Effects of Energy-Cost Variation on Feasibility of Electrifying the Cincinnati-Atlanta Main Line of the Southern Railway System

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A study completed in 1975 considered the economics of electrifying the Cincinnati-Atlanta main line of the Southern Railway System. The differential cash flow of electric operation versus diesel operation, computed over the interval 1975-2002, yielded a 6.0 percent rate of return for electrification. This paper summarizes a study that applied plausible variations in energy prices to the operating scenarios used in the 1975 study. Two time intervals were chosen for analysis, taking a 2-year construction period for electrical facilities, followed by 26 years of operation. The first interval, 1975 through 2002, is identical to that of the initial study. For this interval, if the price of diesel fuel is taken as its maximum and dollar inflation is ignored, the rate of return for electrification ranges from 9.8 to 6.1 percent, depending on the price of electrical energy; if an annual dollar inflation of 10 percent is included, the corresponding rates are 20 and 15 percent. If the price of diesel fuel is taken as its minimum and dollar inflation is ignored, the rate of return for electrification is less than 35 percent; if an annual dollar inflation of 10 percent is included, the rate of return is less than 10 percent. The second interval was 1983 through 2010. For this interval, if the price of diesel fuel is taken as its maximum and dollar inflation is ignored, the rate of return for electrification ranges from 13 to 9.2 percent, again depending on the price of electrical energy; if an annual dollar inflation of 10 percent is included, the range of rates is 23 to 19 percent. If the price of diesel fuel is taken as is its minimum and inflation is ignored, the rate of return for electrification is less than 5 percent; if an annual inflation of 10 percent is included, the rate of return ranges from 7 to 10 percent.

In a 1975 study by the Electro-Motive Division (EMD) of the General Motors Corporation the costs were compared of diesel versus electric locomotive operations on the 782-km (486-mile) Cincinnati-Atlanta line of the Southern Railway System (1). That study took initial energy prices as

1. 0.33 cents/MJ (1.2 cents/kWh) for electrical energy and
2. 7.92 cents/L (30 cents/gal) for diesel fuel,

used these prices for the 1975 base, and applied to them an annual inflation rate of 1.5 percent. In the study summarized in this paper, these prices have been taken as variables. And precisely because energy prices appear to be the most unpredictable costs and because these costs dominate the cash flow, this study has focused on the effects they produce.

All other capital costs, maintenance costs, operational parameters, and traffic projections used here are identical to the EMD figures. The capital costs (in 1975 dollars) used in the EMD study and retained in this one are summarized below (1 kW = 1.341 hp and 1 km = 0.62 mile).

Item	Cost
Diesel locomotive (2237-kW unit), $	425 000
Electric locomotive [4474-kW (diesel equivalent) unit], $	750 000
Main line catenary and substations, $/track-km	39 248
Yard catenary and substations, $/track-km	19 624
Communication and signal alterations (entire line, site-specific), $	31 398 000
Clearance costs (entire line, site-specific), $	4 000 000

Several comments on this table are appropriate. The $4 million associated with clearance is an average of $5114/route-km ($8230/route-mile). Because much of the territory is mountainous, some of these costs could also be accrued for diesel operations because of higher or wider cars (or both) and loads. However, in this study, these costs are assigned to the electric case only.

The maintenance costs (in 1975 dollars) used in the EMD study and retained in this one are summarized below.

Item	Cost
Diesel locomotive maintenance, $/year + $/km	19 332 + 0.062 14
Electric locomotive maintenance, $/year + $/km	5865 + 0.062 14
Annual catenary and substation maintenance, $/track-km	546

[Locomotive maintenance costs are more often stated as entirely variable, i.e., cost per kilometer. Converting to this convention and using the locomotive annual utilization figures given below, one obtains 17.4 cents/km (27.8 cents/mile) for diesel and 9.32 cents/km (14.9 cents/mile) for electric. This is a ratio of 1.87, slightly lower than the range of 2 to 3 commonly argued in the industry. An independent (confidential) study in 1970 computed a ratio of 2.6 based on suggested maintenance, but without field experience.]

The operational parameters used in the EMD study and retained in this one are summarized below (1 metric ton = 1.1023 short tons).

