby diapers, copper, color televisions, tires, and trucking. The purpose of the study was to identify the policies of the few companies that really succeed in tougher times and to compare those policies across industries to highlight patterns of success. The scope included 40 industries and several hundred companies and covered a period from 15 to 30 years. Donald V. Potter, President of Windermere Associates, evaluated the major issues in his article Success Under Fire: Policies to Prosper in Hostile Times (*8*).

The headlines of the 1980s revealed the highly competitive nature of many markets. The extreme competition brought low margins, intense cost controls, and management turmoil. Several large industry leaders failed to survive as independent companies. Potter suggested that the following six phases typify the route of failure for many companies: margin pressure, market share shifts, product proliferation, self-defeating cost reductions, consolidation and

TABLE 1 Estimates of Nationwide Primary Pollutant Sources and Amounts, 1990 (7)

POLLUTANT SOURCE	WEIGHT OF POLLUTANT PRODUCED					
	CO	NO_x	HC	SO_x	Part.	Total
Rail	0.2	0.6	0.1	0.1	0.0	1.0
Other Transportation	41.1	7.7	6.9	0.9	1.7	58.3
Fuel combustion (stationary sources)	8.3	12.3	1.0	18.8	1.9	42.2
Industrial processes	5.2	0.7	8.9	3.4	3.1	21.2
Solid waste disposal	1.9	0.1	0.7	0.0	0.3	3.0
Miscellaneous	9.5	0.3	3.0	0.0	1.3	14.1
Total weight of each pollutant	66.2	21.7	20.6	23.2	8.3	139.8

Note: Data are in millions of tons per year. CO = carbon monoxide, NO_x = nitrogen oxide, HC = hydrocarbon, SO_x = sulfur oxide, Part. = particulate matter.

shakeout, and rescue. The hostility in the marketplace typically arises from expansion of aggressive competition. The expanding competition results from new entrants attracted by the current price structure in the industry. The new entrants typically can compete well with their price, whereas the higher costs of the remaining firms result in returns that become unattractive.

According to Potter, the key to winning in hostile markets is satisfied customers. Management policies that promote reliability create real benefit because reliability is difficult to copy. The winner also reduces the costs of providing benefits to the customer while offering the best value in the market. Losers cut costs by cutting customer benefits. Finally, winners reduce unit costs, thereby creating the most productive cost structure. Units are what customers buy and competitors discount. In many cases, winners add to total costs in order to gain more customer volume over which to spread a somewhat fixed cost structure.

Intercity Freight Transportation: A Hostile Marketplace

The efficient movement of products and goods, both in domestic and foreign commerce, is critical to American competitiveness. For many products, both the raw materials and the finished goods must be transported considerable distances to make the products available to the ultimate consumer. The nation's highway, waterway, pipeline, and air networks all are important in this transportation service. In particular, railroads are major transporters of coal, grain, chemicals, motor vehicles, consumer products, forest products, minerals and ores, and primary metals.

As in most industries, a railroad obtains business whenever the customer chooses that railroad over the competition. A supplier of the transportation service must meet the needs of the customer. In the case of transportation, customers have stated that reliability, price, information, time of arrival, transit time, seamless service, billing accuracy, ease of doing business, electronic data interchange, loss and damage, equipment suitability, sales, and claims are the most important features of the service.

The intercity freight transportation industry now is intensely competitive. Figure 1 shows the intercity freight transportation market for all transport modes in revenue freight ton-miles (9). The total transportation market has grown 16 percent since 1980. The truck market has grown 36 percent, whereas the rail market has grown only 15 percent. In contrast, Figure 2 shows the revenue market share of rail versus trucks (9). Railroad revenues have remained essentially flat for the past 10 years, whereas the growth in gross revenues has accrued to trucking. The combination of these two circumstances means that rail revenues in cents per ton-mile have been declining. Figure 3 shows this trend both in current dollars and constant

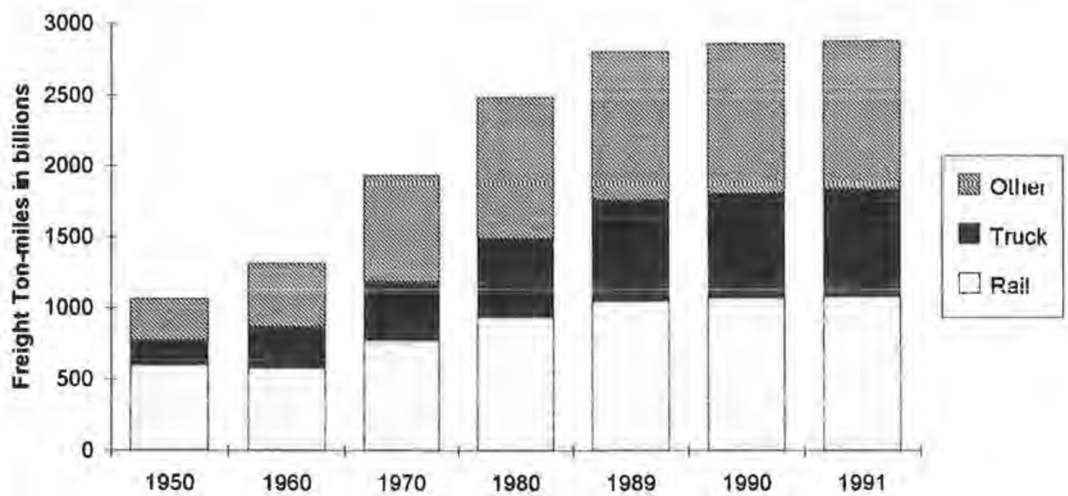

FIGURE 1 U.S. intercity revenue freight ton-mile distribution by mode.

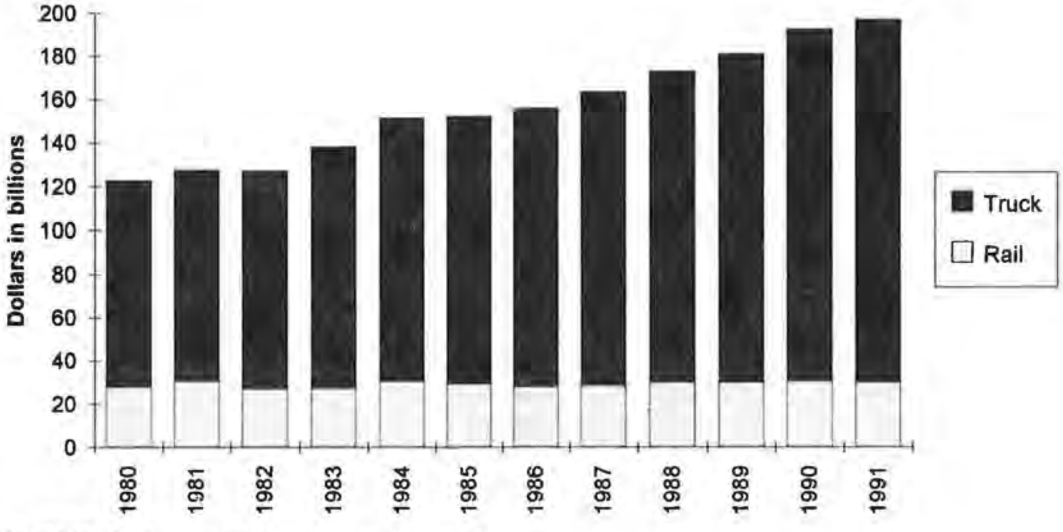

FIGURE 2 Intercity freight revenue by mode.

dollars (*10*). The revenue per ton-mile trend over the past 10 years is an average decline of approximately 2 percent per year in current dollars.

Such long-term downward trends suggest intense competition. The expanding total freight transportation pie is one factor constraining the level of competition. The growth and advantages of intermodalism to the transportation customer and the need to provide seamless and, therefore, convenient service dock to dock means that railroads and trucking firms must cooperate, as well as compete, in the marketplace. Such attributes also tend to constrain the level of competition while maintaining a highly aggressive market.

Railroad Industry Response

Railroads have committed to major programs in quality to focus on customer service and improvement of the overall transportation process. These efforts should improve performance in the many areas affecting the customer. Potter (*8*) believes that a customer's flight to the competition on the basis of quality changes market share more slowly than price discounting, but the change is more permanent. The effect of these efforts on market share and revenues per ton-mile remains to be seen.

