climbing and the cost of electric power was stable, the rate of return looked very attractive. Now that the cost of electricity appears to have caught up with petroleum prices, it is not as attractive as it once was. And, until we find out about the many unknowns mentioned above, we do not know how attractive the rate of return would be in the future.

SUMMARY

Let us review some of the advantages, disadvantages, and uncertainties that we are concerned with when we consider electrification. There are a number of advantages.

1. Electrification would reduce the dependence of transportation on petroleum. Assuming about 10 percent of the nation's railroads were electrified, savings could be in excess of 7 billion L (2 billion gal) of diesel fuel a year.
2. Electrified lines would have lower fuel costs. However, there are enough uncertainties in the area of future costs that the tendency in making electrification studies is to use a conservative approach, i.e., to project escalation of electric power rates at approximately the same rate as petroleum fuel costs. This conservative approach reduces the estimated return on investment to a marginal level. The calculation of return on investment is more sensitive to fluctuation in electric power rates and diesel fuel costs than any other single item.
3. The railroads would reduce their air pollution problem, returning it to the power plant, where control can be more readily accomplished.
4. The maintenance cost for electric locomotives is two-thirds that for diesels.
5. Electric locomotives have higher adhesion and the ability to furnish short bursts of additional power for climbing grades.
6. Fewer electric locomotives are required, since they have higher availability and less maintenance.
7. There is a decreased need for an inventory of material, including petroleum fuel, lubricating oil, and replacement parts for the internal-combustion engine.

The disadvantages are primarily the high capital cost, low estimated return on investment, and the fact that there are pressing needs for the money elsewhere. There are other disadvantages among the many uncertainties that still exist, specifically:

1. We are not sure the electric locomotive has been developed as thoroughly as it can be.
2. We do not know what it will cost to deal with the problem of signals and communications because we really do not know what kinds of problems a 25 or 50-kV system will create.
3. We do not know where the money for electrification is coming from. Some railroads may be able to afford the substantial investment, assuming that the return on investment were attractive, but for marginally profitable railroads federal assistance, in the form of tax incentives or some other kind of assistance, will probably be required.
4. We do not have any confidence in our ability to predict the cost of electric power over the next few years, much less over the 30-year expected life of an electrified system. Without some reassurance on this point we will not see electrification to any degree in the immediate future without government sponsorship.

I personally believe that electrification of heavy-density rail lines in this country will come, but I do not know when. Many of the uncertainties mentioned above might be clarified as a result of the Railroad Revitalization and Regulatory Reform Act. Specifically, the Secretary of Transportation guaranteed obligations of the Consolidated Rail Corporation up to $200 million for the purpose of electrifying high-density main-line routes. Certainly an expenditure of this magnitude and the upgrading of existing electrified rail lines should produce answers to some of our questions. The sooner we deal with the issues and uncertainty that exist, the sooner we can move forward.

An Economic View of Railroad Electrification

Scott B. Harvey, Association of American Railroads, Washington, D.C.

There are many proponents of railroad electrification and very few vocal opponents. Arguments based on economics and energy policy have been marshalled in favor of substantial investment in electrification. But despite these arguments, no major investment in electrifying rail freight lines has occurred in recent years. It is my position that, even if the major arguments advanced in favor of electrification are correct, many issues need to be resolved before substantial public or private investment in electrification is made. I will here assume that the conclusions reached by general studies are valid and suggest other considerations that have prevented electrification and are likely to continue to do so.

To briefly state the issue, there are two competing motive-power technologies—the diesel electric and the electric. U.S. railroads overwhelmingly use diesel-electric power. Proponents of conversion to full electrification contend that, for certain high-density lines, electrified systems are superior economically and operationally. The findings of several studies (1, 2, 3, 4) are summarized below.

1. Electrification is technologically and operationally feasible.

2. Economic justification requires arraying and comparing the economic variables over time and at assumed volume levels.

3. The motive-power characteristics of electric systems are such that fewer, more powerful locomotives are needed. Electric locomotives have a longer economic life—perhaps 30 years compared with 15 to 18 for diesels (3). The cost/unit power may be lower for electric locomotives. The net result is that a smaller investment in locomotives is required for an electrified system than for a dieselized system.

4. Electric locomotives require less maintenance per locomotive-kilometer. If the experience of foreign countries and on electrified portions of the former Penn Central Transportation Company is representative, maintenance costs might be 25 to 50 percent those of diesel maintenance costs (4). Fewer locomotives and less maintenance per kilometer will result in savings in operating expense.

5. An electrified system, however, requires substantial investment in fixed facilities that are not required for diesel operations. Catenaries, substations, and signaling and communication systems may cost from $75 000 to $300 000 or more/route km ($120 000 to $500 000/route mile) (1). Reconstruction of facilities to maintain clearances and permit electric operations might cost up to $100 000/route km ($160 000/route mile) (1).