Item	Value
Traffic base (1975), gross metric tons	36 288 000
Annual traffic growth, %	3.3
Diesel locomotive annual avg use, km	173 904
Electric locomotive annual avg use, km	193 960
Availability: diesel locomotive, %	90
Availability: electric locomotive, %	95

In this table, the traffic base is averaged over the four operating districts between Cincinnati and Atlanta; the variation between districts is less than 14 percent. In the estimate of annual traffic growth, no allowance has been made for capacity saturation of single-track territory. From 1975 to 2010, traffic will increase by a factor of 3.1. If it is assumed that the same loading assignments will be maintained, this corresponds to an increase from 10 to 31 daily trains in each direction. Not shown above, but also retained from the EMD study, were the electrical efficiencies of

1. 80 percent for catenary transmission and
2. 95 for substation conversion.

Locomotive efficiencies are inherent to the loading ratings assigned in the EMD study. The relative performance of the two locomotive types under overload condition is not explicitly stated or provided for in the EMD report. Also, no attempt was made to optimize locomotive use or otherwise improve operational strategies in either study.

METHOD

The method used in this study of computing the rate of return is identical with that used in the EMD study. The annual cash flow for diesel and electric operations are computed separately and then summed. In the analysis, the costs associated with electric operation are taken (arbitrarily) as negative quantities and the costs associated with diesel operation are taken as positive. The resultant summed cash flow is thus a differential cost. A positive sign for the sum indicates a saving brought about by electrification. Conversely, a negative sign indicates a net saving in diesel relative to electric operations. The rate of return is then computed for a 28-year interval. A computer program is used to find an equivalent interest rate for capital such that the net cash flow is zero for the (28-year) investment cycle. This interest rate is then the rate of return on the operation. Note that this definition does not take into account investment opportunities, borrowing considerations, or combinations of these factors.

Two major intervals were analyzed:

1. Case 1, which uses the interval 1975-2002 (this is the same time span used in the EMD work and differs only in energy pricing), and
2. Case 2, which uses the interval 1983-2010 (this updates the older study and reflects the lead times associated with financing, engineering, and constructing a project of this magnitude).

ENERGY PRICES

Because energy-price projections are fundamental to this study, it is important that the best estimates available be used in the calculations. Discussions were held with individuals who have had experience in projecting energy prices, and a survey of the literature was made. There was general agreement that a recent report published by the Federal Energy Administration (FEA) provides an authoritative basis for future energy price estimates (2).

The FEA report lists energy prices projected for a variety of international and domestic events. These prices were established from predictions of supply and demand for three price levels of imported oil (in 1975 constant dollars): (a) $50.29/m^3 ($8/barrel), (b) $81.71/m^3 ($13/barrel), and (c) $100.57/m^3 ($16/barrel). Twelve scenarios were reported, 10 for 1985 and 1 each for 1980 and 1990.

Escalation in prices is due to political, social, and technological factors manifested in the international economy. The differences in pricing therefore reflect the interaction of many complex forces. Although it recognizes the limitations and difficulties inherent in such forecasting, the FEA study does establish plausible and consistent energy prices.

By using the data and formulas given in the FEA report, maximum (MAX) and minimum (MIN) energy prices were developed. These prices take into account differences for delivery. For the present study, two delivery regions are of interest: east south central (ESC), which includes all of Kentucky and Tennessee, and south Atlantic (SA), which includes all of Georgia.

The 1985 delivery energy costs developed are summarized below (1 cent/L = 3.86 cents/gal and 1 mill/MJ = 3.6 mills/kWh).

	Price in 1975 Constant Dollars	
Energy Source	Maximum	Minimum
Electrical, mills/MJ	8.39	6.06
Diesel fuel, cents/L	11.89	7.13

Although the prices given above are reported to three or four significant figures, this was done only to show calculated differences between assumptions and does not imply this precision in estimation. Prices are stated in constant (1975) dollars; therefore, dollar inflation was included in the analysis.

In the table above, note that the lowest price for electrical energy is 6.06 mills/MJ (21.8 mills/kWh); this is a 1985 price, expressed in constant 1975 dollars. Compared with the 1975 price of 3.32 mills/MJ (12 mills/kWh) used in the EMD study, this is an 82 percent increase, equivalent to a 6.15 percent average annual rate from 1975 to 1985. The maximum 1985 electrical-energy price of 8.39 mills/MJ (30.2 mills/kWh) is 152 percent of the EMD (1975) figure. This is equivalent to an annual 1975 to 1985 increase of 9.7 percent.