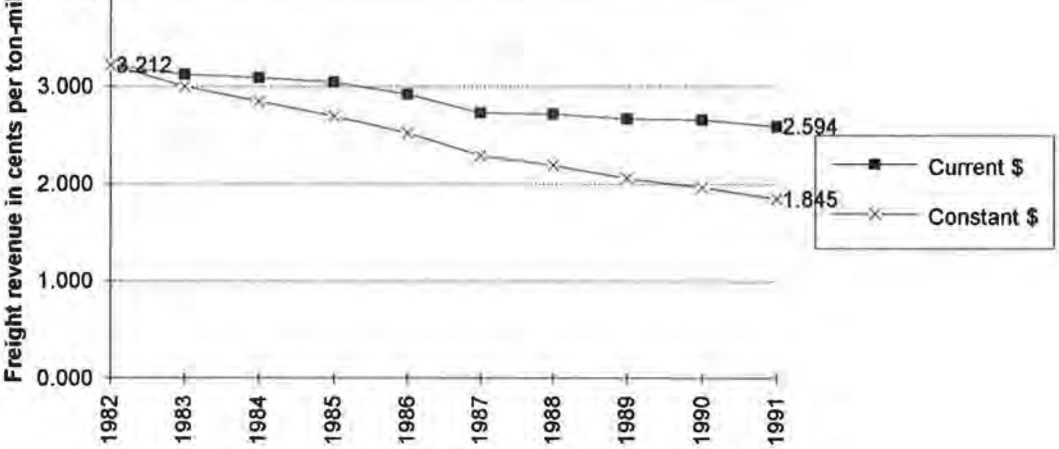

FIGURE 3 Railroad industry average freight revenue per ton-mile.

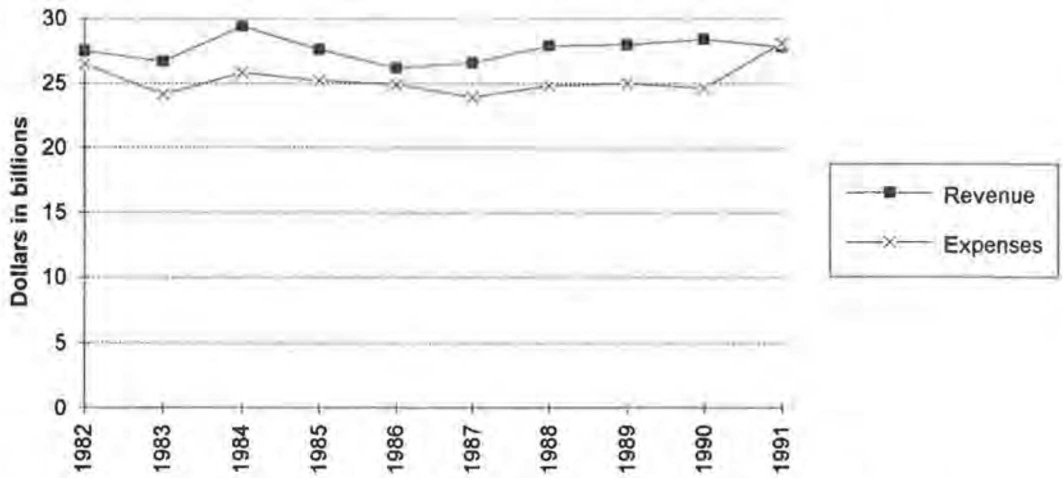

FIGURE 4 Railroad industry average operating revenues and operating expenses.

The railroad industry's ability to survive the downward trend in rates has been the result of a substantial decrease in expenses per ton-mile. Figure 4 shows the comparison between operating revenues and operating expenses for the industry (*10*). Cost containment has kept pace with declining revenues for most years since 1982. Further analysis reveals where the gains in productivity and efficiency occurred. Railroad employment is shown in Figure 5 for the past 10 years (*10*). Employment in the railroad industry dropped 36 percent between 1982 and 1991. Although the use of contracted services has increased, the decrease in employment has meant a large improvement in productivity across a broad set of measures, including revenue ton-miles per employee-hour, as shown in Figure 6 (*11*). Not all of the productivity gains were due to reducing employment. Increasing train size by increasing the average tons per train (Figure 7) was responsible for some of the efficiency improvements (*11*). With respect to energy and the environment, the revenue ton-miles per gallon of fuel consumed improved 40 percent between 1982 and 1991, as shown in Figure 8 (*11*).

Financial Health of Railroad Industry

What have these productivity improvements meant in financial terms? The industry average return on investment is gaining but is still below the cost of capital for the industry. The low

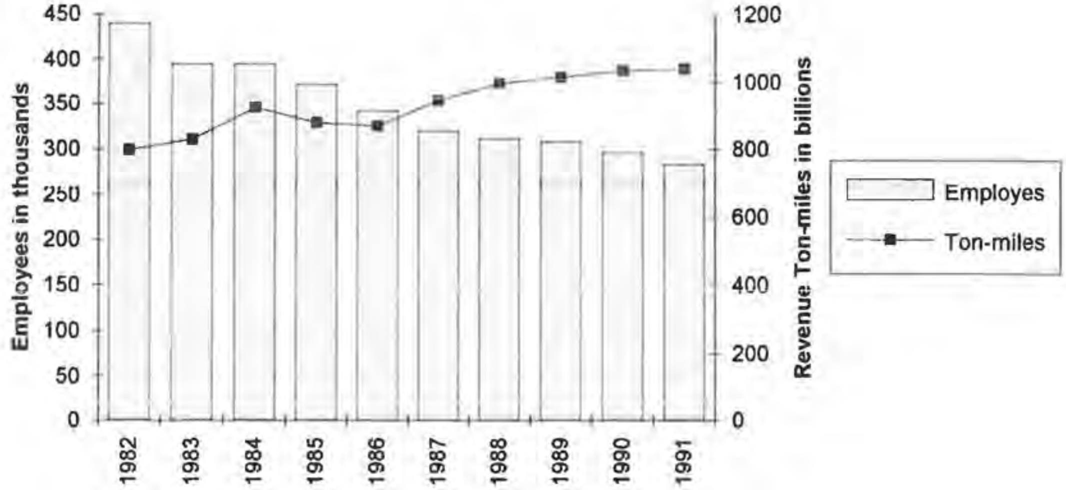

FIGURE 5 Railroad industry total employment and revenue ton-miles.

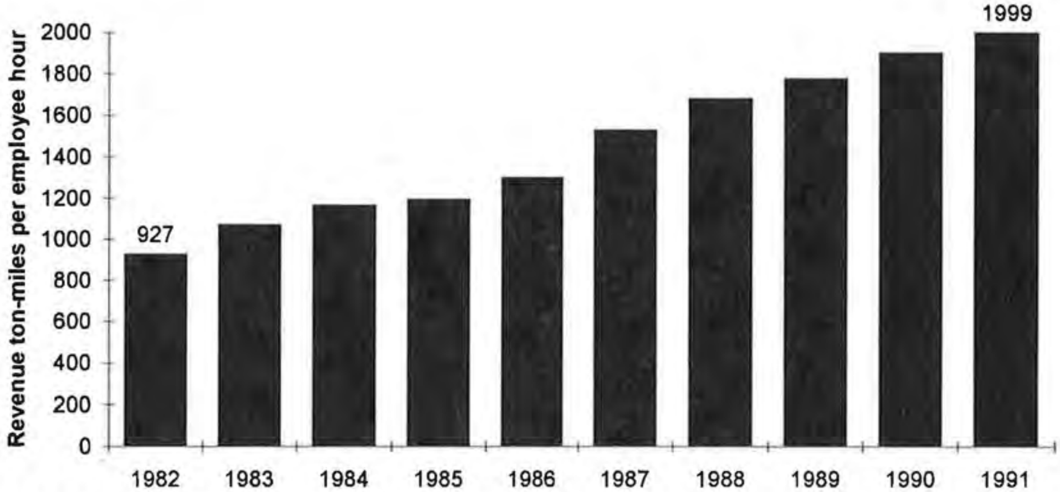

FIGURE 6 Railroad industry average human productivity.