6. Electrified systems rely on power generated by electric utilities, which may in turn use a variety of energy sources—coal, atomic power, hydroelectric power, oil, and so on. Diesel operations rely on diesel fuel and are, therefore, subject to the vagaries of oil prices and supply. Energy efficiency and energy costs are about even now (4, 5), but diesel oil prices are likely to rise more than electric power rates over the life of the investment, thus generating operating expense savings from electrification.

7. The size of the required fixed-facility investment and the characteristics of electric motive power mean that high-density operations over a minimum route length are required for economic feasibility. Estimates of minimum route density run from 18 to 36 gross Tg (20 to 40 million gross tons) annually. The minimum route length appears to be 400 km (250 miles). Therefore, the entire rail system cannot be economically electrified. Most studies propose electrification for about 10 percent of the current trackage, which carries about 50 percent of the volume (3).

8. Electrification of high-density lines requires substantial initial investment; the returns come in the form of reductions in operating expenses in future years. These expense reductions can produce a return on investment. How great that return would be is subject to some doubt, but returns of 15 to 20 percent before taxes for electrification of particular lines have been estimated in some studies (1, 2).

9. The economics of electrification will vary considerably for lines of like density according to grade, traffic characteristics, terrain, access to electric power, and so on. Electrification must be studied on a line-by-line basis. Rates of return can vary significantly, and no overall formula to predict which rail lines should be electrified (if any) has yet been developed.

There is considerable debate on some of the points this summary makes, e.g., the magnitude of the maintenance savings that can be predicted. The arguments have been sufficiently persuasive, however, to prompt several individual railroads and the federal government to invest in detailed studies of the electrification alternative. These studies should permit more precise calculations of the values of the variables involved. In spite of these studies, there has not yet been a major conversion from diesel to electric operation in the United States, although interest continues. Since economists give great weight to the presumptive validity of the decisions of economic institutions, an initial hypothesis can be drawn that electrification is viewed as a marginal investment by railroads. The benefits of electrification apparently do not now justify conversion, but they may do so in the future.

OTHER ECONOMIC ISSUES

Continuing study should narrow the range of estimated investment requirements and operation and cost savings, but there are many other economic issues that must be addressed before meaningful conclusions concerning electrification can be reached. These issues relate primarily to the ability of industry to finance electrification and the desirability of such investment, given the current uncertainties about government policy.

1. There is a basic methodological question. The economic comparisons that have been made are between electrified and dieselized systems. Since the comparisons must be made over the life of the investment—30 years is assumed in most studies—many technological assumptions are necessary. For instance, a major source of savings from electrification is in maintenance. Should diesel locomotives become more efficient in the future, projections must assume either the same rate of improvement for electric systems or a reduction in the benefits of electrification.

More fundamentally, there may be other alternatives than electrification and dieselization. A recent review by the U.S. Department of Transportation (DOT) discussed electrification briefly and concluded that "it is not clear whether turning coal into electricity is preferable to developing a locomotive that burns coal or a coal derivative to power a locomotive directly" (6). Clearly, the methodology employed assumes the selection of optimum alternatives, and the importance of considering alternatives increases when the advantages at the margin are apparently as slim as they are in comparing dieselization and electrification.

2. Some proponents of electrification have contended that service reliability and speed would be improved and, therefore, additional traffic generated as a result of electrification. Most general studies have not taken this factor into account. The procedure has been to compare electric and diesel systems at the same projected volume levels. Since the speed and reliability characteristics of diesel locomotives have not been the primary limitations on improving rail service, this procedure is probably correct.

There are several other rail industry problems that affect service quality, including track and yard conditions, time spent in yards and interchange, and so on. These conditions need to be resolved before major service gains can be made. Nevertheless, electrification, along with other changes, could increase revenue generation. Potential increased revenue should be considered carefully, in particular in terms of possible diversion from other modes, since traffic growth would be a potential benefit and would also increase density and improve the economics of electrification.

3. Even under the most optimistic projections of electrification, the entire rail system would not be electrified. Since diesel operations would still be used on lower density lines and in yards, a number of operational

questions concerning a dual system would be raised. From an economic point of view, there is the real possibility of generating costs that should be charged to electrification. For instance, the ability to interchange locomotives throughout the system and to respond to changes in demand would be reduced in the case of a mixed fleet. Certain economies of scale would be eliminated and the remaining diesels might be less efficiently used. The cost of reduced utilization should be charged to electrification.