The MAX and MIN 1985 diesel fuel prices are 11.89 and 7.13 cents/L (45 and 27 cents/gal) respectively. Compared with the 1975 price [7.93 cents/L (30 cents/gal)] used in the EMD study, the corresponding (1975 to 1985) annual rates are 4.1 percent and minus 1.1 percent.

The table above gives prices for 1985 only. For the present study, projections to the year 2010 were needed. These extensions were developed from statements and data in the FEA reports and other sources (3). For a constant-dollar economy, the consensus expectation is that

1. Diesel-fuel prices will increase an average of 3 percent annually after 1985 and
2. Electrical-energy prices will remain relatively constant after 1985.

As before, dollar inflation was included in the subsequent analysis.

The FEA estimates and these post-1985 projections are shown in Figures 1 and 2; the historical prices are added for reference. The prices shown between 1975 and 1985 were interpolated by assuming a constant annual rate of change over the interval.

In Figures 1 and 2, note that the 1975 prices differ from those used in the EMD study. In particular, these plots show

1. Diesel fuel at 8.98 cents/L (34 cents/gal) [versus the EMD study price of 7.93 cents/L (30 cents/gal)] and
2. Electrical energy at 4.43 to 6.09 mills/MJ (16 to 22 mills/kWh) (versus the EMD study price of 3.32 mills/kWh).

In Figure 2, electrical-energy prices are shown as the U.S. average from 1965 to 1972. From 1972 to 1975, the range of prices reflects the variance of negotiated rates. For comparison, the industrial rate in the

Cincinnati-northern Kentucky area was in the range of 4.99 to 5.54 mills/MJ (18 to 20 mills/kWh).

Throughout this report, the electrical-energy prices used are industrial rates. However, railroad rates may be greater than these industrial rates because of the poor load-factor characteristics of railroads and the relatively poor power factor of the AC traction system. The unbalance produced by single-phase loading of a three-phase power supply may also incur a penalty.

The prices shown in Figures 1 and 2 were the basis for the calculations of cases 1 and 2.

RESULTS

Case 1

The case 1 inputs, except for energy costs, are identical to those used in the EMD study. Energy costs are as shown in Figures 1 and 2 for the operating interval 1977-2002.

The rate of return for electrification versus the annual inflation rate is shown in Figure 3. For the combination of diesel fuel prices at MIN and electrical energy prices at MAX, electrification costs exceed diesel costs for each year of operation (1977-2002); therefore, this combination of prices does not appear in Figure 3.

Case 2

Case 2 was developed to test the economic feasibility of a realistic start of construction. The 1985-2010 prices shown in Figures 1 and 2 are used in this case.

Figure 4 shows the sensitivity of rate of return to inflation for combinations of energy prices in the same manner as Figure 3.

The post-1985 diesel-fuel prices shown in Figure 1 reflect an annual increase of 3 percent, with electrical-

Figure 1. Diesel-fuel prices.

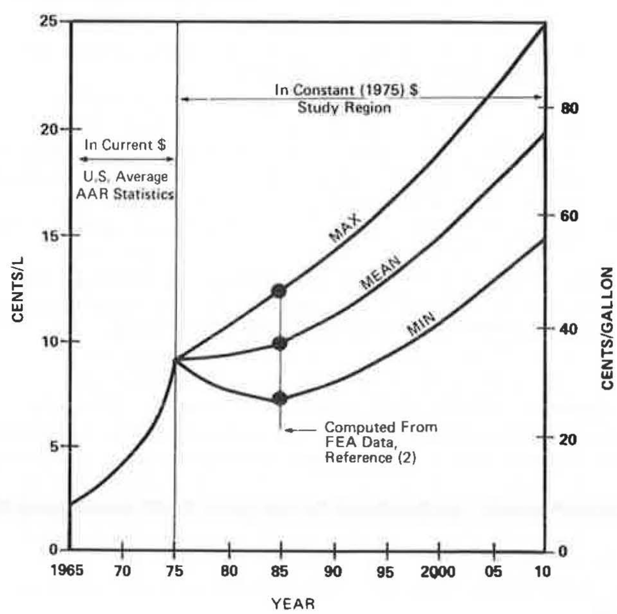


Figure 2. Electrical-energy prices.