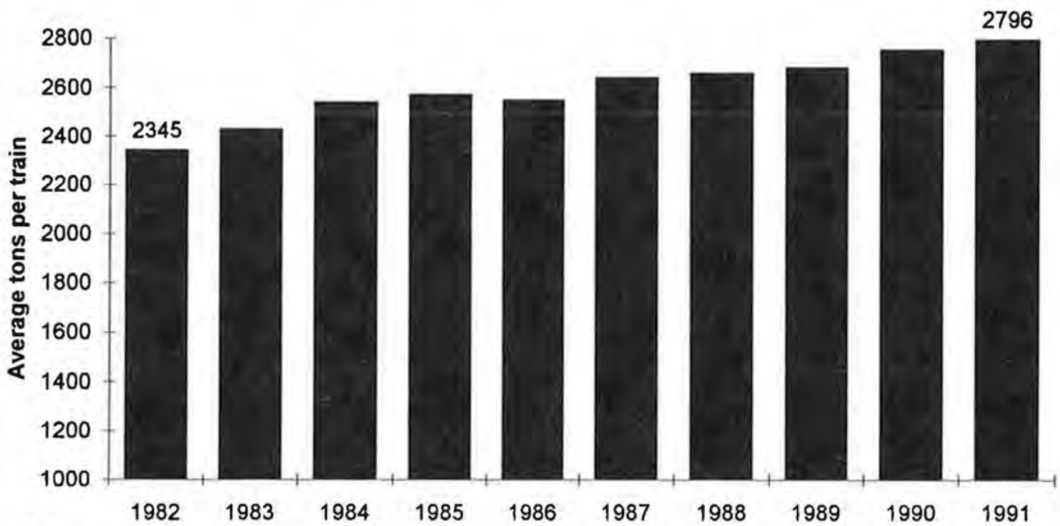

FIGURE 7 Railroad industry average train weight.

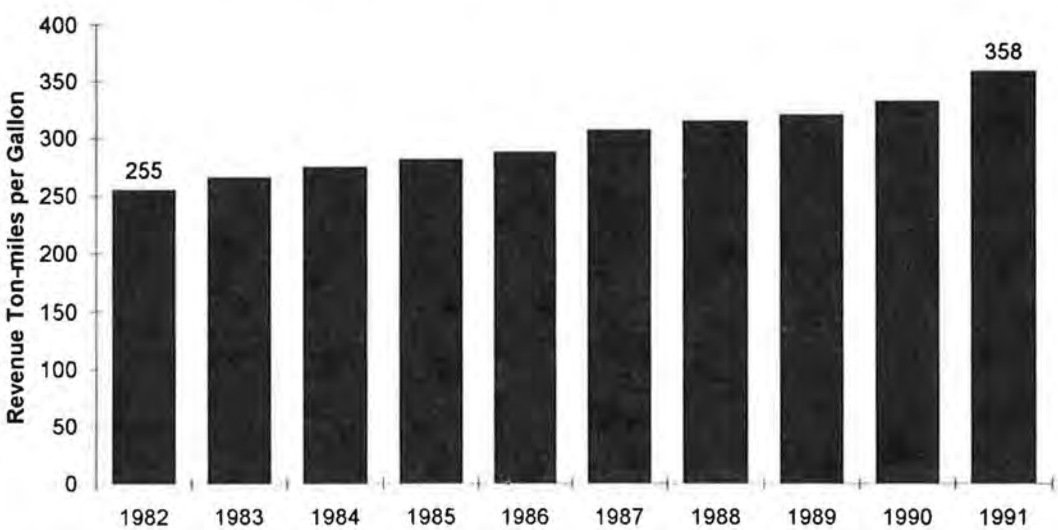

FIGURE 8 Railroad industry average fuel efficiency.

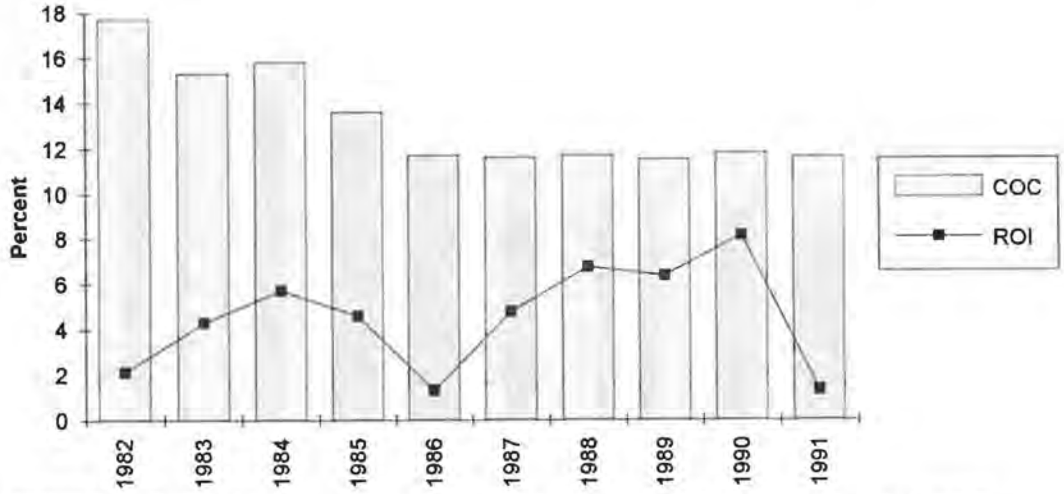

FIGURE 9 Railroad industry average return on investment (ROI) and cost of capital (COC).

inflation rate in the U.S. economy in recent years, along with refinancing of much of the railroad's debt, has lowered the cost of capital to nearly 11 percent from 18 percent in 1982, as shown in Figure 9 (*11*). In addition, the sale of underused fixed assets, such as noncore trackage sales to short lines, together with improved locomotive fleet use and overall cost containment, have lead to steadily improved profits in the industry in recent years.

Although shareholders' return on equity is not as great for the railroads as for regulated utilities (pipelines and electric companies) or the chemical or pharmaceutical industries, railroad returns have improved since 1982, as shown in Figure 10 (*11*). Such improvement must continue for railroads to be the transportation solution for the future.

The Future

A key characteristic of the near term appears to be a continuing 2 percent annual decline in revenues per ton-mile. As noted by Potter (*8*), participants in hotly competitive industries need to be careful not to engage in self-defeating cost reductions. Railroads must avoid cutting costs in ways that impair their ability to satisfy customers. According to Potter, these impairments

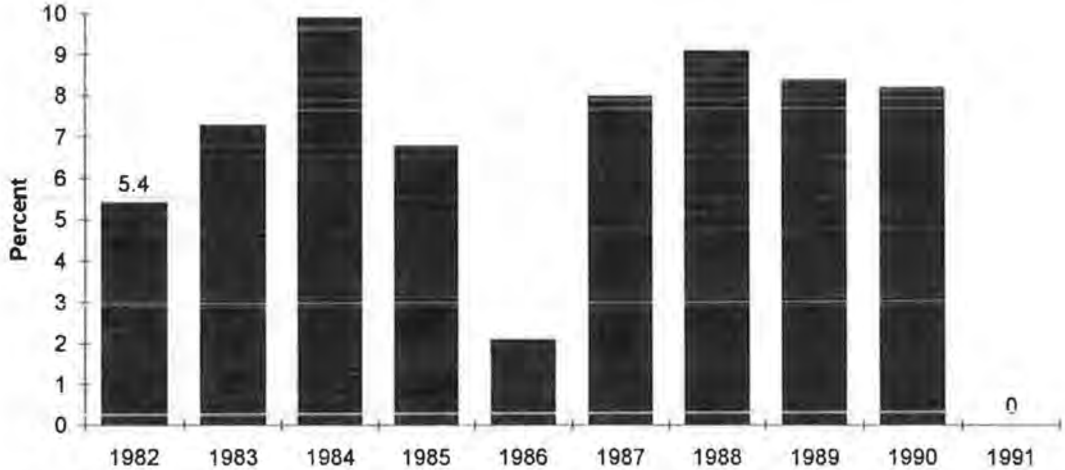

FIGURE 10 Railroad industry average return on shareholder equity.

typically fall into three categories: feature failure, quality slippage, and distribution conflicts. For railroads, failure to keep pace with improving quality standards demanded by shippers may be the most damaging.

Until unit revenues improve, railroads must continue cost containment efforts in line with the steadily decreasing revenue per ton-mile; however, operating cost reductions must not lead to customer dissatisfaction. This is why quality improvement processes are so important and why railroad research is critical. This and future conferences must focus on the strategic needs of the railroads to make them more competitive and define the research that can help propel the industry toward significantly improved customer focus and substantially reduced operating costs. For instance, on Santa Fe, motive power costs, including maintenance and depreciation, consume approximately 10 percent of freight revenues (*11*). Locomotive diesel fuel oil consumes approximately 10 percent of freight revenues (at roughly $0.65/gal). Assuming that revenues per ton-mile continue to decline by 2 percent annually, each cost center has to be cut by 2 percent. Therefore, with annual revenues of more than $2 billion, Santa Fe motive power maintenance costs and fuel costs combined must be reduced by $10 million each year to compensate for the reduced revenue. Attracting new business will require even more improvement. It should be obvious that long-term survivability eventually depends on stabilizing or increasing revenue per ton-mile. This increase or stabilization will occur when railroads reduce their cost structure so that competitors no longer enter the market and when the railroads provide quality service to the customer.