4. The economics of electrification raise important structural issues for the industry. A 1973 study (3) concluded that 9929 route km (6171 route miles) were economical to electrify but did not attempt to identify which lines should be electrified when a route had more than one rail carrier (3). The ability to translate the potential into actual investment would be limited by the need to resolve complex issues of intraindustry competition.

For instance, DOT's recent line classification study identified certain corridors of excess rail capacity in the nation. In many of these corridors, the density is more than sufficient to meet the minimum requirements for electrification, but only one, or none, of the carriers operating lines in the corridor generates a density on its own lines sufficient to justify electrification. The line from Dallas-Fort Worth to Houston is an example. The corridor has a density of 73 gross Tg (81 million gross tons), but none of the five carriers operating in the corridor generates more than 24 gross Tg (27 million gross tons) (7). Restructuring and the elimination of excess and duplicate capacity have been major goals in recent rail legislation. Accomplishing these goals would increase electrification possibilities and, should electrification prove economic, the arguments for further restructuring would be strengthened.

5. Although economic studies indicate that electrification of certain high-density lines would produce a rate of return sufficient to cover interest and amortization, this is not enough to warrant investment, despite the principles of marginal economic analysis. The railroad industry has been suffering from capital shortages. As a result, many alternative investments that promise a return equal to or greater than electrification have not been made. In the railroad industry, capital budgets are the product of the availability of funds rather than the rate of return on potential investments. Further, a substantial proportion of most railroad's capital budgets is dictated by the requirements of staying in business and by legal requirements (8). In this environment, electrification must find its place among a number of capital alternatives, some of which do not really involve discretion, others of which are desirable but have been deferred in the past, and some of which may promise a higher return on investment.

6. Probably the single most important point, even if all these issues were resolved in favor of electrification, is that it is highly questionable whether the industry could support the substantial investment required. By one estimate, electrification of 10 percent of the total trackage would cost more than $7 billion (9). In comparison, current capital spending amounts to $1.5 billion/year, and most agree the industry should be spending at a much higher level to meet deferrals and growth requirements. Even at current levels of capital spending, the industry is burdened by relatively high debt-equity ratios and rising fixed charges. Prospective lenders would question the ability of the industry to support spending on electrification. Even if funds were guaranteed by the government, the fixed charges and debt-equity impact would make investment questionable for railroads for financial reasons.

7. There is the crucial issue of uncertainty. Calculating potential return on investment does not resolve this issue, and the use of sensitivity analysis, probabilities, and payback periods only serves to improve its definition. In general, as uncertainty and the size of the investment increase and the time stream of benefits lengthens, a given return is viewed less favorably. It is not an exaggeration to say that the failure of an electrification project could break a railroad.

Railroads apparently view the costs and benefits of electrification as being highly uncertain. They are uncertain about many of the key variables, including the economic life and maintenance requirements of locomotives, the feasibility and cost of diesel-electric interactions, the future price of electricity and diesel fuel, and so on. While experience from electrification demonstrations would help to reduce this uncertainty, current doubts are deep-seated.

8. Although there are convincing arguments in favor of lessening rail reliance on diesel fuels, there are also considerable uncertainties concerning the future of electric power in terms of supply and price. Electric utilities have had difficulty raising capital and have huge capital requirements. There are unresolved environmental issues concerning the use of coal and atomic power. Several changes in utility pricing schemes designed to increase rates to volume users are being considered as a means of conserving energy. The relative prices of diesel fuel and electric power have changed over time. From 1959 to 1972, oil and electric prices rose at about the same rate. In 1973 and 1974, the relative price of diesel fuel shot up, but since then electric power rates have been increasing more rapidly than diesel fuel prices (10).

In terms of energy conservation and public policy, most studies conclude that electrification, while it would reduce oil consumption, does not save energy. Since railroads are relatively small users of oil (less than 2 percent of domestic consumption) (4) and would be relatively small users of electric power, their fate under either fuel source would ultimately be tied to national energy policies and programs. For example, an oil policy that relied on price controls and rationing rather than price-based allocation might benefit the economics of the diesel alternative.

9. Finally, there is the question of the interest and possible role of the government. The thrust of this argument has been that private funding of large-scale electrification would be doubtful. The arguments for a major government role would follow a familiar logic: Railroads are important and are both energy efficient and environmentally efficient; electrification is the most apparent means of reducing the dependency of transportation on oil; and electrification could improve the industry's economic health. Therefore, government investment in electrification would accomplish two objectives—aiding the industry and reducing oil use—at once.

The most obvious question, from the point of view of public policy, is whether economic health for the industry and reduced oil use in transportation can be accomplished by more efficient, effective means, such as the alteration of promotional policies to encourage rail versus highway movement. Looking at the issue from an energy viewpoint, a $7 billion expenditure would reduce oil requirements by less than 1 percent—in an industry that is relatively efficient in its energy use—and would not reduce overall energy requirements.