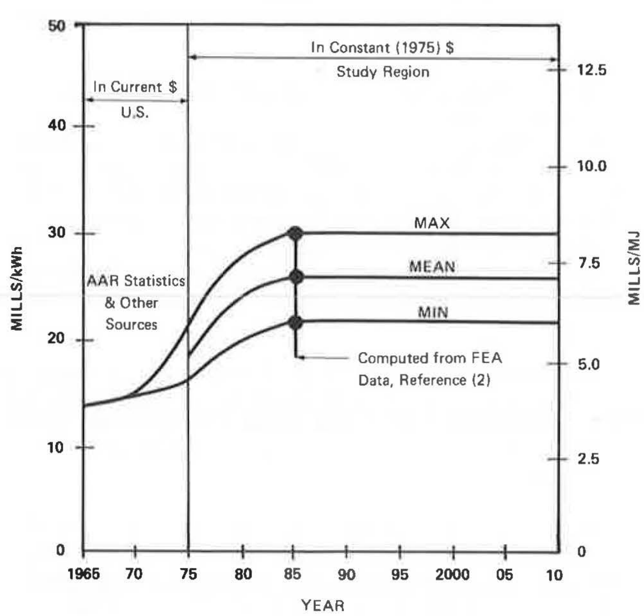


Figure 3. Rate of return for electrification at different energy price combinations: 1977-2002 operations.

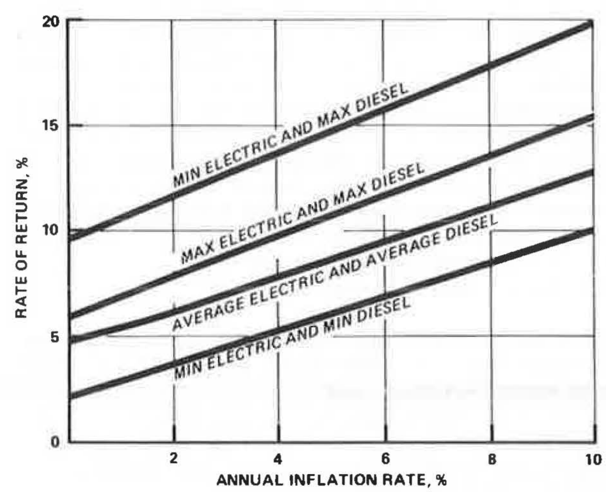


Figure 4. Rate of return for electrification at different energy price combinations: 1985-2010 operations.

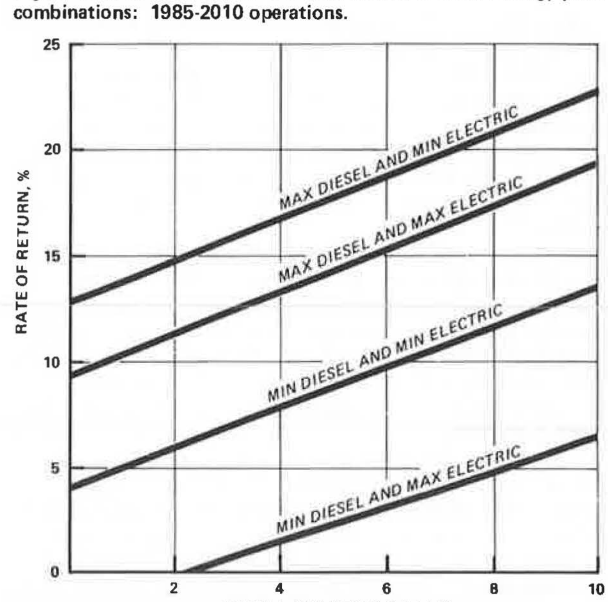
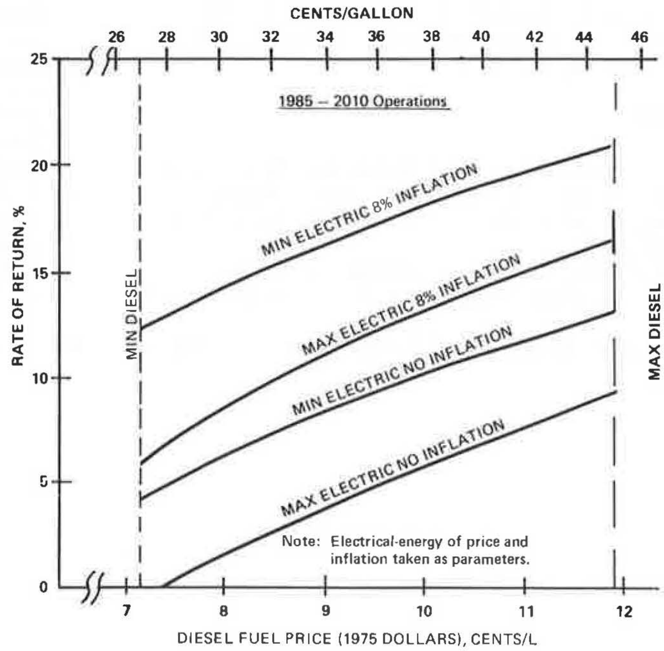