ENERGY CONSUMPTION IN RAIL TRANSPORTATION

Importance to Railroads

After dieselization in the late 1940s and the early 1950s and the resultant greater convenience of energy handling and the greater range of the locomotives between fueling points, railroads became less concerned with fuel. During the 1970s, when severe disruptions occurred in the supply, the cost of diesel fuel increased dramatically. The price for diesel fuel to the railroads in the 1950s and 1960s was approximately $0.10/gal. By 1975, the price was $0.30/gal; it increased to $1.00/gal in 1981 (*10*). The price has since been as low as $0.49/gal (in 1988). Railroads' attention to energy efficiency and consumption increased with the cost of fuel.

In addition, railroads began recognizing that improvement in fuel efficiency was important and the comparison with the fuel efficiency of trucks was equally important in the overall transportation marketplace. In 1981, when fuel represented 12.5 percent of operating revenues for railroads and substantially more for trucking companies, fuel became a strategic factor. Today, locomotive fuel consumes 7 percent of operating revenues and costs nearly $2 billion annually industry wide.

Railroad energy consumption can be reduced in three major ways: shutdown of idling locomotives, reduced train resistance, and improved locomotive efficiency. During the late 1970s and throughout the 1980s, all three methods were examined and used to reduce fuel consumption. Locomotive manufacturers began making locomotives more fuel efficient. In addition, railroads, especially through the Association of American Railroads (AAR) research program, began investigating ways to reduce consumption. New railroad equipment such as the lightweight and aerodynamic intermodal car became commonplace, as did such new concepts as locomotive-mounted wheel-rail lubrication.

These fuel efficiency improvements enable the industry to reduce average fuel consumption annually. The industry average fuel consumption during the past 10 years is shown in Figure 11. The industry average fuel consumption on a ton-mile basis is shown in Figure 8. The decline is approximately 2.5 percent per year in the short term. As noted earlier, all things being equal, the fuel consumption per ton-mile per year must decline by at least the same 2 percent annual decline in revenue per ton-mile.

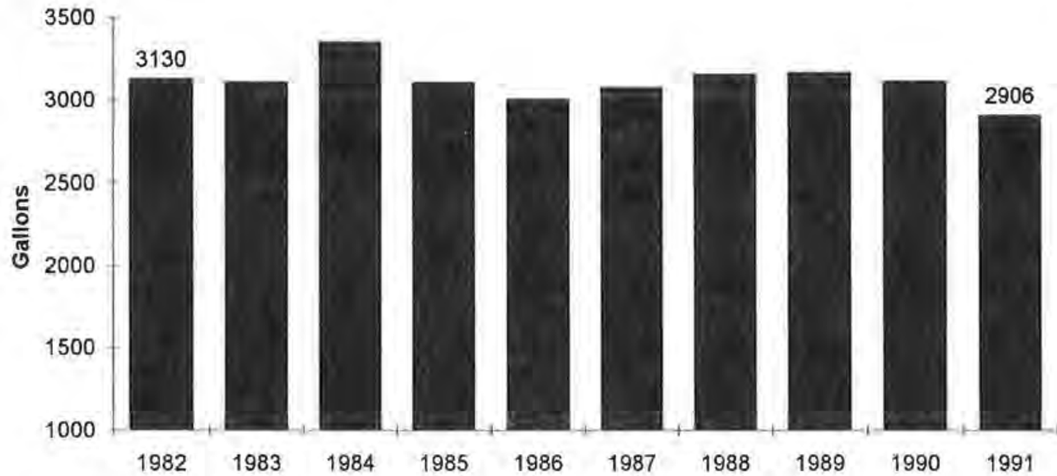

FIGURE 11 Railroad industry total annual diesel fuel oil consumption.

Comparison with Trucks

Abacus Technology Corporation, under contract to the Federal Railroad Administration (FRA) of the U.S. Department of Transportation (DOT), studied rail and truck fuel efficiencies (*12*). Trucks in rail competitive businesses achieve 84 to 135 lading ton-mi/gal. By comparison, in 1990 the railroad industry averaged 332 revenue ton-mi/gal (*10*). Thus railroads' average fuel efficiency is 2.5 to 4 times greater than that of trucks. The Abacus Technology Corporation study compared rail and truck fuel efficiencies on a route- and commodity-specific basis. The comparisons included 60 mi of rail switching or 60 mi of drayage added to each of the rail moves. The truck fuel consumption in the long-distance routes was 1.72 to 5.16 times the railroad fuel consumption on a lading ton-mile per gallon basis.

The Argonne National Laboratory Center for Transportation Research, Energy Systems Division, in 1990 forecast energy demand by mode of transportation through 2010 (*13*). The assumptions for this forecast included substantial improvement in the overall fuel efficiency of trucks. Improved engines, aerodynamics, tires, engine lubricants, and transmissions could yield a 40 to 50 percent overall improvement in fuel efficiency. The truck savings outlined amount to approximately 4 percent per year. Accordingly, a railroad fuel savings of only 2 to 2.5 percent does not keep pace with the competition.

Locomotive Shutdown

The shutdown of idling locomotives is an important means of conserving fuel. Locomotives consume 3 to 5 gal/hr when idling. Because locomotives do not have antifreeze in the radiator cooling water, the engines cannot be shut down in freezing weather without draining the cooling water. Many railroads have policies that if locomotives will not be used within 2 or 3 hr and the temperature will remain above 40°F, the locomotive will be shut down. In most areas of the United States, locomotives can be shut down much of the time when not in use. In 1992, Santa Fe saved 4.2 million gal of fuel by shutting down idling locomotives.

Train Resistance Research

Railroads funded millions of dollars in train resistance research for several years in the mid-1980s to improve fuel efficiency. A major overview of this work can be found in AAR Report R-800, *Vehicle Track Resistance Research, A Summary Document* (*14*). The topics covered include aerodynamic resistance, bearing friction, wheel-rail friction (tangent and curves), grade resistance, inertial forces, suspension damping resistance, and track deflection and damping resistance. Many detailed studies are published as AAR reports and American Society of Mechanical Engineers papers on each of the researched topics. The studies include theoretical analysis and laboratory and full-scale testing. Computer train energy models were developed incorporating all the new information, thereby making evaluation of railroad energy usage much easier. The research was an AAR, railroad, supplier, and academia joint effort. Earlier work was sponsored by the federal government.

An analysis of the fuel consumption of some Santa Fe Railway intermodal trains demonstrates the relative importance of the various causes of fuel consumption and identifies where savings can be achieved and the problems with achieving future savings. The causes of fuel consumption for an intermodal train between Chicago and Los Angeles on Santa Fe is shown in Figure 12. Moving trains up grades consumes 40 percent of the total fuel used. Acceleration of the train adds 10 percent. Aerodynamic losses amount to 30 percent, and wheel-rail friction and bearing losses combined account for 20 percent of fuel consumption. A more detailed study of the savings from reducing train resistance can be found in work by Smith (*15*). Obviously, reducing fuel consumption by reducing train resistance requires altering train and car characteristics and slowing train speeds.

Train Weight

For an intermodal train running between Chicago and Los Angeles, approximately 40 percent of the fuel consumption is caused by moving the mass of the train up grades. This adds to the potential energy of the train; however, the downhill grades are quite long and the energy is dissipated by braking. Thus the potential energy often cannot be used efficiently. On Santa Fe's preferred route in this corridor, trains are lifted through 25,000 vertical ft. Naturally, the savings could be significant if a device could recover this energy. Use of flywheels or other storage devices and regenerative braking on electrified territory would recover the otherwise dissipated energy.

A major effort is needed to control train weight. The train weight includes the lading weight, the locomotive weight, and the tare weight of the cars. Railroads are paid to move lading and, therefore, the lading weight is the only beneficial weight on the train. The weight of the cars and the locomotives is not revenue weight and serves only to carry the lading and move the train safely. The tare weight of cars and the empty car miles is a major issue. On Santa Fe, only 50 percent of the gross ton-miles (not including locomotive ton-miles) are revenue lading ton-miles. Thus the opportunities for improvement are substantial. The weight of the locomotives relative to the horsepower provided is another important factor. A 4,000-hp, four-axle locomotive for intermodal service is attractive because of the greater power/weight ratio than previous locomotives, particularly the 3,000 hp, six-axle locomotive. The ratios of revenue ton-miles to gross ton-miles with and without locomotives become key measures in reducing fuel consumption caused by weight. The empty stanchions on intermodal flats, double-stacked cars with single containers, repositioning of locomotives, and movement of empty cars all affect this key measure.