Further, public investment in an alternative technology like electrification represents an approach that is different from current public policy directions. Congress has passed major rail legislation in recent years that assumes that the industry's problems are not technological but rather structural and regulatory. It is too early to

predict the success or failure of the resulting policies. The impact of industry restructuring and regulatory reform has yet to be measured. Nor has the issue of current promotional policies and their impacts on transportation been addressed. The impact of restructuring, regulatory reform, and modification of current promotional policies would need to be assessed before electrification could be justified on the grounds of transportation policy.

SUMMARY

There are convincing arguments that electrification can have economic and energy benefits. These benefits are not, however, sufficiently large now to merit extensive private investment, particularly in an industry that has the economic characteristics of railroading. What might be interpreted as a failure of the industry to adopt the best possible technology is really the reflection of conditions in an industry that is already highly capital intensive, has difficulty raising capital, and cannot afford risky or marginal projects.

In these circumstances, major electrification has to await basic changes in the industry's financial condition, further research, and perhaps government-sponsored demonstrations to reduce uncertainty, as well as the resolution of the basic uncertainties surrounding national transportation and energy policies.

REFERENCES

1. E. G. Schwarm. Engineering Cost Data Analysis for Railroad Electrification. Arthur D. Little, Inc., Cambridge, Mass., and Transportation Systems Center, U.S. Department of Transportation, 1976.
2. E. G. Schwarm. Factors Affecting Railroad Electrification as Applied to Conrail. Arthur D. Little, Inc., Cambridge, Mass., and United States Railway Association, 1975.
3. A. H. Muir, H. T. Heitz, and K. Hecht. Cost-Effectiveness Review of Railroad Electrification. Pan-Technology Consulting Corporation, Inc., Washington, D.C., 1973.
4. Task Force on Railroad Electrification. A Review of Factors Influencing Railroad Electrification. Federal Railroad Administration, U.S. Department of Transportation, Feb. 20, 1974.
5. C. G. Swanson and H. H. Vogel. Energy and Environmental Factors in Railroad Electrification. Mitre Corporation, McLean, Va., 1975.
6. National Transportation Trends and Choices to the Year 2000. U.S. Department of Transportation, 1977.
7. Preliminary Standards, Classification, and Designation of Lines of Class I Railroads in the United States. U.S. Department of Transportation, 1976.
8. Rail System Investment Analysis: Description of the Railroad Investment Process. Ernst and Ernst and R. L. Banks and Associates, Inc., Washington, D.C., 1976.
9. D. R. Austin. Electrified Railroads—A Catalyst in the Economy. Paper presented at the Joint ASCE-ASME Transportation Meeting, Seattle, Wash., July 26-30, 1971, ASCE Meeting Preprint 1434.
10. Wholesale Prices and Price Indexes. Bureau of Labor Statistics, U.S. Department of Labor, 1976.

A Financial View of Electrification

Henry H. Livingston, Kidder, Peabody and Company, Inc., New York

We talk earnestly about a national policy for energy, especially for a number of industries that are subject to substantial change. This certainly affects electrification of the railroad industry, but there may be even more changes in sight for the utilities.

The utilities are now large consumers of oil and thus add to the nation's burden in buying oil from abroad. But the utilities can pass the costs of that fuel through to the bills of their customers and can thereby comply conveniently and readily with environmental standards on stack emissions by burning higher cost low-sulfur oil. If, however, they were to convert to coal, they would have to make capital investments in new boilers or boiler conversions. These capital costs cannot be passed on to the customers on a current basis; only after increases in rates have been approved can they recover capital costs. Therefore the utilities' conversion to coal would present capital problems similar to those electrification presents for the railroads.

Long delays, often caused by regulatory agencies, inhibit the recovery of capital costs by the utilities, which in turn dilutes their return on investment over the life of the new plant. Although a 15 or 20 percent return on capital may be anticipated in several years, there is no return until well after the plant is put into operation unless adequate flows of funds are available at the outset. In fact, there is often a negative return because the cash flow that provides the initial capital investment, regardless of source, is diverted from the assets column of the balance sheet of the utility (or the railroad company) making the investment, especially if there is a long lead time until completion.

The present tax incentives for additional investment are an important part of this. They are being offered by the federal government as an aid to economic recovery. Currently, the railroad industry is generating about 8 percent of the total investment tax credit generated nationally. But because the resultant net rate of return on railroad investment is so low—and therefore taxable income is likewise so low—this investment tax credit has not been fully used. So the proposed increases in investment tax credit as an incentive to conversion may not necessarily stimulate future additions to capital investment for industries that already have a low rate of return.