Figure 5. Rate of return for electrification as a function of base year (1985) and diesel-fuel price: 1985-2010 operations.



energy prices stable. By using the MAX and MIN electric prices as parameters, rates of return were computed as a function of base year (1985) diesel-fuel price. The results are shown in Figure 5 without dollar inflation and for an annual inflation of 8 percent.

DISCUSSION OF RESULTS

The analyses (cases 1 and 2) are based on projections from FEA estimates that have been checked against other sources. Not all of these sources are independent of the FEA figures. The converse is also true. However, the projections through 1990 are believed to be the best estimates currently available, notwithstanding the vagaries of forecasting.

The costs used in the study are for conventional energy sources. Certain exotic technologies (e.g., solar energy, geothermal energy, and synthetic fuels) may be expected to contribute in the future. However, these sources are expected to contribute no more than 1 percent to the U.S. energy pool through 1990. Given the long lead times that will be required to perfect these technologies and the time required to construct significant capacity, this conclusion appears valid. Production of oil from shale is included in some of the FEA scenarios (2) and is not considered an exotic technology in the present context.

Beyond 1990, the impact of new technologies is even more difficult to assess. However, given the energy prices developed in this study and the fundamental economic laws of supply and demand, marked decreases in electrical-energy costs do not appear likely. Rather, a general stabilization of prices is indicated, due in large measure to saturation of technology and the mix of primary energy sources used to produce power. As a separate check of electrical prices used in this study, it is useful to compute an absolute ceiling.

A recent study has established the maximum costs of electricity for a 1982 New England scenario (4). With 10 percent annual inflation, energy costs in 1982 are projected to be

1. Nuclear—13.38 mills/MJ (48.3 mills/kWh),
2. Coal (without scrubbers)—17.56 mills/MJ (63.4 mills/kWh), and
3. Coal (with scrubbers)—20.89 mills/MJ (75.4 mills/kWh).

Recent increases in uranium prices will contribute an estimated 2.77 mills/MJ (10 mills/kWh) to the 1982 nuclear price, which means that this price is then 16.15 mills/MJ (58.3 mills/kWh) [i.e., 8.28 mills/MJ (29.9 mills/kWh)] in 1975 dollars.

However, New England power is typically 0.14 to 0.55 mills/MJ (0.5 to 2 mills/kWh) less costly than Cincinnati-Atlanta power (2). The ceiling (regional) price is thus 8.86 mills/MJ (32 mills/kWh) for the area of interest. This is in excellent agreement with the 8.37 mills/MJ (30.2 mills/kWh) used in this study. Thus, nuclear power may, in fact, serve as a ceiling.

The corresponding price ceiling for post-1985 synthetic fuels can be projected from current estimates. On an energy-equivalent basis, the 1976 price of synthetics, if sufficient production capacity were available, would be $151/m^3$ to $170/m^3$ ($24/barrel to $27/barrel) (5). This is (approximately) a factor of two greater than the current price of imported oil. The 1985 price estimate (energy equivalent) ranges from 98 to 178 percent of the maximum price of domestic offshore oil (6). Moreover, the construction and operation of plants in sufficient quantity to supply a significant fraction of U.S. energy needs is not likely before the year 2000. These considerations tend to support the oil-price projections shown in Figure 1.

For both case 1 and case 2, dollar inflation produces a (nearly) linear increase in rate of return. These are shown as linear functions in Figures 3 and 4. The departure from linearity is less than 5 percent over the range of the independent variable.

Because both relative and absolute energy prices dominate the cash flow, significant escalations in future prices should initiate further study.

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**Mr. Ingram was with Bechtel when this research was performed.*