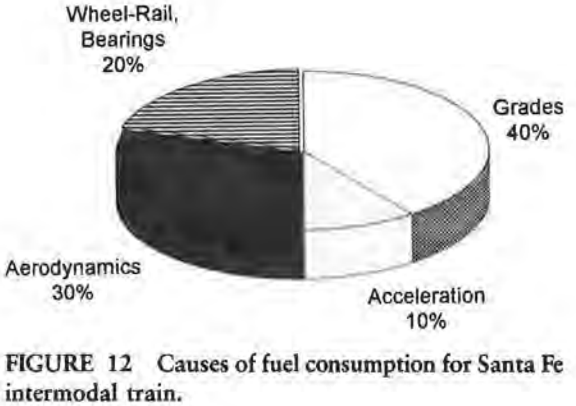

FIGURE 12 Causes of fuel consumption for Santa Fe intermodal train.

Acceleration of Train Mass

Acceleration accounts for 10 percent of the fuel consumption on an intermodal train. This is a product of two factors: train mass and velocity change. Acceleration changes the momentum of the train, and the energy would be recovered usefully if the train were allowed to coast to a stop. However, trains typically are braked for reasons such as adherence to train schedules. Thus the energy used to increase train momentum often is wasted. Because of the large train mass, the fuel consumption to increase train speed is quite high. If the speed is not changed often, the fuel spent is spread over a long distance and becomes a smaller factor. Through training, engineers today must look ahead at speed restrictions for curves, possible slow orders, and movement through turnouts and must accelerate only to a speed that can be sustained for many miles. Slow orders, in general, result in significant fuel and time penalties.

Aerodynamic Drag

Aerodynamic losses account for 30 percent of the intermodal train fuel consumption. Aerodynamic drag is composed of two major train characteristics: skin drag, which is a function of the roughness of the sides and tops of the cars, and pressure drag, which is airflow against generally vertical surfaces. The exterior side posts on coal cars are an example of large surface roughness. A gap in a train due to an empty stanchion, a 40-ft trailer on a platform designed for a 48-ft trailer, or the end sheet of an empty rotary dump coal gondola produces large pressure drag. Aerodynamic losses are a function of the velocity of the train (relative to the air) squared. The aerodynamic drag doubles in moving from 50 mph to 70 mph. Running at 50 mph into a 20 mph headwind results in double the drag compared with 50 mph with zero headwind.

Wheel-Rail and Bearing Friction

Finally, 20 percent of the fuel consumption in intermodal service results from friction in bearings and wheel/rail contact on the gage face of the rail. The bearing losses primarily occur in the sliding seal used to keep water and dust out of the bearing. New designs of labyrinth seals that produce substantial fuel savings are now on the market. The removal of the contacting seal reduces the torque required by 25 to 50 percent, whereas some of the new special seal designs reduce torque by 50 to 60 percent (*16*).

Wheel-rail friction has been studied intensely during the past 8 years. The losses are significant and controllable. The use of steering trucks or the placement of lubricant in the zone of contact greatly reduces the friction. Since the friction also produces wear, the savings from reducing the friction also include reduced wheel and rail wear. The first advantage produced from locomotive-mounted lubricators is a substantial reduction in locomotive wheel replacement due to thin flange. Savings in wheel replacements for this cause can easily reach 50 percent.

Locomotive Efficiency

Beginning with the energy supply disruptions in the 1970s, locomotive manufacturers steadily improved locomotive fuel efficiency. The locomotives purchased within the past 3 years are roughly 20 percent more fuel efficient than locomotives purchased in 1972. The development and use of electronic fuel injection offer perhaps a 1 to 2 percent further improvement in fuel efficiency.

Barriers to Improvement

For the most part, a great deal is known about train resistance and how to decrease fuel consumption by reducing train resistance. The major problem is applying the results of the research. Because the global measurement of fuel efficiency on a railroad is based on the sum total of fuel used for all activities, the impact of any one action is relatively imperceptible. This leads to lack of conviction that the action has a beneficial result. Fuel efficiency varies monthly because of traffic mix, weather, crises of the moment in train operations, and other factors. Indirect means of measurement, such as locomotive wheels replaced for thin flange, are important. In addition, the complexity of changing equipment characteristics means that improvements come slowly and require considerable persistence. Consider the problems with trailer sizes. Significant volumes of 28-, 40-, 45-, 48-, and now 53-ft long trailers exist. These are being mixed on trains, and the desire is to place them on articulated equipment. The result is that the net/tare ratios and the size of the gaps between trailers vary considerably from train to train. The proliferation of varying sizes of equipment means the platforms cannot be optimized for fuel consumption, nor are equipment costs optimized. This needs to be considered with intermodal containers as this segment of the market expands.

The second major barrier to more substantial improvements to fuel efficiency is the low price of diesel fuel. Current prices are in the $0.65/gal range, whereas prices in the early 1980s sometimes exceeded $1.00. On many railroads, the short-term focus of railroad management, the reduction in staff and analytical function for cost reduction purposes, and the low price of fuel combine to make fuel efficiency today a lower priority than locomotive availability and use, labor costs, and other issues.

Consider just the application of locomotive-mounted lubricators. The benefits have been known for more than 5 years. The payback on the investment is typically less than 2 years, yet some major railroads still are not using the technology. Even on Santa Fe Railway, where close attention is paid to the lubricators, the bad order ratio for the equipment is approximately 40 percent. Thus a significant portion of the benefits are left unrealized.

To sustain a continuing 2 percent decline per year in energy consumption, a wide range of programs is needed. The easiest means is to reduce train speed; however, in many instances this likely would reduce customer satisfaction and line capacity and would not be a satisfactory global solution. Small changes in equipment to reduce train resistance also will not achieve short-term results because of the typically small purchases of new equipment each year. A systematic effort to reduce weight, aerodynamic losses, wheel/rail friction, and bearing friction is required. In addition, improvements in operations to segregate time-sensitive loads, slow down trains for which speed is not essential, reduce yard delays, reduce on-line equipment failures, reduce empty car-miles, reduce acceleration losses, avoid over powering trains, and avoid repositioning of locomotives would yield major cost savings for both fuel and equipment. A balanced and sustained emphasis is needed to achieve the required results.

Environmental Impacts From Railroad Activities

Railroads affect the environment in a number of ways. They sometimes generate noise in rail operations that can disrupt the speech and sleep of neighbors. Maintaining rights-of-way, which sometimes involves earthwork, can affect adjacent waterways and wetlands. Maintenance of railroad equipment generates various waste products, such as hazardous wastes at shops and recovered diesel and lubrication oils. Rights-of-way and major terminals can generate fugitive dust, an air pollutant. Discharged wastewater from shops and fueling facilities can pollute streams and other surface waters. Past spillage of fuel and other chemicals at facilities can contaminate soil and groundwater. The transportation of hazardous materials results in infrequent but sometimes catastrophic spillage of chemicals that can immediately affect people, property, and the environment. Finally, the use of internal combustion engines to power railroad equipment generates emissions to the atmosphere. The magnitude of the impact needs to be considered in comparison with the benefits of the service, the alternative means of transportation, and the ability of the railroads to further reduce or mitigate the impacts.

The major environmental impact of the railroads on a mass basis is the emission of nitrogen oxides from locomotives, which contributes to the formation of ozone. Nitrogen oxides are formed during the combustion of the fuel in the engine cylinders. Because air is approximately 78 percent nitrogen and 21 percent oxygen by volume, large amounts of gaseous nitrogen are present in the engine cylinders during the combustion process. Most of the oxygen reacts with the hydrocarbons in the fuel. At the high temperatures in the cylinders, some of the remaining oxygen reacts with the nitrogen to form nitrogen oxide and nitrogen dioxide, collectively called oxides of nitrogen (*17*). Considering the approximately 3 billion gal of diesel fuel consumed each year by the railroad industry, the nationwide nitrogen oxide emissions are roughly 600,000 tons per year. Because the railroads consume small amounts of energy—2.5 percent of the nationwide transportation energy consumption—they are also a small contributor to the air pollution problems.

EPA Study of Railroad Emissions

EPA studied railroad emissions in five areas in the United States that are nonattainment or approaching nonattainment and that had significant railroad activity (*18*). The assumption was that if railroads were shown not to be significant contributors to pollution in these regions, then they should not be major contributors in other areas of the country. The five areas chosen by the EPA for study included Philadelphia, Chicago, St. Louis, Kansas City, and Los Angeles. The National Ambient Air Quality Standards for ozone are violated in each of these regions. In addition, Kansas City, St. Louis, and Chicago have some of the greatest concentrations of rail traffic in the nation. The regions selected, therefore, should represent a worst case for ozone and its precursor, nitrogen oxide emissions, as related to railroad activity. The study techniques were crude because the number of locomotives in an area was based on tallies by FRA railroad inspectors. In addition, all the locomotives were assumed to have duty cycles in these geographic areas equivalent to industry-wide average duty cycles.

The results of the Los Angeles area study are similar to other more detailed studies performed by the railroads and CARB. The results for the other regions have not been verified by more intensive studies and, therefore, the results are crude assessments at best, totally inaccurate at worst. In particular, the results for Chicago appear unreasonable because of the large number of locomotives assumed to be in the area. EPA reached such conclusions as the range in oxides of nitrogen emissions from railroads was 2 to 15 percent of the total emissions of the areas studied. In addition, technological approaches for the reduction of nitrogen oxide emissions from diesel engines generally resulted in increased particulate emissions (smoke) and increased fuel consumption. In general, shutdown of idling locomotives reduces railroad emissions and fuel consumption. However, emissions from "cold starts" could work counter to an optimal shutdown policy. The cost-effectiveness of reducing locomotive emissions appears similar to the cost-effectiveness of controls for automobiles, trucks, and motorcycles, but data for making these estimates are limited.

The EPA recommendations for action included gathering sufficient data on locomotive emissions to permit an accurate determination of railroad emissions and their effects. More information is needed on the particulate emission rates and how they would be affected by reducing nitrogen oxide. EPA further recommended that techniques for the control of locomotive emissions be evaluated with respect to feasibility of application to both new and in-use locomotives, cost of control, and impact on railroad operations. Such studies would reduce the uncertainties in the present estimates and allow determination of the need for federal control of railroad emissions.

CARB Locomotive Emissions Study

CARB and the California railroads performed a detailed study of locomotive emissions relative to other sources of emissions (*19*). The study period was 1987 because that was the date of the most recent detailed inventory. The study concentrated on nonattainment areas in the state. The level of emissions for the Los Angeles metropolitan area is presented in Table 2. Railroads contribute 2.9 percent of the total basin nitrogen oxides, 1.8 percent of the sulfur dioxide, and approximately 0.1 percent each of the hydrocarbon, carbon monoxide, and fine particulates.

TABLE 2 1987 Emission Inventory Estimates by Category for Southern California

SOURCE[a]	HC[b]	CO	NO_x	SO_x	PM 10[c]
Stationary sources	614	219	282	51	1102
On-road sources	602	4278	664	32	59
Other mobile sources[d]	75	512	141	42	14
Total for all sources	1291	5009	1087	125	1175
Trains(*19*)	1.5	4.7	31.5	2.2	.7
Trains: percent of total	.12	.09	2.9	1.76	.06
Trains: percent of total mobile sources	.22	.1	3.91	2.97	.96

NOTE: Data are in tons per day. HC = hydrocarbon, CO = carbon monoxide, NO_x = nitrogen oxide, SO_x = sulfur oxide, PM = particulate matter.
[a]Taken fron CARB's 1987 Emission Inventory Estimates by Category (*19*, pp. 4, 5).
[b]Reactive HC only.
[c]All locomotive particulates are assumed to be PM10.
[d]Includes CARB's estimate of 1987 train emissions.

This contribution does not appear significant at first glance; however, the air quality in the South Coast Air Quality Management District (SCAQMD) (Los Angeles metropolitan area) resists improvement in spite of significant reductions in many sources of pollutants.

In 1989, the state standard for ozone was exceeded 150 days in the Pomona and San Bernardino areas of the SCAQMD (*20*). Health advisory levels were exceeded 80 days in 1989 in the same areas. On the worst days, the air quality was three times the standards. The general trend has been improving, but not quickly. Between 1976 and 1989, the number of days per year exceeding federal standards decreased by 31 percent.

A large number of sources have reduced emissions of photo chemical smog (ozone) precursors (nitrogen oxide and volatile organic compounds) by relatively large amounts (70 to 80 percent). Power plants, industrial boilers, refineries, manufacturing plants, and other facilities have made major reductions. New automobile standards are at only 10 percent of the original emissions. Paint formulations and even charcoal lighter fluid have changed specification to reduce emissions. In the near future, even the emissions of lawn mowers, chain saws, and other small equipment will be regulated.

More is known of railroad emissions and the air quality problems in southern California because of the long-term nature of the problems there. However, the largest number of ozone nonattainment areas are in the East. The area from Baltimore to Boston, much of the Ohio River Valley and the Great Lakes Region, Dallas, Houston, Atlanta, and Birmingham and Montgomery, Alabama, are nonattainment for ozone. Thus locomotive emissions are not air pollution problems in California only. The lesser severity of the problem or the availability of more reasonable reductions from other sources may not require quite the same reductions in railroad emissions as that in southern California. The operational problems that would be created by differing state standards and the current language of the Clean Air Act do not allow for tailoring railroad emission reductions for each nonattainment area.

Results of the Harvard University Six Cities Study (*21*) showed that exposure to air pollution by extremely fine particles in Steubenville, Ohio, amounted to a 26 percent higher risk of dying than from the exposure levels experienced in Topeka, Kansas, or Portage, Wisconsin. The research linked the concentration of fine particles chiefly to deaths from heart and lung diseases. Whether the risk of dying from this cause was significant compared with all other causes of death needs to be considered in evaluating these results. Other studies increasingly conclude that particulates generate significant health problems. At a minimum, the railroad industry cannot limit its focus solely to nitrogen oxides and must consider other pollutants when evaluating nitrogen oxide reductions.

MOTIVE POWER FOR THE FUTURE

The motive power of the future must help the railroads become more competitive than other modes of transportation. Locomotives must be cost-effective while being environmentally friendly, comfortable for the train crews, and safe. The definition of cost-effective must include first cost, reliability, maintenance cost, and fuel efficiency. In the history of motive power development, there have been incremental improvements and occasional radical changes. In the future, there will be consideration of evolutionary improvements such as a 4-degree retard in injection timing, increased cooling of combustion air, and increased injection pressure to reduce emissions. More technological changes include electronic fuel injection, use of alternative fuels such as ethanol, methanol, and natural gas as a sole source or as the major fuel in a dual-fueled engine, and spark-ignited engines. Among the most radical technologies being considered is use of hydrogen-powered fuel cells for the prime mover. The pace of technological development in railroad motive power has increased significantly during the past few years.

Environmental regulations will have a profound impact on locomotive engine design, cost, maintenance, and performance in the next decade. Federal standards on future engines will require manufacturers to incorporate an array of technological changes and will present the railroads with the challenge and opportunity to decide both the prime mover type and fuel of the future. It is impossible to say at this time what impact the cost of federal and state regulations will have on the current engine population. It is possible that those regulations will require major retrofits in the late 1990s and early 2000s, which could burden the railroads and weaken their competitive position in certain markets. It is also possible that some or all older engines (pre-1970 for example) will have to be retired sooner than planned.

Environmental Regulations for New Engines

The Clean Air Act requires that EPA regulate exhaust emissions from all new engines and set standards at "reasonable" levels, given existing technologies and the likely ability of manufacturers to adapt those technologies to locomotive engines at a reasonable cost.

The first EPA specifications for new locomotives will probably be effective no sooner than 1999 or 2000. They are currently expected to set the maximum allowable nitrogen oxide specification at 5.5 to 6.5 grams per brake horsepower hour (g/bhp-hr) and particulates at approximately 0.25 g/bhp-hr. These specifications are similar to EPA truck standards. The current in-use locomotives generate approximately 10 to 15 g/bhp-hr of nitrogen oxide and 0.2 to 0.4 g/bhp-hr of particulate matter. These levels may be attainable by the locomotive engine manufacturers on diesel engines using petroleum fuel. Because of the extensive trade-off between nitrogen oxide emissions and particulate emissions, a stringent particulate standard may severely constrain the manufacturers in reducing nitrogen oxide emissions. The standards appear to be attainable in truck engines; however, truck manufacturers have made more radical engine design changes in the process for trucks than can likely be accommodated in railroad engines. In fact, some engine manufacturers started engine designs from a clean sheet of paper to meet the standards. These manufacturers amortize their design, development, and tooling costs over annual sales of 50,000 units per year, whereas locomotive manufacturers can do so over only 200 units annually. In addition, the locomotive engine is considerably different from truck engines primarily because of the slower engine speed. Engine changes currently under consideration to achieve these reductions include increased charge air cooling, increased fuel injection pressure, electronic fuel injection, and piston and cylinder redesign.

Environmental Regulations for Existing Engines

The long life of railroad engines means that reducing emissions on the existing locomotive engine fleet may be desirable from the regulatory agency viewpoint. One plausible scenario is that EPA would set standards only for new locomotives, and California would set standards for existing locomotives. Other states could petition EPA to adopt the California standards for existing locomotives. Thus all U.S. railroads would be affected by the California standards. Another possibility is that EPA will occupy more of the field. At this time, CARB is considering a market-based "bubble" scheme. Under this scheme, each railroad company will be allowed a maximum mass of emissions by type (nitrogen oxide, particulate matter, carbon monoxide, hydrocarbon, and sulfur oxide), which would decline each year until some point in the future when no further decreases would be needed.

Such a scheme would be an indirect control of engine emissions levels that would allow railroads freedom to optimize technologies and operating practices to reach the required emissions levels. What is unusual for mobile sources is that the users, that is the railroads, not the engine manufacturers, would be responsible for whatever changes to engine technology are necessary to comply with the emissions levels. The actual responsibilities have yet to be determined for manufacturers and users.

The emissions levels considered by CARB are a 70 percent reduction in nitrogen oxide by 2001, 50 percent reduction in particulate matter by 2002, reduction of sulfur oxide through use of low-sulfur highway fuel starting in 1994, and no increases in carbon monoxide or hydrocarbon. A further 10 percent reduction in nitrogen oxide (to a total reduction of 80 percent) would be required by 2009, except in the Los Angeles area, where a total reduction of 90 percent would be required. These reductions are all with respect to the total emissions generated in 1987. Attainment of these levels, if possible at all, would require a combination of the following actions:

- Purchase new, lower-emissions locomotives, re-engine locomotives with new, lower-emissions engines, or both. Use of alternative fuels and electrification of the mainlines may be required.
- Modify existing locomotive engines for reduced emissions.
- Reduce fuel consumption per ton-mile through changes in operating practices and rolling stock, which translates into a reduction in emissions.

Freight railroads in California estimate that operating efficiencies will reduce all emissions by 10 to 25 percent in the various air control districts by 2001. National Railroad Passenger Corporation (Amtrak) officials believe that Amtrak's improvement will be smaller. The nitrogen oxide fleet average would have to be reduced by 45 to 60 percent instead of 70 percent and particulate matter by 25 to 40 percent instead of 50 percent. Such levels on individual engines would be approximately equal to the currently anticipated EPA standards for new engines. It may not be possible to retrofit some older engines. Therefore, it will probably be impossible to meet the proposed CARB bubble levels unless these older engines are removed from service in California. There is also significant doubt that new engines on diesel fuel can achieve the suggested reductions.

CARB has a number of key design considerations in the development of a proposed regulatory framework. In addition to the maximum emission reductions, CARB is concerned with modal shifts to less environmentally friendly modes of transportation, such as trucks. In developing regulations to reduce locomotive emissions, it will be important to ensure that rail costs are not increased to such a degree that traffic shifts to more polluting modes or that harm occurs to major sectors of the California economy such as viability of the southern California ports. CARB also desires performance-based standards, incorporation of both technological and operation measures, flexibility to accommodate different operations, accommodation of future growth, optional market-based mechanisms, compliance with state and federal law, and compatibility with future freight transport policy.

Lowered Emissions Retrofit Technology

Locomotive diesel engines are somewhat modular in design and can accept newer technology in the form of replacement parts during normal maintenance or at the time of an engine overhaul or remanufacture. Nearly every engine in use today has some upgrades that the manufacturer introduced after delivery of the engine. New injectors and improved combustion air cooling typically are retrofittable to some degree in many engines. Obviously, there are limits to the extent that characteristics of new engines can be incorporated into products placed in existing engines.

Prime Mover Technology

Many industry experts predict that, even with the most rigorous development program possible, the conventional petroleum-fired diesel engine will fall short of meeting the emission standards likely to be required by the year 2000 and especially by the year 2010. It is therefore prudent for railroad researchers to be actively evaluating the alternatives. The objectives of this research should be twofold. First, the candidate technologies should be evaluated to determine their suitability for application to the railroad environment, the prospects for development success, and the likely development schedule. Second, they should be evaluated for compatibility with the current diesel-electric practice and with the other candidate technologies so that any phase-in can be as efficient and least disruptive as possible.

On the basis of current information, the following prime mover technologies have been identified as possible alternatives for use by the railroads into the first quarter of the next century. Primary energy sources (energy conversion systems) are natural gas, methanol, multiple small diesel engines (with or without distributed power), electrification, gas turbines, and hydrogen fuel cells. Secondary energy sources (advanced storage systems) are advanced storage batteries and high-speed flywheels.

Primary Energy Sources

Primary energy sources convert chemical energy or stored energy from a source external to the locomotive to electromechanical energy for traction power. As an example, a primary energy source may be an on-board, fossil-fuel-driven prime mover (such as a diesel engine or gas turbine) providing mechanical energy to an electrical generator to produce the electrical energy for locomotive traction motors. Alternatively, it may consist of a current collection device on the roof of the locomotive drawing electrical energy from an overhead distribution system. In turn, the overhead distribution could be fed from a utility supply powered by hydro-electric turbines, or fossil-fuel-fired or thermal-nuclear-powered steam turbines.

Byproducts of the chemical energy conversion process (e.g., combustion exhaust emissions or spent nuclear fuel) are a major concern from the environmental standpoint. Indeed, exhaust emissions is a major issue on which the petroleum-fired engine is being challenged. Therefore, selection of the alternative technologies will be made on the basis of lowest pollution levels, costs, and benefits.

As a source of power for railroad traction, the conventional petroleum-fired diesel engine is a mature technology. Typical engine output powers range from 2,000 hp for road switcher units to 4,300 hp for mainline freight service, with an overall thermal efficiency of 34 to 36 percent. Indications are that the future trend is to increase the power rating toward 6,000 hp/unit for mainline operation. Currently, power levels are limited by a requirement that the prime mover weight and including fuel supply be a maximum load of 65,000 lb per axle, 390,000 lb for a six-axle locomotive.

As previously mentioned, a major disadvantage of the current diesel engine technology is the level of emissions produced by the combustion process, particularly the levels of oxides of nitrogen and carbon dioxide. Typically, existing locomotive diesel engine nitrogen oxide levels are in the 10 to 15 g/bhp-hr range, which is unacceptable for the future. Retrofit technologies (electronic fuel injection, retarded engine timing, and increased charge air cooling) are expected to bring nitrogen oxide emission levels down to 7 or 8 g/bhp-hr, but at the expense of fuel efficiency, smoke, and particulate emissions. This performance may be acceptable in the interim, but not for the long term.

Natural Gas

Natural gas may be used as an alternative fuel in the locomotive diesel engine as a result of a direct conversion of existing equipment or as a design for new engines. The technology is applicable to both two-stroke and four-stroke cycle engines. Currently, the preferred natural gas fuel variant is refrigerated liquid methane, obtained by refining compressed natural gas. Due to the relatively low energy density (in British thermal units per cubic foot) of liquid methane, fuel for the gas-fired road locomotives has to be carried in cryogenic fuel tenders instead of in on-board fuel tanks. The remaining equipment on the locomotive (alternator, propulsion system, and controls) is identical to the conventional diesel electric locomotive. In fact, petroleum-fired and gas-fired locomotives can be operated in the same motive power consist.

Three combustion technologies are currently in use or under development for the use of natural gas as a diesel engine fuel. These technologies are dual fuel pilot injection, direct gas injection, and direct liquid natural gas injection. Each has advantages and disadvantages relative to costs, flexibility of operation, power levels, energy efficiencies, safety, and locomotive emissions. Spark-ignited engines operating on natural gas could power locomotives, especially switch engines. Reductions in the power per engine weight ratio and losses in fuel efficiency as compared with diesel engines would result. Nitrogen oxide and particulate emissions are believed to be quite low.

The current price of natural gas is approximately half the cost of diesel fuel on an equivalent British thermal unit basis. Such a price difference creates interest in natural gas as a fuel on economics alone. Obviously, the future cost is uncertain. The environmental benefit for most of the proposed locomotive natural gas engines is not sufficiently known. Research is under way with locomotive manufacturers and several railroads. Both switch engines and road power are involved. In addition, a group of railroads, suppliers, and some environmental agencies have funded a large study of emissions, infrastructure needs, safety, and the effects on capital cost, operating cost, and maintenance requirements of using natural gas as a railroad fuel. A large amount of knowledge will be collected during the next 2 years.

Electrification

Because electrification is already a mature and established technology, no major technical developments are necessary to implement it. The main barriers to the widespread implementation of electrification are economic. These barriers include capital and operating costs and operational disruption during construction. In addition, the entire system must be constructed before any value is created. One potential impact on operational costs and flexibility is peak-period electrical demand charges. The current evaluation of electrification for southern California reveals a $4 billion to $5 billion first cost, minor locomotive maintenance savings, no energy savings, and substantially increased maintenance-of-way costs due to the catenary maintenance. The early, incomplete California studies of electrification estimate the nitrogen oxide reductions to cost $4,000 to $10,000/ton. By comparison, current EPA proposals for emissions reduction are estimated to cost no more than $400/ton.

Methanol

The use of methanol blends with gasoline is undergoing demonstration field evaluation in automobiles in many locations, including California. The high cost of methanol makes the fuel relatively unattractive as a diesel fuel replacement. Obtaining good ignition of the fuel is difficult in diesel engines. The fuel has been certified in one diesel truck engine complying with the truck nitrogen oxide standards and is regarded favorably by some in the EPA Mobile Sources Office.

Gas Turbines

Gas turbine generator sets for stand-by power are common. They are generally designed to run on a multitude of fuel types, including natural gas. In the past, gas turbine-electric power was used for traction in freight operations on the Union Pacific Railroad. The gas turbine–powered locomotive design is similar to diesel-electric locomotives. The gas turbine prime mover is connected to a traction generator through a gearbox. The main propulsion system is identical to that of the diesel electric locomotive. Three passenger railroad applications have been demonstrated, each with gas turbines driving hydraulic transmissions as part of specially designed, lightweight trains. Two of these designs are still in use in the northeastern United States.

The main disadvantage of gas turbines for motive power is that they are not efficient for partial loads and, therefore, do not follow the railroad locomotive duty cycle effectively. Their performance and fuel consumption characteristics are best suited to constant load applications. However, gas turbines generally produce significantly lower levels of emissions and have power/weight ratios higher than diesel engines. Therefore, they may lend themselves to future applications to locomotives in combination with secondary storage devices or in special high-power use applications.

Fuel Cells

The fuel cell uses a chemical reaction to directly produce electricity. A fuel cell is an electrochemical engine that converts the chemical energy of a fuel and an oxidant directly to electricity. The principal components of a fuel cell are catalytically activated electrodes for the fuel (anode) and the oxidant (cathode) and an electrolyte to conduct ions between the two electrodes. For some of the most promising fuel cells, hydrogen is the preferred fuel. Oxygen is the typical oxidant and can be supplied in the form of air or purer oxygen. Overall energy efficiencies starting with conversion of natural gas to hydrogen are in the 40 to 43 percent range.

Many experts predict that the fuel cell will eventually replace the internal combustion engine. However, major developments are necessary to reach that point technically, let alone from the cost-benefit standpoint. However, of all the alternatives evaluated for this study, fuel cells hold the most promise for meeting the emission levels for transportation that some regulatory agencies are contemplating for the 21st century. There are wide-ranging points of view, but some advocates are projecting that, by the end of the first quarter of the next century, the fuel cell may even replace the internal combustion engine on economics alone. Manufacturers have a long way to go because the cost of the power systems for a Proton Exchange Membrane power cell currently powering a bus is approximately $5,000/kW, whereas locomotive engines cost less than $200/kW. The current durability of the power cells is only 3,000 hr, whereas a minimum of 40,000 hr would be desired for a locomotive. Because railroad locomotives already incorporate electric motor-based propulsion systems, application of fuel cells to the locomotive is less radical than application to automobiles or trucks.

A joint initiative recently undertaken by SCAQMD and the U.S. Department of Energy (DOE) will study the feasibility of two prototype locomotive designs incorporating fuel cell power plants. The two designs under consideration are a road switcher and a high horsepower road locomotive. If considered successful, it is probable that at least one of the designs will be built, provided the necessary funding can be obtained from public and private sources. Funding for the feasibility study is being provided jointly by SCAQMD and DOE. California railroads and AAR, on behalf of the entire railroad membership, have been invited to act as technical advisors to this study.

Secondary Energy Sources (Advanced Storage Devices)

As a general concept, these devices would be used in conjunction with a primary energy source, such as a small on-board diesel generator set, a gas turbine generator set, or overhead electrification. They could also be used to recover much of the potential energy currently lost during braking. The storage system would be sized to provide the peak power demands, or during interruptions to the primary supply, while absorbing power from the primary energy source during periods of low demand and braking. Advanced storage devices could be batteries, flywheels, or a volume of gas that is pressurized to increase its energy content.

The main drawback of batteries typically is the low energy capacity/weight ratio. The military has sponsored research on improving batteries. Similar requirements for some of these applications may allow railroads to benefit from this research.

The use of flywheels for smoothing rotating shaft torque pulsations is well known. For example, internal combustion engines have employed flywheels for that purpose since their invention. Flywheel capacities of 30,000 hp-hr have been predicted by some experts as being imminent. These storage devices could be used to store the energy from a smaller, constantly loaded, prime mover power plant (such as a gas turbine) and release the stored energy during peak power operations and be used to store braking energy.

What Does All of This Mean?

The future seems to be a combination of good news and bad news. The good news is that the transportation sector continues to grow in terms of ton-miles per year. The bad news is that revenues per ton-mile continue to erode at a rate of approximately 2 percent per year. This puts considerable pressure on costs per ton-mile and contributes to intense competition. As the carriers reduce costs, the shippers get more cost-effective service. Shippers continue to demand higher quality service. Railroad labor and railroad suppliers of locomotives, cars, fuel, and other commodities have been partners to major changes that have improved the railroads' competitive position. Such changes must continue and must be focused on satisfying the needs of shipper customers cost-effectively while being safe and environmentally friendly.

The railroads are being pressured to reduce locomotive nitrogen oxide emissions by at least 60 percent because of earlier reductions to trucks and automobiles. In some nonattainment areas, more reductions may be demanded. Even though railroads generate far less nitrogen oxide on a ton-mile basis, the pressure will remain to reduce emissions to the maximum extent technologically feasible, especially in nonattainment areas. The improvement in emissions initially will involve changes to the existing diesel engine running on diesel fuel. More radical alternatives further in the future range from use of natural gas in engines similar to the current engines to hydrogen-powered fuel cells. These technologies will be considered successful only when the railroads' competitive position is enhanced or at least kept comparable with other modes.

The emphasis on train resistance must be elevated further. Too little has been done, to date, in using the knowledge gained during the 1980s. The relatively low cost of diesel fuel, currently, and the uncertainty of the future price pushes railroad management into making decisions lasting 30 years on information that is valid for only a few years. If railroads do not make better decisions for the long term, they will not be competitive in the long term. This is especially true for purchases of cars and locomotives. The railroad industry should be reducing fuel consumption (gallons per ton-mile) by 3 to 4 percent per year. This reduction will require structural changes in the car fleet and car design and in motive power and operational improvements.

What Do You and I Need to Do?

The necessary improvements will not be achieved without better information. Railroad professionals need to jointly describe their vision of the future and develop the research programs to propel the railroads there. Research is needed particularly for hardware, but better forecasts of energy costs, perhaps involving probabilities instead of just a single forecasted price, are also essential. Train energy models make great analytical tools for studying alternatives but do little to help terminals and dispatchers make daily decisions on equipment.

A number of groups, partnerships, and coalitions are providing some answers to some of the questions. The railroads and AAR have a substantial on-going effort. The locomotive manufacturers and some other suppliers aggressively seek improvements. DOE, DOT, air quality management districts, and national laboratories are involved in projects with the railroads and suppliers. A number of universities and firms, such as Southwest Research Institute, contribute as well.

The major issue is how to develop the joint vision and how to coordinate the work to avoid duplication, unnecessary research, and untimely information. The challenge for railroad professionals is to put aside much of their self-interest and perhaps suspicion and cooperatively create research initiatives that will be to their mutual benefit. The collective action should achieve considerably more than what individuals could accomplish. Furthermore, time is of the essence because energy dependence and air quality problems resist change, to the mutual detriment of all.

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